Development of E-Student Worksheet Based on Problem Based Learning Assisted by Augmented Reality in Science Learning to Improve Digital Literacy Skills

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Abstract

Learning in digital era still faces obstacle in the form of low student`s digital literacy skill. This study aims to develop valid, practical, and effective E-LKPD based on PBL assisted by AR to improve digital literacy skills. This type of research is R&D with a research method adapting 4D development model. The novelty of this research is the combination of E-LKPD with the PBL model assisted by 3D media from Assemblr combined using Canva to increase student interest in learning process which is then adjusted to digital literacy indicators to improve student`s digital literacy skills. The subjects of this study were 105 students at SMPN 1 Batukliang. Data analysis for validity used the CVI test from the validity results using instruments validated by 3 experts. Practicality data was seen from implementation of the learning process, teacher responses, and student responses. Effectiveness data was analyzed using N-Gain and Mann Whitney Tests from the results of the student`s pretest and posttest. The results of the validity showed a CVI value of 1.00 (valid). The implementation of learning showed an average value of 92% (very practical); teacher response 82% (very practical); and student response 91% (very practical). Meanwhile, the effectiveness received an N-Gain value of 0.70 (effective), the significance value of the Mann Whitney digital literacy test was 0.012, which means there is an influence of E-LKPD to improve students' digital literacy skills. Based on the data obtained, this AR-assisted PBL-based E-LKPD is valid, practical, and effective for use in the learning process.

Keywords: Development; E-Student Worksheet; Problem Based Learning; Augmented Reality; Digital Literacy

INTRODUCTION

Rapid developments in the 21st century related to technology, multimedia, information and communication in the digitalization era have influenced all aspects of human life, including the field of education (Muhimmatin et al. 2025). Students are required to have various skills in order to survive and compete, this is important because students are digital natives, meaning the current generation uses gadgets more for activities, making them vulnerable to incorrect information (Syefrinando et al. 2022). Education has also played a role in sustainable development. Digital literacy is crucial in Education for Sustainable Development (ESD). Digital literacy is crucial for achieve ESD goals because it enables individuals to understand, access, and use digital technology wisely and responsibly (Savitri et al. 2025).

However, when looking at Indonesia's technological capabilities, the 2021 Management Development Institute (IDI) compiled a list of knowledge sources, ranking Indonesia 53rd out of 60 countries with a score of 50.146. Furthermore, specifically for technology, it ranked 49th out of 64 countries. Furthermore, the Portulans Institute, through its 2021 Network Readiness Index, also noted that Indonesia still has several weaknesses in

preparing for technology, including the implementation of the SDGs, quality education, and the ICT regulatory environment (Zulkarnain et al. 2024). Based on the results of student observations conducted at SMPN 1 Batukliang, out of 20 students, the most frequently used applications were WhatsApp (17 students), TikTok (15 students), and Instagram (9 students), with an average duration of 4.3 hours of cellphone use. Only a few used the internet for learning purposes. This problem is a challenge for the world of education to improve student skills, one of which is digital literacy skills. Thus, innovation in learning is needed to improve digital literacy skills.

The term digital literacy was first introduced by Gilster & Watson (1997) as the ability to understand and use information from various digital sources. He stated that digital literacy is the ability to use technology and information from digital devices effectively and efficiently in various contexts, such as academics, careers, and everyday life (Kurnianingsih et al. 2017). According to Sutisna et al. (2020), digital literacy is the ability to use and utilize digital tools such as computers, laptops, and mobile phones to obtain and convey information. Learning that optimally utilizes digital tools will certainly be very helpful in improving digital literacy skills. The development of digital literacy aims to map and integrate the essential knowledge, skills, and attitudes needed by each individual to be able to develop and succeed optimally in the digital era (Chang et al. 2023). Digital literacy encompasses several aspects, such as the ability to search for information, critical skills in evaluating information, and the ability to use digital tools to complete specific tasks. Digital literacy is considered the ability to use the internet and digital media. Digital literacy skills are crucial for students so they can utilize information technology effectively in their learning (Perdana et al. 2020). In its current application, digital literacy makes it easier for people to be wiser in utilizing and accessing technology.

The characteristics of digital literacy do not only refer to the skills of operating and using various information and communication technology devices (hardware and software platforms), but also to the process of "reading" and "understanding" the content of technological devices as well as the process of "creating" and "writing" into new knowledge (Kurnianingsih et al. 2017). Mastering digital literacy in the context of learning can make educational processes and outcomes more effective, streamlined, and strengthened (Sukarno, & Widdah, 2020). Mastering these skills will certainly help students adapt to the digital era. Gilster (1997:3) in Usman et al. (2022) groups digital literacy into four core competencies that a person needs to have so that they can be said to be digitally literate, including:Internet Searching, Hypertextual Navigation, Content Evaluation, AndKnowledge Assembly.

Firstinternet searchingas a person's ability to use the internet and carry out various activities on it. SecondHypertextual Navigation as a skill for reading and dynamic understanding of the environmenthypertext.Content Evaluationnamely a person's ability to think critically and provide assessments of what is found online accompanied by the ability to identify the validity and completeness of the information referenced by the linkhypertext. FourthKnowledge Assemblythe ability to organize knowledge, build a collection of information obtained from various sources with the ability to collect and evaluate facts and opinions well and without prejudice.

Based on the information from various sources above, engaging and innovative media or learning resources that integrate technology are needed to train students' digital literacy skills. Learning media is one of the factors that supports student success (Ramdani et al. 2023). The use of visual literacy-based learning media is considered to help students understand the material better, increase learning interest, and improve learning outcomes (Indah & Fadilah, 2024). The learning process using digital media in the education system requires instructional design and approaches to transform education into a more engaging and interactive one (Riani et al. 2021).

Facing the need for more effective and engaging science learning media, the use of E-LKPD (Electronic Student Worksheet) is one way to increase teacher creativity and innovation

in using learning media (Sumanik & Siregar, 2023). The use of E-LKPD certainly requires digital media, thus aligning with the goal of improving students' technology use skills. The advantage of E-LKPD is that it can simplify and narrow space and time, thus making learning more effective. The variety of learning resources, virtual learning models, and learning applications used will further encourage student creativity in virtual learning. This can improve students' digital literacy skills more optimally (Sukarno, & Widdah, 2020).

One technological innovation that can be used in E-LKPD is the use of AR. AR has been widely used in education due to its unique characteristics that combine virtuality and reality (Li et al, 2025). AR is a type of technology that interactively combines real and virtual objects to produce 3D objects for display on the screen. AR is widely used in various fields, one of which is education (Fitria, 2023). In the world of education, AR is an effort to adapt the learning process to the era of the industrial revolution (Rejekiningsih et al. 2023). There is great transformative potential for AR technology to revolutionize science, technology, engineering, and mathematics (STEM) education, effectively bridging theoretical knowledge with practical applications to create more meaningful learning experiences (Zekeik et al. 2025). The use of AR in STEM learning reveals that AR-based learning applications provide learning activities that can provide stimulation to students, because a number of features and designs are similar, allowing students to influence the improvement of their conceptual understanding (Elmqaddem, 2019).

The use of AR can improve visualization, motivation, learning experience, and student quality in science learning. The focus of AR will continue to grow in the modern era, supported by technological advances (Zufahmi et al. 2025). AR) is recognized as an educational tool that promises to encourage visualization, and contextualize abstract concepts to increase student motivation and understanding (Voulgary et al. 2024). AR is a technology that visualizes scientific phenomena with innovative features to make learning more effective and achieve better results (Ropawandi, 2023). AR-based media can assist the learning process by presenting objects that may be difficult to present in the real world (Aini et al. 2021). AR also enables learning content in three-dimensional (3D) form, so it can visualize things that are difficult to see. In addition, AR's ability to bring virtual objects into the real world in real time can activate a sense of presence, closeness, and immersion in students (Qumillaila et al. 2017). Although there are many benefits there are positive learning outcomes and findings related to AR-based learning, but its implementation has not been carried out on a large scale (Zhang, 2022). Therefore, this research is expected to expand the use and utilization of 3D media using the Assemblr application designed using Canva, combined with the PBL model and adapted to digital literacy indicators in science learning with Ecology and Biodiversity material.

The implementation of E-LKPD in this study is also inseparable from the learning model, the learning model used is PBL. PBL is a learning approach that begins with solving a problem, to solve the problem students need new knowledge to solve it (Sofyan et al. 2017). To produce students who are able to solve problems, direct involvement in searching and analyzing information is required (Algiani et al. 2023). PBL makes students learn to solve a problem so that students will apply the knowledge they have or try to find out new knowledge needed to solve the problem (Amalina et al. 2024).

AR-assisted PBL-based e-LKPD is a learning resource developed as a solution to students' low digital literacy skills. Based on research conducted by Wahyuni et al. (2022), which developed an Android-based mobile learning module, found that using Android-based media can improve students' digital literacy. Previous studies have utilized interactive e-LKPD (Electronic Student Worksheet) to improve digital literacy. However, these studies often lack transparency regarding specific content creation pathways and tools, focus less on explicitly targeting detailed digital literacy sub-indicators, and lack strictly defined ecological use cases.

Therefore, the novelty presented in this study is not simply a combination of existing technologies, but rather the development and validation of pedagogically aligned E-LKPD that

integrates Assemblr-based AR through a defined Canva path, and is explicitly calibrated to produce measurable improvements in the level of digital literacy indicators. Based on the above explanation, the development of this AR-assisted PBL-based E-LKPD aims to improve the ability to use digital media which has an impact on improving students' digital literacy skills. The hypothesis of this study is assumed that after using AR-assisted PBL-based E-LKPD, there will be an increase in students' digital literacy skills.

METHOD

Research Design

This research is a Research and Development (R&D) study that uses Thiagarajan's 4D research model. R&D is a research method used to develop or validate products used in education and learning (Sugiyono, 2013). The 4D development model was developed by Sivasailam Thiagarajan, Dorothy S. Semmel, and Melvyn I. Semmel (1974). The 4D model consists of four development stages: Definition, Design, Development,and Dissemination. Each stage is designed to ensure that the developed learning media meets user needs and is effective in the learning context. Details of the activities carried out at each stage can be seen in Figure 1.
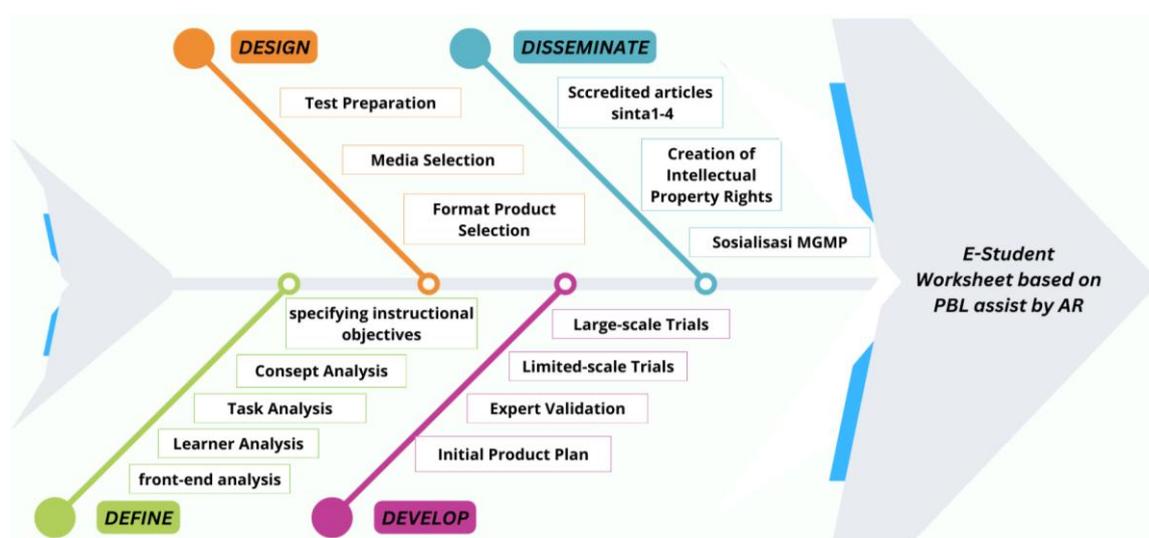

Figure 1. 4D Research Procedure

Definition Stage

The first stage of definition involves establishing and defining development requirements. Generally, a needs analysis and development requirements are conducted based on user needs and tailored to the product being developed. Five types of analysis are performed:front-end analysis, learner analysis, task analysis, concept analysis and specifying instructional objectives.

Design Stage

The second stage, namely design, is the initial product design stage that is adjusted to the results of the analysis in the definition stage. There are three steps carried out at this stage: preparation of teaching materials, selection of product format, and initial product design. The resulting and developed product, namely AR assisted PBL-based E-LKPD, can be accessed through Hyperlink https://bit.ly/Hadyatul_Muizzatissalmi_I2E02310004. The following shows the E-LKPD design which displays the PBL syntax in Figure 2, AR Objects and QR Code on Figure 3, and google form on Figure 4.

Figure 2. E-LKPD display containing PBL syntax

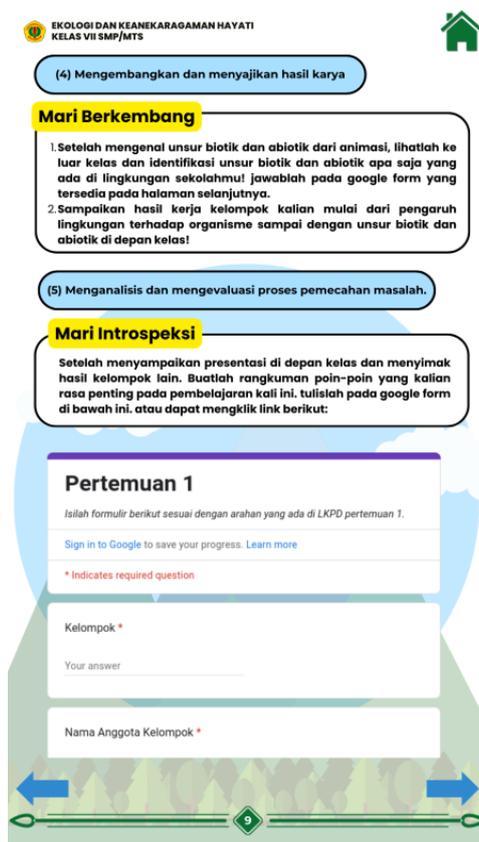**Figure 3.** E-LKPD display containing 3D animation and QR code

Figure 4. E-LKPD display containing Google Form

Development Stage

The third stage, development, is a refinement of the previous stage, producing a final product that has undergone revisions. The product produced in the design stage is then validated by three experts. After validation, revisions are made based on the suggestions and input from the three experts to produce a valid product. After the product is declared valid by the validators, a trial is conducted with students. This trial is divided into two stages: a limited-scale trial and a largescale trial. After the trial, the product is revised again to ensure that the developed product is practical and effective.

Distribution Stage

The final stage is dissemination. After the product is declared valid, practical, and effective, product dissemination activities are carried out. In this study, the dissemination process was carried out in three ways: first, through socialization activities in the MGMP forum, second, through creation of scientific articles, and thirdly, creation of IPR (Intellectual Property Rights) as legal protection for the work and innovations created by researchers.

The following are the implementation dates and outputs of each stage that has been carried out which can be seen at Table 1.

Table 1. Implementation Time and Output of the 4D Development Phase

Stage	Month	Output
Define	April 2025	Observation results
Design	May 2025	Product prototype with the following details:
		- E-LKPD
		- ATP
		- Teaching Module
		- Digital literacy test questions
Develop	June – September 2025	- Validity data
		- Practical data

Stage	Month	Output
Disseminate	October 2025	- Effectiveness data - E-LKPD socialization activities for MGMP IPA teachers - Validity article

Population and Sample

The product trial in this study was conducted at SMPN 1 Batukliang using four classes in grade VII. There were two trials: a limited-scale trial and a large-scale trial, with each trial using two classes. The number of samples used in the limitedscale trial was 53 students, while the large-scale trial used 52 students. Details of the number of samples can be seen inTable 2.

Table 2. Research Sample

No	Trials	Class	Number of Samples	Woman	Man
1	Limited scale trials	VII 2	27	16	11
2	Limited scale trials	VII 3	25	12	13
3	Large-scale trials	VII 4	27	14	13
4	Large-scale trials	VII 5	26	14	12
	Amount		105	56	49

Instruments & Procedures

The data collection techniques used were validation sheets, learning implementation sheets, teacher response questionnaires, student response questionnaires, and digital literacy test questions. Validity was assessed from the validation sheet results completed by the validator. Product practicality was assessed from learning implementation data, teacher responses, and student responses in a limited trial in two classes, namely class VII 4 and class VII 5 at SMPN 1 Batukliang. Product effectiveness was assessed from the results of data analysis.pretestAndposttestStudents in a large-scale trial in 2 different classes, namely class VII 2 as the control class and class VII 3 as the experimental class.

Data analysis

The data analysis technique used to measure the validity of the product that has been made is by using CVI developed by Lynn (1986) which uses 4 categories of choices, namely very good, good, less and very less with consecutive scores of 4, 3, 2, and 1. Scores of 4 and 3 are said to be valid, while scores of 2 and 1 are said to be invalid. The CVI content validity index is the proportion of valid divided by the number of experts, or can be seen in the following formula:

$$V = \frac{\Sigma \text{ Score}}{\text{N x Score}_{\text{maks}}}$$

Information:
V   = Content validity index
N   = number of validators
c   = the number of categories the validator can select

Then the data interpretation is carried out based on Polit & Back (2006), if the number of validators is 3 to 5 then the validity of the CVI or I-CVI item is valid if the value obtained is 1. Meanwhile, the overall validity of the instrument can be seen from the S-CVI/ Ave value (Scale-Content Validity Indexes/Average). If the S-CVI/Ave value is 1, the instrument is considered valid. In this study, three validators were used, so the product is considered valid if the S-CVI/Ave value is 1.

The practicality of the instrument is measured by the percentage of questionnaire results obtained. Practicality data analysis was performed by calculating the answers quantitatively using the following percentage formula:

$$Averange = \frac{\text{Scores obtained}}{\text{Maximum score}} \, x \, 100\%$$

After obtaining the percentage results, the results were interpreted using practicality criteria. This study consisted of four meetings for a limited-scale trial. Afterward, teachers, observers, and students were asked to complete a teacher response questionnaire, an implementation questionnaire, and a student response questionnaire. The practicality criteria were divided into five criteria based on a Likert scale. The mapping of these five criteria can be seen in Table 3.

Table 3. Practicality Criteria (Mahmud, 2022)

Scoring Results (%)	Practicality Criteria
0-20	Impractical
21-40	Less practical
41-60	Quite Practical
61-80	Practical
81-100	Very Practical

A large-scale trial was then conducted to obtain pretest and posttest data. This study involved six meetings for the large-scale trial. The first meeting began with the administration of pretest questions, and the final meeting was used for the posttest. Pretest and posttest data were analyzed to determine students' digital literacy skills in general and by indicator after using the AR-assisted PBL-based E-LKPD. The data analysis used was as follows: N-Gain using excel and Test Mann Whitney using SPSS. The formula of N-Gain, that is:

$$N - gain \, (g) = \frac{\text{Spost} - \text{Spre}}{\text{Smaks} - \text{Spre}} \, x \, 100\%$$

After analyzing the pretest and posttest data in the experimental and control classes using the formula above, the results were obtained with a range of 0-1. The effectiveness of the product can be seen from N-Gain criteria on Table 4.

Table 4. Effectiveness Criteria (Hake, 1998)

Results	Criteria
N-Gain ≥ 0.7	High
0.7 > *N-Gain* ≥ 0.3	Medium
N-Gain < 0.3	Low

Besides N-Gain Test hypothesis testing was also carried out using Mann Whitney test. Mann-Whitney test is a non-parametric test that is unbiased and consistent for testing hypotheses (Nugroho, 2008).Mann-Whitney test conducted using the SPSS application. After getting the results Mann Whitney test From SPSS, the significance value is seen. If the significance value obtained is ≤ 0.05, it can be concluded that there has been an increase in digital literacy skills.

RESULTS AND DISCUSSION

Validity

Before producing a valid product, several stages must be completed. These stages begin with the definition stage, which generates learning objectives, the design stage, which produces a prototype of the developed product, and the validation stage, which generates validator scores

that determine whether the product is valid or not. The definition stage includes five analysis steps: front-end analysis, learner analysis, task analysis, concept analysis, and specifying instructional objectives. This stage involves teacher interviews and student questionnaires.

Front-end Analysis

Based on interviews with science teachers at SMPN 1 Batukliang, it was discovered that SMPN 1 Batukliang uses the independent curriculum. Several problems frequently encountered during the learning process were also identified. Teachers at the school still rely solely on textbooks, leading to a lack of varied learning resources for students. Furthermore, teachers also face problems such as students' lack of focus and interest in participating in the learning process, particularly in science. Although the school has adequate facilities and infrastructure, such as computer labs and LCDs, their use is not optimal. This is in line with research of Rahma et al. (2023) explains that good learning must utilize existing media, especially in the 21st century, which must be adapted to digital based media. The use of learning media is crucial because it serves as a provider of innovative materials, guidance, mentors, and motivators in learning. Therefore, innovative and varied media or teaching materials are needed, as well as those appropriate for the digital era, to increase student learning interest.

Learner Analysis

Based on the teacher's answers during the interview, it was found that students' digital literacy skills were still low. These skills needed to be improved to support effective learning. A questionnaire completed by students revealed that most of them were familiar with technology and the internet, but their use of technology and the internet focused on games and social media. Based on observations of 20 students, the most frequently used applications were WhatsApp (17), TikTok (15), and Instagram (9), with an average usage time of 4.3 hours. Only a few used the internet for learning purposes. The following shows the results of the student observation questionnaire Table 5.

Table 5. Student Observation Results

Student	Duration of HP usage (Hours)				Frequently used applications						
	2	4	6	8	Tiktok	IG	WA	Youtube	Google	Spotify	Game
S1		√			√	√	√	√	√	√	
S2		√			√	√	√	√			
S3		√			√	√	√	√			
S4		√					√				
S5		√			√	√					√
S6		√			√	√	√				
S7			√			√	√	√			√
S8		√			√	√	√				
S9			√		√		√	√			√
S10			√		√	√	√				√
S11				√	√	√	√				
S12			√		√		√		√		
S13			√				√				
S14		√			√	√	√	√	√		
S15		√			√	√	√		√		
S16	√						√	√			
S17		√			√		√	√			
S18		√					√	√			√

Student	Duration of HP usage (Hours)				Frequently used applications						
	2	4	6	8	Tiktok	IG	WA	Youtube	Google	Spotify	Game
S19	√				√						√
S20				√	√						
Number	2	11	5	2	15	11	17	9	4	1	6

Task Analysis

Analysis of student assignments based on interviews with teachers revealed that assignments are typically drawn from textbook questions. Assignments relevant to everyday problems are rarely given. Furthermore, the assignments do not hone students' digital literacy skills.

Concept Analysis

Concept analysis was conducted by analyzing learning outcomes, the flow of learning objectives, and learning outcome indicators. After conducting the analysis, the Ecology and Biodiversity topic was finally selected. This topic was chosen because of its suitability to the PBL model used.

Specifying Instructional Objectives

After conducting the four previous analyses, the results were summarized into learning objectives. These objectives were tailored to the material used and the desired objectives. The material used was Ecology and Biodiversity. The following material and the desired objectives can be seen in **Table 6**.

Table 6. Learning objectives

Material	Objective
How does it affect environment on an organism?	After reading the text and observing 3D media, students can accurately analyze the impact of the environment on living things.
How do the components of an ecosystem interact?	After identifying the interrelated biotic and abiotic components, students can effectively analyze the interactions between the components that make up an ecosystem.
What is the difference between indonesia's biodiversity and other parts of the world?	Based on information gathered from various sources, students can clearly and comprehensively explain the differences between biodiversity in Indonesia and other parts of the world.
How-can influence humans against ecosystems?	After studying cases of environmental degradation, students can effectively analyze the impact of human activities on ecosystems.
Why should biodiversity conservation be carried out?	After discussing and reading conservation material, students can explain the importance of biodiversity conservation clearly.

The design phase involved three steps: developing teaching materials, selecting a product format, and developing an initial product design. The research resulted in a prototype of an AR-assisted PBL-based E-LKPD.

Preparation of Teaching Materials

In its implementation, E-LKPD certainly cannot stand alone, there are teaching materials. In addition to the E-LKPD, this study also developed instruments in the form of ATP, Teaching Modules, and Digital Literacy Test Questions. ATP is designed as the primary reference for developing learning outcomes, objectives, materials, and learning activities. The Teaching Module is designed to guide teachers in implementing AR-assisted PBL-based

learning. The digital literacy test instrument is designed to measure students' ability to use technology to find, understand, and disseminate information.

Product Format Selection

PBL-based E-LKPD products assisted by AR are created using the application Canva while AR is in the form of 3D media created using an application Assemblr. The 3D media is then inserted into the existing design Canva. The product is designed for Android but can still be accessed via laptop or PC. The product is distributed using the format hyperlink.

Initial product design

The product developed is an AR-assisted PBL-based E-LKPD designed to help students master science material while developing digital literacy skills. The initial step was to design the E-LKPD structure to conform to PBL syntax. The main components included a cover page, user instructions, student identity, learning objectives, main material and material descriptions, and PBL-based learning activities. The E-LKPD was created using the platform Canva. The following display of the design stages in the Canva application can be seen at **Figure 5.**
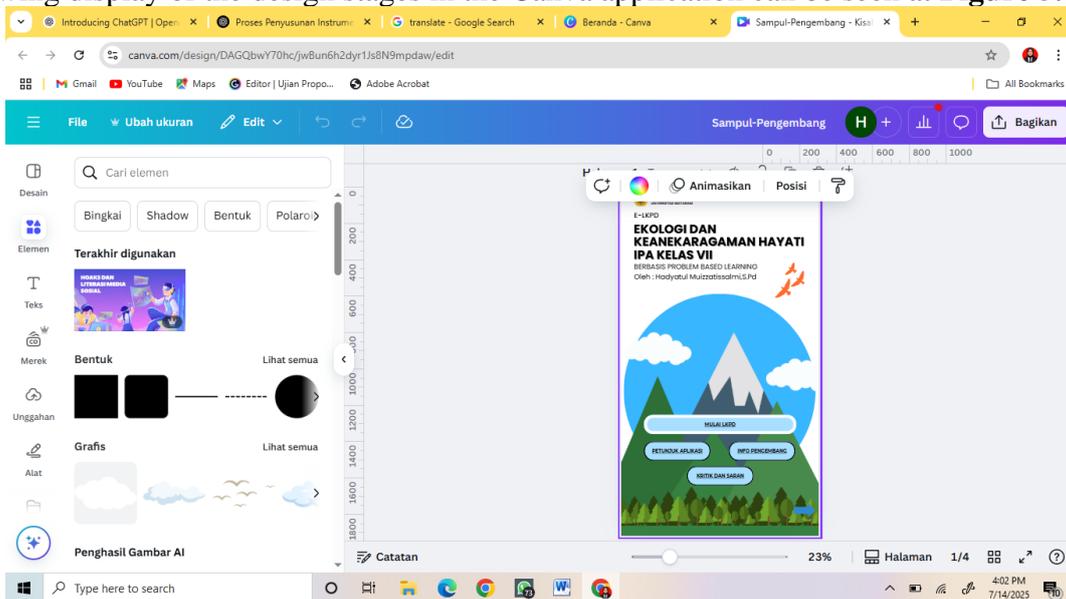

Figure 5. Designing E-LKPD using Canva

The next step is to design 3D media according to the E-LKPD material. The materials used are those included in the Ecology and Biodiversity Chapter. The following displays the 3D media design stages. Assemblr can be seen on **Figure 6.**

Figure 6. 3D Media Design using *Assemblr*

In addition to 3D media, the E-LKPD also includes instructional videos taken from YouTube and then integrated into the design using Canva tools so they can be opened directly without leaving the E-LKPD. To make it easier for students to answer questions, a Google form is also provided that can be filled out directly.

The development stage refines the results obtained in the design stage. This stage involves several processes: expert validation, limited-scale trials, and large scale trials. The results of each process are described below.

Expert Validation

As a first step, expert validation was conducted to ensure that the products and instruments developed were fit for purpose and suitable for use. Validity was calculated using CVI (Content Validation Index), which aims to determine the extent to which the product content aligns with competencies and learning objectives. The results obtained from all validators showed an average S-CVI/Ave score of 1, which falls within the valid criteria. Data obtained from the validators were analyzed using Excel; details of the analysis can be seen in Table 7.

Table 7.Research Instrument Validation Test Results

Product	Average			S-CVI/Ave	Category
	V1	**V2**	**V3**		
ATP	90,1	95,45	95,45	1	Valid
Teaching Module	85.83	95	93.33	1	Valid
E-LKPD	83.33	96.43	94.05	1	Valid
Digital Literacy Test	82.14	92.86	94.64	1	Valid

This table presents the results of validity tests on the developed products: ATP, Teaching Module, E-LKPD, and Digital Literacy Test. All scored 1, thus categorizing them as valid. This means that experts agree that the product's content, structure, and components are appropriate and suitable for use as learning instruments and tools.

Practicality

Limited Scale Trial

The practicality of the product was assessed through the results of the learning implementation, teacher responses, and student responses. This data was obtained from a limited-scale trial. During the learning process, the research process was directly supervised by subject teachers who acted as observers. Four meetings were conducted using E-LKPD PBL-based assisted by AR. The following is the learning process carried out by the class which can be seen in **Figure 7**.

(a)   (b)

Figure 7. (a) Presentation of discussion results on solutions to environmental problems
(b) Direction of the learning process in class by the teacher

The results of the data analysis obtained from the limited-scale trial varied widely. Data related to practicality were seen from the results of the learning process implementation sheet, teacher responses, and student responses. The results of the learning implementation percentage showed that the use of E-LKPD in the learning process had been implemented well, as the average had reached 90%. The highest percentage of meetings occurred at meeting 4, followed by meeting 1, and then the second and third meetings. Details of the learning implementation percentage data can be seen in Table 8.

Table 8. Results of Observations on Learning Implementation

Meeting	Assessment aspects			Percentage	Criteria
	Introduction	**Core**	**Closing**		
First	95	94	87	92%	Well executed
Second	92	91	87	90%	Well executed
Third	91	92	87	90%	Well executed
Fourth	94	95	87	96%	Well executed
	Average			92%	Well executed

This table shows the results of observations of learning implementation during a limited-scale trial. Observers (subject teachers) observed how learning using the product progressed across four sessions. All values, including the criteria, were met, indicating that the learning tool was implemented as planned without significant obstacles.

Next, we examine the teacher response data. Teacher responses were measured to assess the product's practicality from the instructor's perspective. The teachers who responded to this study were the same as the observers. This allowed them to assess several aspects, such as the material, presentation, language, and usefulness of the product. The average teacher response score was 82, which falls within the very practical criteria. The following details the teacher assessment results Table 9.

Table 9. Teacher Response Results

No	Rated aspect	Teacher Response	Criteria
1	Material Aspect	81	Very practical
2	Display aspect	88	Very practical
3	Language aspects	75	Very practical
4	Benefit aspects	83	Very practical
	Average	82	Very practical

This table contains teacher responses to the product, based on four aspects: material, appearance, language, and usability. All scores fall within the highly practical criteria. This means that teachers feel that the products developed are useful, easy to use, and meet science learning needs. In general, the use of E-Student Worksheet media helps teachers in the learning process. Learning becomes more practical when using media as a learning aid (Surachman et al, 2015).

In addition to seeing the teacher's response, the student's response regarding the practicality of the product was also seen. Students who have used E-Student Worksheet in several meetings can certainly assess several aspects such as material aspects, appearance aspects, language aspects and benefits aspects. The average value given by students was 91. The following details of the results of student responses can be seen in Table 7.

Table 10. Student Response Results

No	Rated aspect	Student Response	Criteria
1	Material Aspect	90	Very practical
2	Display aspect	91	Very practical
3	Language aspects	92	Very practical

| 4 | Benefit aspects | 91 | Very practical |
| | Average | 91 | Very practical |

This table displays student responses after using the product. The aspects assessed were the same as those assessed by teachers: material, appearance, language, and usability. All aspects fell into the highly practical category, indicating the product was considered engaging, easy to understand, and beneficial for science learning.

Overall, the limited-scale trial, which yielded data on learning implementation, teacher responses, and student responses, demonstrated that the developed E-LKPD is practical for use in learning, supported by good implementation data and positive responses from teachers and students. In line with this, Nabilla et al. (2022) stated in his research that interactive E-LKPD can be used as a teaching material media that can identify and train digital literacy skills.

Effectiveness

Large-Scale Trial

A large-scale trial was conducted in two different classes, namely class VII 2 as the control class using conventional methods without using E-LKPD and class VII 3 as the experimental class using the PBL model and AR-assisted PBL-based E-LKPD. There were six meetings conducted using AR-assisted PBL-based E-LKPD. The first meeting was used for the pretest, while the last meeting was used for the posttest. The following is the learning process carried out by the class which can be seen in **Figure 8**.

| (a) | (b) |

Figure 8. **(a)** Presentation of discussion results on solutions to environmental problems **(b)** Direction of the learning process in class by the teacher

Done N-Gain Testbased on pretest and posttest scores to measure the improvement of students' digital literacy skills. ResultsN-Gain Test shows improvement in experimental class is higher compared to the control class. The valueN-Gainin the experimental class it entered the high criteria while in the control class the valueN-GainIt falls into the Medium criteria. The resultsN-Gain TestDigital literacy skills can be seen in Table 11.

Table 11. N-Gain Test Results of Digital Literacy Skills

| Class | Mark | | N-Gain | Effectiveness criteria |
	Pretest	*Posttest*		
VII 2 Control	49	72	0.43	Medium
VII 3 Experiments	46	84	0.74	High

This table contains the calculation resultsN-GainStudents' digital literacy skills were obtained using the formula of posttest score minus pretest score divided by the maximum score minus the pretest score as shown in the method section. These results show the valueN-GainThe experimental class had a higher score than the control class, thus concluding that AR-assisted PBL-based e-LKPD learning effectively improved digital literacy skills compared to

conventional learning. These results align with statement of Yulianci et al. (2017) stated that students who learn with interactive multimedia have better learning outcomes.

Changes in Indicator Levels

Specifically, improvements in digital literacy skills are also seen in the improvement of each digital literacy indicator. Based on the results of the pretest and posttest in the large-scale trial, an analysis was also conducted.N-Gaineach digital literacy indicator. There is a different increase in each indicator as seen from the students' answers. Indicators Internet Searching, Hypertextual Navigation, and Content Evaluationget a high value with criteria while the indicatorKnowledge Assemblyreceived a score with moderate criteria. The following pretest and posttest results for each indicator of digital literacy skills can be seen in Table 12.

Table 12. N-Gain Test Results of Digital Literacy Ability Indicators

| Class | Indicator | Mark | | N-Gain | Criteria |
		Pretest	Posttest		
VII 2 Control	Internet Searching	54	84	0.65	Medium
	Hypertextual Navigation	44	66	0.39	Medium
	Content Evaluation	52	70	0.38	Medium
	Knowledge Assembly	48	70	0.42	Medium
VII 3 Experiments	Internet Searching	44	91	0.83	High
	Hypertextual Navigation	50	89	0.78	High
	Content Evaluation	56	91	0.79	High
	Knowledge Assembly	38	73	0.57	Medium

From the table above it can be seen that the valueN-Gainexperimental class is higher than the control class. However, on the indicatorknowledge assemblymarkN-Gainit still falls into the moderate criteria. Based on the implementation of learning during the research for the part of training the abilityknowledge assemblyStudents were asked to combine information from search results, group discussions, and AR displays. However, not all students were able to integrate the information logically. Some simply copied information from various sources without understanding the steps of the solution they were creating.

N-Gain value on the indicatorinternet searchingshows that students have experienced an increase in their ability to search for information more accurately and efficiently. Students have also experienced an increase in the indicatorshypertextual navigation, seen from their ability to navigate the various links available in E-LKPD, such as videos, articles, and other additional resources. Indicatorscontent evaluation showed a modest improvement. Students began to be able to distinguish between valid and invalid information and consider the accuracy and relevance of the sources they access. However, some students still tended to accept all information that appeared on the first page of search results without verifying its validity.

N-Gain value on the indicator internet searching showed that students experienced an increase in their ability to search for information more accurately and efficiently. During the use of E-LKPD, students were often asked to search for information to answer problem-based questions, which encouraged them to use appropriate keywords in search engines. Another study conducted by Apriliyanti (2025) who conducted learning using website-based learning media found that the use of internet-based learning media improved students' ability. internet searching 100% with very good criteria. Meanwhile, the ability that experienced the lowest improvement was knowledge assembly.

Students also experienced improvements in indicatorshypertextual navigation, This can be seen from their ability to navigate the various links available in the E-LKPD, such as videos, articles, and other additional sources. This activity supports them in broadening their understanding of the topics being studied. As for obstacles encountered during the study, some students faced technical difficulties, such as slow devices when opening multiple links at once, or confusion in moving from one page to another that are interconnected. The use of interactive

E-LKPD was also carried out by Simamora and Asri (2024), in which E-LKPD is also usedhyperlinkwho trains students so that in their research they get results that show a significant increase in the indicators hypertextual navigation.

Indicator content evaluation showed a less significant improvement. Students began to be able to distinguish between valid and invalid information, and to consider the accuracy and relevance of the sources they access. This was evident when they selected information from articles rather than personal blogs. However, some students still tended to accept all information that appeared on the first page of search results without verifying its validity. This indicates that content evaluation skills still need strengthening through more targeted guidance and practice. Another study conducted by Apriliyanti (2025) also showed that the indicator content evaluationranked third out of four indicators, so further improvement is needed.

Next, a hypothesis test was conducted based on the pretest and posttest data. Because the data obtained in this study, after being tested for normality, indicated that the data were not normally distributed, a non-parametric test was used Mann Whitney. The digital literacy scores of students in the control and experimental classes obtained during the large-scale trial were processed using SPSS. Mann-Whitney test for Digital Literacy shows a significance value of 0.012. Summary of data from the results of the hypothesis test with Mann Whitney test which was analyzed via SPSS IBM 26 can be seen at Table 13.

Tabel 13. Digital Literacy Hypothesis Test Results

Test	Value
Mann-Whitney U	203,500
Wilcoxon W	528,500
Z	-2,520
Asymp. Sig. (2-taild)	**0,012**

The significance value obtained is less than 0.05, so it can be concluded that there is a statistically significant difference in the Digital Literacy scores between students in the control class and students in the experimental class. Based on the two tests carried out, the results showed that the product The methods developed have been effective. Mayer (2011) stated that students who learn with interactive multimedia have better learning outcomes compared to classes that do not learn using interactive multimedia.

Finally, after the E-LKPD has been created as valid, practical, and effective, the dissemination stage is carried out. The E-LKPD that has been validated, practical, and effective can be accessed via a barcode onFigure 8The dissemination stage was carried out in 3 ways, namely socialization in MGMP, creation of Scientific Articles and creation of IPR. The e-LKPD that had been created was socialized through a science teacher discussion forum. The response results showed that teachers' understanding of AR before the socialization was relatively low, while their understanding of PBL was relatively better. The socialization that was carried out was able to increase teacher interest, as evidenced by all respondents expressing interest in using PBL-based e-LKPD assisted by AR that was in accordance with the material and curriculum. Most teachers were also interested in developing similar products although they still needed guidance. The estimated obstacles included limited tools, low student understanding, and limited implementation time.

Usability, Access and Constraints

In summary, in accordance with the research objective of developing valid, practical, and effective AR-assisted PBL-based e-LKPD to improve digital literacy skills, students' digital literacy skills have improved after using AR-assisted PBL based e-LKPD. However, there are several indicators that need to be further improved to truly maximize the improvement of these two abilities and achieve satisfactory results. For example, the indicatorsknowledge assemblyon digital literacy skills,Students still need to be trained more intensively to determine

the sources that will be used and how the information obtained can be arranged to form structured information. E-LKPD can be accessed via the link https://bit.ly/Hadyatul_Muizzatissalmi_I2E02310004 or can be done by scanning the barcode on Figure 8.

Figure 8. E-LKPD Product Barcode

Regarding the obstacles encountered during the research, some students faced technical difficulties, such as slow devices when opening multiple links at once, or confusion when moving from one linked page to another. In addition, the indicatorscontent evaluationSome students still tend to accept all information that appears on the first page of a search without verifying its validity. This indicates that content evaluation skills still need strengthening through more targeted guidance and practice. The implementation of the knowledge assembly indicator also faces challenges in that not all students are able to integrate the information logically. Some simply copy information from various sources without understanding the steps involved in the solution. Despite achieving the planned research objectives, the E-LKPD product has several limitations. One limitation is that it cannot yet be accessed offline. This limitation arises because during research, internet connection is often a constraint, resulting in some students completing the E-LKPD later than others. Another limitation is that several indicators have not been optimally improved, namely: knowledge assembly, so further research is needed to create an E-LKPD that is capable of maximally improving all digital literacy indicators.

CONCLUSION

Based on the objectives and results of the study, it can be concluded that the AR assisted PBL-based e-LKPD in science learning with ecology and biodiversity material is valid, practical, and effective in developing students' digital literacy skills. The digital literacy indicator that experienced the highest improvement started with internet searching with an N-Gain value of 0.83, content validity with an N-gain value of 0.79, hypertextual navigation with an N-gain value of 0.78 and finally knowledge assembly with an N-gain value of 0.57.So in the future, further development is needed to perfect the product which can improve the overall indicators.

RECOMMENDATION

The research conducted showed quite satisfactory learning outcomes and received a positive response from educators and students. However, several weaknesses were found in the E-LKPD in training certain indicators, for example, the indicator Knowledge Assembly that need to be improved. Therefore, further development is needed that focuses on improving the performance of E-LKPD, focusing on digital literacy indicators that have not yet been optimally improved.

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AUTHOR CONTRIBUTIONS STATEMENT

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Agus Ramdani	✓	✓				✓		✓	✓	✓	✓	✓		✓
Dadi Setiadi	✓		✓	✓			✓			✓	✓	✓	✓	

CONFLICT OF INTEREST STATEMENT
The authors state that they have no conflict of interest related to the research, authorship, or publication of this article.

INFORMED CONSENT
We have obtained informed consent from all individuals included in this study.

REFERENCES
Aini, AN., Prasetyowati, D., Prayito, M., Nugroho, AA., Ariyanto, L. (2021). *Pengembangan Aplikasi Augmented Reality Menggunakan Unity*. Semarang: Universitas PGRI Semarang.

Algiani, S. R., Artayasa, I. P., Sukarso, A. A., & Ramdani, A. (2023). Application of guided inquiry model using self-regulated learning approach to improve student's creative disposition and creative thinking skill in biology subject. *Jurnal Penelitian Pendidikan IPA*, 9(1), 221-230.

Amalina, S. N., Muhlis, M., & Ramdani, A. (2024). Pengembangan E-Bahan ajar berbasis problem based learning terintegrasi etnosains. *Jurnal Ilmiah Profesi Pendidikan*, 9(4), 2518-2524.

Apriliyanti, S. D., & Qomariyah, N. (2025). Pengembangan media pembelajaran website "sarafku" pada submateri sistem saraf untuk melatih kemampuan literasi digital. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, 14(2), 530-540.

Chang, Chu Y., Kuo, Hsu C., & Du, Zhengyi. (2023). The role of digital literacy in augmented, virtual, and mixed reality in popular science education: a review study and an educational framework development. *Virtual Reality*, 27, 2461–2479.

Elmqaddem, N. (2019). Augmented reality and virtual reality in education. Myth or reality?. *Int. J. Emerg. Technol. Learn.*, 14(3), 234-242.

Fitria, T. N. (2023). Augmented reality (AR) and virtual reality (VR) technology in education: Media of teaching and learning: A review. *International Journal of Computer and Information System (IJCIS)*, *4*(1), 14-25.

Gilster, P. (1997). *Digital literacy (p. 1)*. New York: Wiley Computer Pub..

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, 66(1), 64-74.

Indah, R. A., & Fadilah, M. (2024). Literature review: Pengaruh media pembelajaran literasi visual terhadap hasil belajar biologi siswa SMA:(Literature review: the influence of visual literacy learning media on high school students biology learning outcomes). *BIODIK*, 10(2), 188-198.

Kurnianingsih, I., Rosini, R., & Ismayati, N. (2017). Upaya peningkatan kemampuan literasi digital bagi tenaga perpustakaan sekolah dan guru di wilayah Jakarta Pusat melalui pelatihan literasi informasi. *Jurnal Pengabdian Kepada Masyarakat*, 3(1), 61-76.

Li, G., Luo, H., Chen, D., Wang, P., Yin, X., & Zhang, J. (2025). Augmented reality in higher education: a systematic review and meta-analysis of the literature from 2000 to 2023. *Education Sciences*, *15*(6).

Mahmud, M. (2022). *Skala Pengukuran Variabel-Variabel Penelitian Pendidikan Agama Islam*. Mojokerto: Yayasan Pendidikan Uluwiyah.

Mayer, R. E. (2011). *Multimedia Learning (2nd ed.)*. New York: Cambridge University Press.

Muhimmatin, I., Viclara, D., Jannah, I. N. M., & Rahayu, S. (2025). Developing discovery-based flip e-module to support undergraduate students collaboration. Prisma Sains: *Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram*, 13(3).

Nabilla, N., Edy, S., & Khikmiyah, F. (2022). Pengembangan E-LKPD matematika interaktif berbasis literasi digital. *JPMI (Jurnal Pembelajaran Matematika Inovatif)*, 5(6), 1581-1594.

Nugroho, S. (2008). *Metode Statistika Nonparametrik*. Bengkulu: UNIB Press.

Nevrelova, N., Korenova, L., Lavicza, Z., Bruzkova, N., and Schmid, A. (2024). Enhancing digital literacy in primary education through augmented reality. *Front. Educ.* 9:1390491.

Perdana, R., Jumadi, J., Rosana, D., & Riwayani, R. (2020). The online laboratory simulation with concept mapping and problem based learning (OLS-CMPBL): is it effective in improving students'digital literacy skills?. *Jurnal Cakrawala Pendidikan*, 39(2), 382-394.

Qumillaila, Q., Susanti, B. H., & Zulfiani, Z. (2017). Pengembangan augmented reality versi android sebagai media pembelajaran sistem ekskresi manusia. *Jurnal Cakrawala Pendidikan*, 36(1), 57-69.

Rahma, F. A., Harjono, H. S., & Sulistyo, U. (2023). Problematika pemanfaatan media pembelajaran berbasis digital. *Jurnal Basicedu*, 7(1), 603-611.

Ramdani, A., Jufri, A. W., Jamaluddin, J., & Yustiqvar, M. (2023). Increasing student science literacy: Learning studies using Android-based media during the Covid-19 pandemic. *InAIP Conference Proceedings* (pp.). Mataram, Indonesia: Science Education and Sciences, Mataram University.

Rejekiningsih, T., Maulana, I., Budiarto, M. K., & Qodr, T. S. (2023). Android-based augmented reality in science learning for junior high schools: Preliminary study. *International Journal of Evaluation and Research in Education (IJERE)*, 12(2), 630-637.

Riani, A., Utomo, E., & Nuraini, S. (2021). Development of local wisdom augmented reality (AR) media in elementary schools. *International Journal of Multicultural and Multireligious Understanding*, *8*(6), 154-162.

Ropawandi, D., Husnin, H., & Halim, L. (2023). Comparison of student achievement in electricity using augmented reality between offline and online classes. *Jurnal Pendidikan IPA Indonesia*, 12(1), 55-66.

Savitri, E. N., Sudarmin, S., Nuswowati, M., Saptono, S., & Billah, A. (2025). Analysis of digital literacy needs as the main foundation in education for sustainable development (ESD). *Jurnal Pemberdayaan Masyarakat*, *4*(2), 379-389.

Simamora, A. A., & Asri, M. T. (2024). Pengembangan E-LKPD interaktif untuk melatihkan kemampuan literasi digital peserta didik kelas X SMA pada materi virus. *Berkala Ilmiah Pendidikan Biologi (BioEdu)*, 13(2), 339-355.

Sofyan, H., Kokom, W., & Triwiyono, K. E. (2017). *Problem Based Learning Dalam Kurikulum 2013*. Yogyakarta: UNY Press.

Sukarno, S., & El Widdah, M. (2020). The effect of students metacognition and digital literacy in virtual lectures during the COVID-19 pandemic on achievement in the methods and strategies on physics learning course. *Jurnal Pendidikan IPA Indonesia*, 9(4), 477-488.

Sumanik, N. B., & Siregar, L. F. (2023). Pelatihan pembuatan E-LKPD melalui liveworsheets dan canva di SMPN 3 Merauke. *Jubaedah: Jurnal Pengabdian Dan Edukasi Sekolah (Indonesian Journal of Community Services and School Education)*, 3(1), 14-24.

Surachman, M., Muntari., Savalas, T. R. L. (2015). Pengembangan multimedia interaktif berbasis kontekstual untuk meningkatkan keterampilan berpikir kritis peserta didik kelas XI pada materi pokok sistem koloid. *Jurnal Penelitian Pendidikan IPA* (JPPIPA), 1 (1), 52-58

Suryaningsih, S., & Nurlita, R. (2021). Pentingnya lembar kerja siswa elektronik (E-LKPD) inovatif dalam proses pembelajaran abad 21. *Jurnal Pendidikan Indonesia*, 2(07), 1256-1268.

Sutisna, D., Widodo, A., Nursaptini, N., Umar, U., Sobri, M., & Indraswati, D. (2020). An analysis of the use of smartphone in students' interaction at senior high school. *Proceedings of the 1st Annual Conference* (pp. 221–224). Mataram, Indonesia: Education and Social Sciences, Mataram University.

Syefrinando, B., Sukarno, S., Ariawijaya, M., & Nasukha, A. (2022). The effect of digital literacy capabilities and self-regulation on the student's creativity in online physics teaching. *Jurnal Pendidikan IPA Indonesia*, 11(3), 489-499.

Thiagarajan, S. Semmel, D.S & Semmel, MI. (1974). *Instructional Development for Training Teachers of Exceptional Childre*n. Indiana: Indiana University Bloomington.

Usman., Zulfah., Hardiyanti., Zam, Z., dan Qadaruddin. (2022). *Literasi Digital dan Mobile Learning*. Sulawesi Selatan: IAIN Parepare Nusantara Press.

Voulgari, N., Panagopoulos, M., & Garneli, V. (2024). A systematic review of augmented reality in mathematics education: Fostering learning through art integration. *Arts & Communication*, *3*(2), 4446.

Yulianci, S., Gunawan, G., & Doyan, A. (2017). Model inkuiri terbimbing berbantuan multimedia interaktif untuk meningkatkan penguasaan konsep fisika peserta didik. *Jurnal Pendidikan Fisika dan Teknologi*, 3(2), 146-154.

Zekeik, H., Chahbi, M., Sefian, M. L., & Bakkali, I. (2025). Augmented reality and virtual reality in education: A systematic narrative review on benefits, challenges, and applications. *EURASIA Journal of Mathematics, Science and Technology Education*, *21*(9), em2699.

Zhang, J., Li, G., Huang, Q., Feng, Q., & Luo, H. (2022). Augmented reality in K–12 education: A systematic review and meta-analysis of the literature from 2000 to 2020. *Sustainability*, *14*(15), 9725.

Zufahmi, Z., Rohman, F., & Sari, M. S. (2025). Augmented Reality in Science Learning: A Systematic Literature Review. *Journal of Biological Education Indonesia (Jurnal Pendidikan Biologi Indonesia)*, *11*(1), 274-291.

Zulkarnain, I., Sitepu, Y. S., Sutatminingsih, R., & Rajagukguk, M. (2024). Student's digital literacy competence and its implications for the learning process. *International Journal of Evaluation and Research in Education*, 13(2), 997-1006.