JOURNAL OF WORLD SCIENCE
https://jws.rivierapublishing.id/index.php/jws
Volume 4 No. 8 August 2025
P-ISSN: 2828-8726
E-ISSN: 2828-9307

Development of E-LKPD Guided Inquiry Web Augmented Reality Biodiversity Material Based on Nepenthes Variation to Improve Critical Thinking Abilities and Psychomotor Skills of E-phase students

Djoko Martono, Suyitno Aloysus
Universitas Negeri Yogyakarta, Indonesia
Email: djokomartono@gmail.com, suyitno_al@uny.ac.id

ABSTRACT
This study developed a Guided Inquiry e-LKPD assisted by Web Augmented Reality (WebAR) on biodiversity material based on Nepenthes variations, aiming to enhance critical thinking skills and psychomotor abilities of Phase-E students. The product supports questioning, investigating, and constructing knowledge through 3D visualization of Nepenthes in real environments. A modified Borg & Gall R&D method was applied, with trials at MAN 2 Kota Semarang using a one-group pretest–posttest design. Instruments were expert-validated with very high scores. MANOVA analysis indicated a significant effect of WebAR on improving both critical thinking and psychomotor skills, simultaneously and separately. ANOVA and t-tests confirmed significant differences in learning outcomes between experimental and control groups, with greater improvement in the experimental group. The WebAR-based e-LKPD proved effective in strengthening cognitive aspects and psychomotor skills through interactive learning.

Keywords: Augmented Reality; Critical Thinking; e-LKPD; Guided Inquiry; Nepenthes.

Corresponding Author: Djoko Martono
Email: djokomartono@gmail.com

INTRODUCTION

In facing the challenges of 21st century education, the transformation of the learning system towards the use of digital technology is a necessity. The development of information technology has driven a change in the educational paradigm, where learning is no longer limited to face-to-face interactions, but also through online platforms that demand flexibility and independent learning for students (Trilling & Fadel, 2009). Teachers as facilitators are required to be able to convey learning materials in adaptive and contextual methods, as well as ensure that the learning process remains meaningful even though it is not done directly (RESEARCH, 2022). These changes also encourage students to develop independent learning skills and increase mastery of 21st century skills such as critical thinking, problem-solving, collaboration, and innovation (Bialik et al., 2015). Thus, both teachers and students are required to have the ability to adapt to the dynamics of modern technology-based learning, in order to improve the quality of the learning process and outcomes in a sustainable manner.

One of the main drawbacks of online learning is the limited direct interaction between teachers and students. This condition has an impact on the suboptimal development of students'

critical thinking and psychomotor skills, especially in practice-based learning such as biology. Biology lessons not only emphasize the cognitive aspect, but also require physical involvement through observation, experimentation, and the use of tools and materials in laboratory activities (Hosnan, 2014). If teachers do not use the appropriate learning approach to material that demands psychomotor skills, then students' mastery of these skills tends to be low (One, 2021). In addition, online learning that is one-way and has minimal interaction also hinders students' critical thinking skills, because there is not enough space to actively discuss, question, and reflect on knowledge (Zubaidah, 2010).

Practicum has an important role in achieving the learning objectives of Natural Sciences (IPA), including biology. This activity is supported by education and learning psychology experts because it provides hands-on experience that strengthens concept understanding, increases learning motivation, and develops students' critical thinking and psychomotor skills. Through practicums, students can observe natural phenomena, design experiments, and apply science concepts in real-world situations, ultimately increasing their interest in and understanding of the subject matter (Mulia & Murni, 2022).

Although practicum has become a component in biology learning in Indonesian schools, its implementation has not been optimal. Evaluation of the implementation of biology practicum in several high schools shows that limited laboratory facilities and limited time allocation are the main obstacles (H et al., 2023). The Independent Curriculum allocates limited time for practicum activities, which is felt to lack flexibility for students to develop skills and satisfy their curiosity (H et al., 2023).

In addition, in practice, teachers tend to choose easier and more efficient learning methods, such as lectures, so practicum activities are rarely carried out. This has an impact on the low achievement of learning objectives that emphasize the development of 21st century skills, such as critical thinking skills, problem-solving, collaboration, and innovation (Mulia & Murni, 2022). Therefore, efforts are needed to improve the implementation of practicum in schools, both through the provision of adequate facilities and training for teachers to be able to design and implement effective practicums.

In the Independent Curriculum, Biology subjects have an important role in helping students understand, overcome, and manage 21st century challenges, such as natural resource management, environmental quality, health and disease, and the use of biological technology. Biological Sciences are also used to maintain biodiversity, ecosystem sustainability, human and other organism welfare and their populations, as well as the sustainability of Indonesia's biological resources.

The learning process of Biology in the Independent Curriculum is carried out through a contextual approach and inquiry where all activities are student-centered. Through this approach, students are given authentic learning experiences so that they are trained in solving problems in daily life through scientific work, starting from finding problems, formulating hypotheses, designing experiments, conducting experiments, analyzing data, drawing conclusions, and communicating the results of experiments. This will have implications for students' readiness to face their current life and future (BSKAP Decree 032/H/KR/2024

concerning Learning Outcomes in Early Childhood Education, Basic Education Levels, and Secondary Education Levels in the Independent Curriculum, 2024).

Improving the quality of education in Indonesia continues to be the focus, especially in facing the challenges of globalization and rapid technological developments. The results of the Programme for International Student Assessment (PISA) 2022 show that although Indonesia's ranking has increased by 5 to 6 positions compared to 2018, the average score of Indonesian students is still below the average of OECD (Organisation for Economic Cooperation and Development) countries. Specifically, Indonesia's average score for reading literacy is 359, mathematics literacy is 366, and science literacy is 383, all of which are below the OECD average of 476, 472, and 485, respectively.

Furthermore, only about 18% of Indonesian students achieve at least Level 2 in mathematical literacy, compared to the OECD average of 69%. This shows that most Indonesian students still struggle to apply basic concepts in real-life contexts, which is an important indicator of mastery of high-level thinking skills (Higher Order Thinking Skills - HOTS) (Education GPS, 2022).

The urgency of this research lies in the low achievement of Indonesian students' competencies in mastering high-level thinking skills (HOTS), which is reflected in the results of the Programme for International Student Assessment (PISA) 2022. Data shows that the average scores of Indonesian students in reading, mathematics, and science literacy are still below the average of OECD countries, and only about 18% of Indonesian students have reached Level 2 in mathematical literacy, compared to 69% of the OECD average (OECD, 2023). This condition indicates the need for innovation in the learning process, especially in the learning of biological sciences, which not only emphasizes the cognitive aspect, but also the psychomotor and affective aspect.

The common thread between critical thinking skills and psychomotor skills lies in the integration between cognitive aspects and real actions in the scientific learning process. In the inquiry-based learning approach, especially the guided inquiry model, students are not only required to develop critical thinking skills—such as analyzing data, identifying variables, and compiling inferences—but are also required to perform psychomotor activities such as observing real objects, manipulating learning media, recording findings, and presenting results in a practical way.

According to Ennis (Ennis, 1996), critical thinking is an intellectual process that aims to make rational and reflective judgments based on evidence. In practice, this thought process requires the support of psychomotor skills, especially when students make observations or experiments to test a hypothesis. This is in line with the opinion of Anderson and Krathwohl (2001) that the process of high-level thinking (HOTS) does not stand alone, but is integrated with other skills, including psychomotor skills, in the context of science learning.

In this study, for example, e-LKPD-based learning with Web Augmented Reality facilitated students to observe and interact with Nepenthes objects visually and practically, so that students not only build knowledge through critical thinking but also through concrete experiences. Activities such as identifying the morphological structure of Nepenthes, matching

species to habitats, as well as using dichotomous keys, demand synergy between logical thinking processes and physical skills.

Thus, the relationship between critical thinking and psychomotor skills is complementary—critical thinking skills direct action, and psychomotor skills provide an empirical basis for more meaningful reflection and decision-making. The integration of the two becomes an important foundation in meaningful science learning, especially in an effort to improve students' conceptual understanding and scientific skills in the 21st century learning era.

Theoretically, this research is based on a constructivist approach, which emphasizes that meaningful learning occurs when students actively build their own knowledge through hands-on experience. The guided inquiry learning model is considered appropriate for practicing critical thinking skills because it encourages students to discover concepts on their own through scientific stages such as formulating problems, formulating hypotheses, conducting experiments, and drawing conclusions. In addition, the application of technology-based learning media, such as (Hosnan, 2014) (Uno, 2021)Web Augmented Reality (WebAR), in line with the technology-enhanced learning that can increase student engagement and allow for interactive and contextual exploration of the material (Khan et al., 2019). Therefore, the development of WebAR-based e-LKPD with a guided inquiry model is important and relevant to answer the challenges of 21st century learning and strengthen students' readiness to face real life.

One of the important aspects of learning Biology is the ability of students to directly observe real objects as part of the scientific process. Biodiversity material requires students to understand the variety of living things in a real context that is close to their lives. However, many biological objects that have high learning value are difficult to access directly in the environment around the school due to geographical limitations, conservation status, or the availability of laboratory facilities.

In this context, Nepenthes (Semar Pocket) was chosen as a learning object because it has a number of advantages in terms of educational, ecological, and morphological uniqueness. Nepenthes is a carnivorous plant that belongs to Indonesia's endemic biodiversity, mainly found in the tropical forest areas of Sumatra, Kalimantan, and Papua (C. M. Clarke, 2001a). Existence Nepenthes in nature has a high conservation value because some species have been included in the category of rare and protected plants (IUCN Red List of Threatened Species, 2023). The uniqueness of its distinctive morphological shape, such as the modification of leaves into insect trap bags, makes it possible for Nepenthes as a concrete example of plant morphological adaptation to extreme environments (Cheek & Jebb, 2001).

Furthermore, the Nepenthes reflect the principles of biodiversity, both at the genetic level (through variation between species and subspecies), at the species level, and at the level of the ecosystem in which they live. This makes it particularly relevant for use in biology learning that emphasizes an understanding of biodiversity (Hosnan, 2014).

However, in school learning practice, introduction to Nepenthes is still very limited, as students are rarely able to observe the structure and variety of the plant directly. This is due to:

- Geographical limitations: Nepenthes grows in tropical areas such as Sumatra and Kalimantan; Not all schools are near their natural habitat, so field access is very minimal (Setiawan, 2017).
- Conservation status: Some species of Nepenthes are protected and belong to the endangered category, so they cannot be used as a direct practicum medium or taken from nature without permission.

As a result, learning relies heavily on static text and images. In fact, observation-based learning is very important in science. Studies show that hands-on experiences such as drawing, exploring, and conducting investigations in the field significantly improve students' observation and scientific thinking skills.

- Passive observation (just looking at pictures) is not enough to develop students' scientific thinking skills. They need to actively observe, think critically, and infer from real data (Soenarno & Miranti, 2021).

To answer these challenges, this study developed an e-LKPD based on Web Augmented Reality (WebAR) that displays digital models Nepenthes interactively and realistically. WebAR technology allows the visualization of three-dimensional objects that can be observed from various angles, as if learners are interacting directly with the plant. In this way, learners not only learn cognitively, but also engage in a more immersive visual and psychomotor learning experience, even in the absence of the presence of an actual physical object (Akçayır & Akçayır, 2017; Khan et al., 2019).

Use of objects Nepenthes It also provides added value in building students' concern for the preservation of local biodiversity. Through digital observations equipped with ecological and morphological information, students can understand the importance of preserving endangered species, as well as learn how plant adaptation is one of the important indicators in the study of ecology and evolution (Cheek & Jebb, 2001; C. M. Clarke, 2001a).

Thus, the selection of Nepenthes as an object in the development of this e-LKPD is not only due to its high visual appeal, but also because of its educational, ecological, and contextual value that is very much in line with the demands of the Independent Curriculum and 21st century competencies. The existence of this object in WebAR-based interactive media is expected to be able to increase student involvement in learning, foster critical thinking skills, and develop psychomotor skills in a more real and measurable way.

Therefore, the development of Web Augmented Reality-based e-LKPD with a Guided Inquiry model on Nepenthes diversity materials is an innovative solution to improve the critical thinking abilities and psychomotor skills of Phase-E students. The use of this technology is expected to answer the challenge of low science and mathematics literacy achievement of Indonesian students, as reflected in the 2022 PISA results, as well as support the achievement of 21st century learning goals that emphasize mastery of high-level thinking skills.

The material chosen by the researcher is biodiversity material, biodiversity is one of the materials that is very close to students' lives, so that this research can help students to be able to solve the problems they face well in accordance with the Learning Outcomes (CP).

The Independent Curriculum, one of the learning outcomes of science subjects in the Elements of Understanding, especially biology, at the end of phase E, it is said that students understand the process of classification of living beings; the role of viruses, bacteria, and fungi in life; ecosystem and interaction between components and influencing factors; and the use of biotechnology in various areas of life. Meanwhile, the learning outcomes in the Process Skills Element include observing, questioning and predicting, planning and conducting investigations, processing, analyzing data and information, evaluating and reflecting, communicating results (BSKAP Decree 032/H/KR/2024 concerning Learning Outcomes in Early Childhood Education, Basic Education Levels, and Secondary Education Levels in the Independent Curriculum, 2024).

From the description above, the researcher tried to conduct research on the development of Electronic Student Worksheets (e-LKPD) through a learning model that according to the researcher can provide the best solution in the teaching and learning process, both online and offline learning of biology subjects related to critical thinking skills and psychomotor skills, in this study the researcher took the example of Biodiversity material, namely through a Web Augmented Reality (WebAR)-assisted guided inquiry learning model. So in this study the title of the research is taken, namely: "Development of e-LKPD Augmented Reality Assisted Guided Inquiry Nepenthes Diversity Material to Improve Critical Thinking Skills and Psychomotor Skills of Phase-E students".

The researcher chose the guided inquiry model because this approach is highly effective in training students' critical thinking skills, which are an important part of 21st century skills. This model provides learning experiences through scientific activities such as formulating questions, developing hypotheses, conducting experiments, analyzing data, to draw conclusions and communicate them; Previous research has shown that guided inquiry approaches encourage active student engagement and improve conceptual understanding in science (Hosnan, 2014) (Uno, 2021)(Furtak et al., 2012).

In its application, the researcher chose the use of Web Augmented Reality (WebAR) as a learning medium because this technology allows the integration of interactive 3D visualizations directly from the browser without the need for additional applications. WebAR has been shown to increase learning motivation, material absorption, and understanding of abstract concepts, especially in the field of science (Khan et al., 2019); (Akçayır & Akçayır, 2017).

The product developed in this study is BioWebAR, an interactive e-LKPD based on Web Augmented Reality (WebAR) designed to support the learning of Biology of Biodiversity materials in class X SMA/MA Phase E. BioWebAR is built using HTML, PHP, CSS, and JavaScript with the Bootstrap framework, equipped with 3D Nepenthes objects that can be accessed through a browser without additional installation. The learning model used is guided inquiry, with exploration stages to presentation, combining observation activities, manipulation of AR objects, and evidence-based task completion. Key features include inquiry learning modules, Nepenthes cultivation simulations, species identification through dichotomous keys, Nepenthes Go educational games, and learning outcomes pages and user profiles. This design

aims to provide an immersive, interactive, contextual learning experience, and encourage students' critical thinking and psychomotor skills.

The development of BioWebAR provides both theoretical and practical benefits for teachers, students, and schools. Theoretically, this media improves critical thinking skills, problem solving, psychomotor skills, creativity, and concept understanding through AR visualization. For teachers, BioWebAR enriches teaching materials, improves the quality of learning, encourages student engagement, and develops technology literacy. For students, these media offer experiential learning, visual-interactive stimulation, strengthening of problem-solving skills, collaboration, multisensory engagement, and student-centered learning. For schools, the application of this technology increases reputation, attractiveness for prospective students, motivation to learn, and the ability to adapt to educational technology developments. Thus, BioWebAR is a learning innovation that combines technology, contextual content, and scientific strategies to improve the quality of biology learning.

RESEARCH METHOD

This study uses the Research and Development (R&D) method by adapting the Borg and Gall development model to develop e-LKPD (electronic Student Worksheets) with a guided inquiry approach assisted by Web Augmented Reality technology on biodiversity materials based on Nepenthes variations. The purpose of the development is to improve the critical thinking skills and psychomotor skills of phase-E students (class X SMA/MA).

This research has two main functions, namely the development function to create an e-LKPD product with WebAR technology and the validation function to test the effectiveness of the product in achieving learning objectives. The adapted development model consists of six main stages: (1) preliminary study and information gathering, (2) research planning, (3) initial product design development, (4) limited field test, (5) major product revision, and (6) extensive field test.

To test the effectiveness of the product, the study used a Pretest-Posttest Control Group Design that compared the learning outcomes between the experimental group using e-LKPD with WebAR technology and the control group using conventional LKPD. The test subjects involved 32 students in class X at Madrasah Aliyah Negeri 2 Semarang City for the 2024/2025 school year. Data collection instruments include needs analysis questionnaires, validation sheets for material and media experts, pretest-posttest, teacher and student response questionnaires, and documentation.

Table 1. Stages of e-LKPD WebAR Development

Phase	Main Activities	Output
1. Preliminary Studies	Needs analysis, literature study, small-scale research of similar products	Identify development issues and needs
2. Planning	Creation of assessment instruments, product planning	Development plans and validation instruments

3. Design Development	Preparation of materials, creation of teaching modules, design of 3D objects, creation of AR websites	e-LKPD WebAR prototype
4. Limited Field Test	Validation of material and media experts, initial revision	Theoretically validated products
5. Main Product Revision	Improvements based on expert input	Field test ready product draft
6. Wide Field Test	Implementation of learning, filling out response questionnaires	Effectiveness-tested final product

The table above shows six systematic stages in the development of a Web Augmented Reality-based e-LKPD adapted from the Borg and Gall model. Each stage has specific interrelated activities, starting from problem identification to producing a final product that has been tested for effectiveness. This development process is cyclical with the possibility of repeated revision at each stage based on the results of evaluation and input from validators and users, resulting in valid, practical, and effective learning products to improve students' critical thinking skills and psychomotor skills.

RESULTS AND DISCUSSION

A. Initial Product Development Results

1. Curriculum Needs Analysis

Analysis of the Independent Curriculum shows that phase E biology learning emphasizes understanding of biodiversity that is relevant to the Sustainable Development Goals (SDGs), especially SDG 13 (Climate Action) and SDG 15 (Life on Land). Biology learning outcomes require students to be able to understand biodiversity based on morphological and taxonomic features and explain the importance of conservation. This research develops a Web Augmented Reality (BioWebAR)-based e-LKPD that integrates Nepenthes variation materials as an interactive learning medium, supporting inquiry-based activities to develop students' critical thinking skills.

2. Results of the Teacher Needs Questionnaire

A survey of two biology teachers showed an average score of almost maximum in all aspects of learning. The teacher gave perfect scores (12/12) for the learning model, (4/4) for critical thinking skills, (8/8) for psychomotor skills, and (10/10) for the material. Learning media received a score of 11.5 out of 13, while WebAR-based e-LKPD was considered very useful with a maximum score (2/2). The teacher suggested the integration of 3D object viewer and classification features, as well as the addition of local content and animated learning videos to increase the appeal of the material.

3. Results of the Student Needs Questionnaire

Analysis of student needs shows that 90.60% of students stated that they need interesting media and learning methods. For critical thinking skills, the majority of students are in the "Very Needy" category with a high percentage. The psychomotor skills aspect also received a positive response. Nepenthes' material was very well received, with most students

showing high interest. The guided inquiry learning model is considered relevant and needed to improve students' understanding of concepts and skills in an in-depth and interactive manner.

4. Small-Scale Research of Similar Products

Evaluations of four AR-based learning products (QuiverVision, Merge EDU, Google Expeditions, and zSpace) using eight assessment aspects showed zSpace had the highest performance (score of 34/40) but required a special device. Merge EDU gets a score of 30/40 with a good balance of features. This analysis reveals that there is no product that has yet comprehensively integrated a guided inquiry approach, task-based evaluation features, and high accessibility without additional installations, so the development of BioWebAR has a great opportunity to fill that gap.

5. Product Interface Design

The product is designed with a six-step guided inquiry model: onboarding, formulating problems, collecting data, analyzing data, formulating conclusions, and communicating results. The responsive interface displays seven main materials: Biodiversity Levels, History of Nepenthes, Nepenthes Cultivation, Nepenthes Morphology, Distribution of Nepenthes, Symbiosis in Nepenthes, and Classification of Nepenthes. Each material comes with a QR-Code to access WebAR 3D objects, intuitive navigation buttons, and a login feature for tracking student progress.

B. Product Trial Results

1. Media Expert Validation

Media expert validation gave a perfect score (5/5) on all aspects: interface display, Augmented Reality quality, connectivity to learning objectives, technical quality, aesthetics and creativity, and safety and accessibility. Media experts assessed the interface design as per the themes of biodiversity, intuitive navigation, and consistency of layout supporting learning. AR features are considered realistic and accessible, able to improve understanding with an immersive visual experience. Suggestions for improvements are focused on the neatness of the display when accessed through a laptop.

2. Validation of Subject Matter Experts

Two subject matter experts gave an average score of 4.75 in the very good category. The quality aspect of the material received an average of 4.5-5, showing conformity with learning outcomes and logical systematics. The correctness of the concept and the relevance of the data are assessed in accordance with the latest scientific developments. Validators suggested improvements to real-life relevance, differences in diversity at the gene and species levels, and the addition of images to tissue culture techniques. Overall, the material is rated worthy with some minor improvements.

3. Hasil Pretest-Posttest

The quasi-experimental research with the One-Group Pretest-Posttest design involved 64 students (32 control classes, 32 experimental classes). The experimental class using e-LKPD WebAR showed a significant increase from the average pretest of 42.94 to the posttest of 81.82, while the control class only increased from 40.78 to 44.66. The paired sample t-test showed a significant difference ($p=0.000$) in the experimental class. The N-Gain score of the

experimental class reached 0.69 (medium-high category), while the control class was only 0.04 (low). The MANOVA test confirmed the significant influence of e-LKPD WebAR on critical thinking skills and psychomotor skills simultaneously.

4. Teacher and Student Responses

The teacher's response questionnaire gave a perfect score (5/5) on all aspects: material suitability, ease of use, potential for improvement in critical thinking, and psychomotor skills. Student responses showed that 90.90% rated e-LKPD in the category of "Feasible" to "Very Feasible", with 27.30% giving an assessment of "Very Feasible". The analysis of students' suggestions identified the need to improve system stability (15.15%), ease of access (12.12%), and simplification of texts (12.12%), but the majority (51.51%) provided positive support and assessed the product as very helpful for learning.

C. Revision and Final Product

1. Revision Based on Input

Revisions are made based on validator and user suggestions. The addition of a special classification menu with "Key to the Dichotomy of Nepenthes Endemic Indonesia" accommodates teachers' needs for classification features. Local content is reinforced by the distribution of Nepenthes in Indonesia and the video of the prey retention experiment. System stability is fixed using base64 encoding for answer storage, addressing special character errors. Viewing is simplified with the hide/show text feature using interactive buttons, and navigation is made easier with direct access to important topics after logging in.

2. Cultivation Experiment Simulation Features

The simulation feature of Nepenthes cultivation from seeds follows the development of the plant during one year of simulation, from the seed phase to maturity. The simulation is programmed based on the age parameters of the plant with automatic visual changes and descriptive narratives of maintenance activities. The process includes substrate sterilization, seeding, fungal infection control, as well as moisture and lighting maintenance. This feature trains students' critical thinking skills in evaluating the causes of failure to grow, considering fungicide dosage, and analyzing environmental impacts on plant development, supporting science process skill-based learning.

3. Key Features of the Nepenthes Dichotomy

The identification feature using a digital dichotomous key allows students to classify 17 species of Nepenthes endemic to Indonesia based on visual characteristics. Students select characteristics gradually (a or b) through digital navigation until they find the appropriate species name. This feature supports the development of science process skills such as observing, grouping, and interpreting data, while building ecological awareness of the importance of local biodiversity conservation.

4. Game Edukatif Nepenthes Go

Location-based games using Geolocation API technology combine interactive mapping (Leaflet + OpenStreetMap), digital compasses, and Augmented Reality WebXR. Students can search and find 17 virtual species of Nepenthes based on GPS coordinates, featuring 3D models, background sounds, and interactive quizzes. The game follows the syntax of guided

inquiry through the stages of exploration, question formulation, data collection, interpretation, and conclusion. Navigation features include an interactive map with location markers, a compass system, a species information popup, and a collection of saveable finds.

5. Integrated End Products

The final product is a comprehensive e-LKPD platform with a responsive interface for desktop and mobile. The home page provides navigation to seven main teaching modules, each featuring inquiry-based activities and interactive AR objects. The tracking system allows teachers to monitor student progress in real-time. The integration of three main features (cultivation simulation, dichotomy key, and the Nepenthes Go game) provides a holistic learning experience, supporting the development of students' critical thinking skills and psychomotor skills according to the learning outcomes of the Independent Curriculum.

The final platform has been integrated with the principles of contextual learning, differentiation, and strengthening of an active learning culture. The use of specific local content in the form of endemic Nepenthes species is not only a means of learning but also a medium for introducing Indonesia's biodiversity wealth in the context of environmental education. The results of the trial showed significant effectiveness in improving student learning outcomes, making this product feasible for widespread implementation in biology learning at the high school/MA level.

A. Final Product Discussion

The final product developed in this study is in the form of e-LKPD based on Web Augmented Reality (WebAR)-assisted guided inquiry on Biodiversity material with a focus on Nepenthes species variation. This development was carried out in response to the needs of 21st century learning that demand interactive, contextual media, and are able to stimulate the critical thinking skills and psychomotor skills of Phase-E students (class X SMA/MA).

This product is designed following the syntax of guided inquiry, namely the stages: (1) Introduction, (2) Exploration, (3) Observation, (4) Investigation, (5) Analysis and Synthesis, and (6) Presentation. Each stage is integrated into a digital-based e-LKPD, with the support of WebAR technology that allows students to observe Nepenthes 3D objects in an immersive real-world context. This AR visualization utilizes the device's camera to display variations of Nepenthes, thus strengthening the connection of the material with the live experience.

In its development, this e-LKPD is also equipped with innovative features such as:

1. The assessment grid in each question consists of criteria, scores, and success indicators, guiding students in answering as well as facilitating formative assessment.
2. Interactive buttons to hide/show text to keep the material concise and not visually overwhelming students.
3. HOTS (Higher Order Thinking Skills) questions with critical and psychomotor indicators, including the Nepenthes classification using a dichotomous key as a data-based scientific approach.
4. Question navigation and automatic grading features allow students to track grade achievement and access questions flexibly.

5. AR-based gamification through the educational mini game "Nepenthes Go" that integrates interactive maps, location detection, digital compasses, and species matching with real location markers.

The results of the validation test by experts showed that the product was declared very feasible (average score of 4.75 from material experts and 5.00 from media experts). Furthermore, the practicality aspect is demonstrated by the perfect score of the teacher and the high acceptance rate by the students (>90% say very practical). This shows that technically and pedagogically, e-LKPD can be implemented in real terms in the learning process in the classroom.

From the aspect of effectiveness, quantitative data shows that the use of e-LKPD has a significant impact on improving students' critical thinking skills and psychomotor skills. The experimental class using the product showed a significant increase in pretest–posttest scores ($p < 0.001$), with a high average N-Gain (0.69). In contrast, control classes using conventional LKS showed no significant improvement. This shows that the integration of WebAR and the guided inquiry approach can drive students' cognitive and motor engagement in a more meaningful way.

Overall, the e-LKPD final product developed proved to be feasible, practical, and effective. Innovations in the use of WebAR and the integration of educational gamification not only address today's digital learning challenges but also encourage the achievement of essential competencies such as critical thinking and scientific skills. Thus, this e-LKPD has the potential to be adopted more widely in the context of high school/MA biology learning, especially on concrete and observational biodiversity topics.

B. Research Limitations

Although the results show that Web Augmented Reality (WebAR)-based e-LKPD with the Guided Inquiry model is effective in improving the critical thinking skills and psychomotor skills of Phase-E students, there are some limitations that need to be recognized in the implementation and development of this product.

First, technical limitations are one of the main obstacles, especially related to mobile phone devices owned by students. Not all student devices support WebAR features optimally, so in some cases, visualization of the Nepenthes model may not run smoothly. This has an impact on the immersive learning experience which should be the main advantage of this media.

Second, technical limitations related to the presentation of Nepenthes 3D objects in Augmented Reality (AR) media are also a challenge. The process of creating accurate and attractive 3D objects requires specialized skills in the field of 3D graphic design, including mastery of modeling software such as Blender. This skill is important so that the Nepenthes model displayed through AR can represent the morphological shape of the plant in detail, realistic, and educational. Without these skills, the visual quality and functionality of 3D models can be suboptimal, ultimately affecting the attractiveness and effectiveness of AR-based learning.

Third, the time of implementation of the trial which is limited to one educational unit and one grade level (class X MAN 2 Semarang City) causes the generalization of results to be limited. Variations in the learning context, student background, and teacher readiness in other schools/madrasas are likely to affect the effectiveness of product implementation more broadly.

Fourth, although aspects of psychomotor skills have been measured through AR-based observation and activity indicators, these measurements still have potential assessor subjectivity. Evaluation of psychomotor skills should ideally be carried out by repeated observation or triangulation assessment (multi-observer) to increase the reliability of the results.

Fifth, the integration of the Nepenthes Go educational game in e-LKPD is still limited to location-based exploration functions and has not been fully utilized to assess overall learning outcomes. Further development may consider the use of games to support more interactive and adaptive formative assessments.

Sixth, the guided inquiry approach requires the readiness of students and teachers in managing the question-based and exploratory learning process. In practice, some students still tend to be passive and wait for explicit direction from the teacher, which indicates the need for further assistance in the habit of higher order thinking skills (HOTS).

These limitations are important considerations for the further development and implementation of similar e-LKPD in the broader context of learning, including adaptation across materials and educational levels.

CONCLUSION

The results of this research and development demonstrate that the e-LKPD assisted by Web Augmented Reality using a Guided Inquiry model on biodiversity material (specifically Nepenthes variation) is highly feasible, practical, and effective in enhancing the critical thinking and psychomotor skills of Phase-E students. Validation by media and material experts, as well as positive assessments from teachers and students, support its quality, while N-Gain analysis and statistical tests confirm significant improvements in the experimental group compared to controls. This interactive learning tool can be effectively utilized by biology teachers to foster Higher Order Thinking Skills (HOTS), provided there is sufficient digital infrastructure and trained, supportive educators. The product is publicly accessible online with a built-in user feedback system for ongoing improvement. For wider dissemination, the product is now available in open access via a link https://man2kotasmg.sch.id/biowebar/ features a user response questionnaire feature as continuous feedback. For future research, further development should focus on enhancing the 3D visual quality of Nepenthes models, incorporating automated evaluation features such as autograding, and conducting cross-school trials to examine broader impacts on other learning outcomes like motivation, scientific literacy, and collaboration, thereby advancing its potential as an adaptable digital learning innovation aligned with evolving technology and educational needs.

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