Development of Augmented Reality-Based Science Learning Media to Improve Creative Thinking Skills and Digital Literacy in Junior High School Students

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Abstract
21st-century skills that students need to have are creative thinking skills and digital literacy. Efforts to improve creative thinking skills and digital literacy can be done through the development of Augmented Reality (AR)-based learning media. Augmented Reality is a current technology that combines real objects (the physical world) with the digital world and will obtain clear and detailed information from objects that are made as if alive. In the field of education, the use of Augmented Reality can produce interesting learning media and facilitate the student learning process. Based on the results of observations conducted on students, the empowerment of creative thinking skills and digital literacy has not been optimally implemented. However, basically the school has recognized the importance of empowering creative thinking skills and digital literacy for students. Creative thinking skills and digital literacy that have not been optimally implemented are not supported by the availability of learning media, especially in science subjects that are in accordance with facts or real objects around them. Creative thinking skills and digital literacy are not optimal and there is no development of science learning media that activates students so that researchers conducted research to develop AR learning media. The purpose of this research is to develop AR-based science learning media to improve creative thinking skills and digital literacy of eighth-grade students. The research and development method is the Lee and Owens method. Results indicate AR learning media developed can improve creative thinking skills and digital literacy of grade 8 students.

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1. Introduction

The effective facilitation of teaching and learning is imperative to equip students with the competencies and skills necessary to adapt to the Industrial Revolution 4.0 in the 21st century (Kirbas & Bulut, 2024). In the contemporary educational landscape, students are expected to exhibit a capacity for novel insights and competencies (Arafat, 2024). The development and enhancement of society will be facilitated by the presence of individuals who possess 21st-century skills (Çetin & Eren, 2023). Scholars posit that 21st-century skills encompass creative thinking and digital literacy (Cantaş et al., 2024).

Creative thinking is a cognitive ability that fosters students' creativity (Masadeh, 2021) and can be viewed as the process of generating useful, new ideas (Kwangpukieo & Sawangboon, 2024). It involves combining ideas to deepen conceptual understanding (Ozalp & Akpinar, 2021), and it underpins other cognitive abilities such as digital literacy (Saregar et al., 2021).

Digital literacy refers to the ability to use digital technology effectively to find, evaluate, create, and communicate information (Korkmaz et al., 2024). The skills and knowledge required continue to evolve alongside rapid technological developments (Net, 2023). Digital literacy extends beyond operating devices or software to include a wide range of cognitive abilities (Uzun et al., 2023).

Prior studies highlight the importance of developing creative thinking and digital literacy across life domains. Digital literacy demands cognitive authority and creativity in using digital media (Waemusa & Jongwattanapaiboon, 2023), and digitally literate individuals must manage information abundance and operate digital media effectively (Kocoglu et al., 2023). Given these benefits, their importance in educational settings is evident (Deiniatur & Cahyono, 2024).

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Efforts to improve creative thinking and digital literacy can be pursued through training in AR use (Buditjahjanto & Irfansyah, 2023). AR combines real-world objects with digital content to present clear, detailed, and lifelike information (Wikanta et al., 2023). In education, AR can yield engaging learning media and facilitate learning processes; AR categories include markerless (physical object tracking), marker-based (e.g., QR codes/symbols), and location-based (GPS) applications (Czerkawski & Berti, 2021).

Based on preliminary observations at a public junior high school (School A) in an anonymized eastern Indonesian city, the empowerment of students' creative thinking and digital literacy has not been optimal, and technology-based science learning media have not yet been developed. Accordingly, this study aims to develop AR-based science learning media to improve creative thinking and digital literacy among students at School A.

2. Method

2.1. Research and Development Model

The research and development model used in the development of learning media is the development model of Lee and Owens (2004). Lee and Owens' research and development procedure consists of 5 stages, namely: (1) Assessment/analysis which includes need assessment and front-end analysis, (2) Design, (3) Development, (4) Implementation, and (5) Evaluation). The stages of the Lee and Owens development model are shown in Figure 1, source: Lee and Owens (2004).

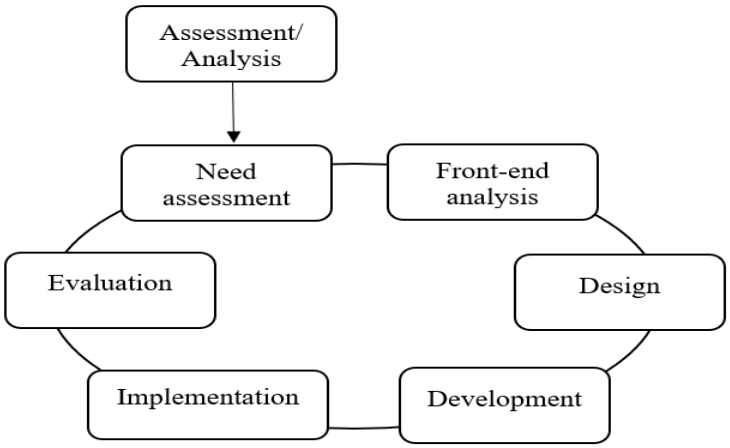

Figure 1. Development Model Stage

2.2. Place and Time of Research

This research was carried out at School A, one of the public junior high school at eastern Indonesia city from August to December 2024.

2.3. Population and Research Sample

The population of this study is junior high school students. The research sample taken was two study groups in grade 8, odd semesters in the 2024/2025 academic year.

2.4. Research Methods

The research methods used are problem identification, literature study, design of learning media prototypes, development of learning media, evaluation of learning media prototypes, implementation of learning media, evaluation, and revision and improvement of learning media. The flow chart of this development research can be seen in Figure 2.

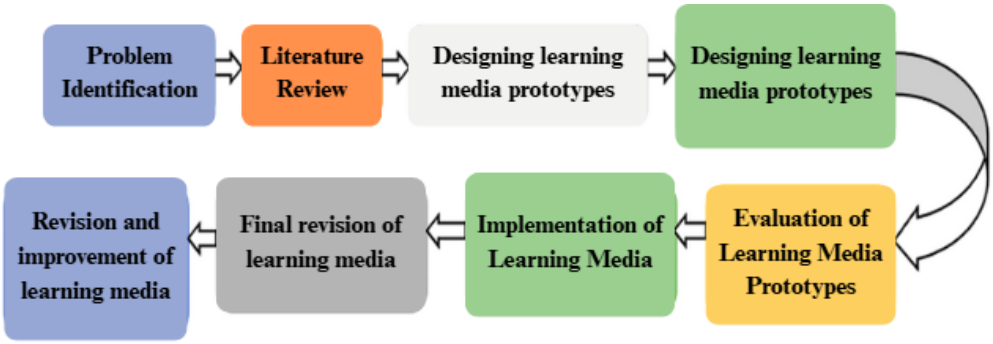

Figure 2. Development Research Flow Diagram

2.5. Research Stages

Research stages can be seen in Table 1.

Table 1. Research Stages

Research Stages	Steps
Problem Identification	Analysis of needs related to the problem to be researched
Literature Study	Study of relevant theories
Planning	Coordination with the school Preparation of initial research instruments Pretest to obtain initial data on digital literacy and creative thinking skills Create a research implementation schedule Preparing facilities, infrastructure, tools, and research materials
Media Development	Prototype AR learning media
Learning Media Trial	Individual trials, small group trials, field trials, and conduct pilot tests on students Contact media experts, practitioners, and subject matter experts Conduct technical reviews by media experts, practitioners, and material experts
Evaluation of Learning Media Prototypes	Evaluation of subject matter experts, practitioners, and media experts Evaluation of the results of individual trials, small group trials, field trials, and conduct pilot tests
Implementation	Carry out a pretest to obtain initial data on digital literacy and creative thinking skills Carry out posttests to obtain final data on improving digital literacy and students' creative thinking skills Develop Augmented Reality learning media based on reviews from media experts, practitioners, and material experts as well as student trial results Implementation of AR learning media to train creative thinking skills and digital literacy
Final Evaluation and Improvement of Learning Media	Posttest to obtain digital literacy data and students' creative thinking skills Evaluation of subject matter experts, practitioners, and media experts Evaluation of the results of individual trials, small group trials, field trials, and conduct pilot tests Processing research data qualitatively about the results of evaluations from media experts, material experts, and practitioners as well as trial results Processing research data on improving creative thinking skills and digital literacy after the implementation of AR learning media development Discussion of the obstacles encountered during the research process Discussion of research follow-up Preparation of reports and documentation Publication of articles in Sinta-accredited national journals

2.6. Achievement Indicators

An achievement indicator is a measure or criterion used to assess the extent to which research goals and objectives have been achieved. This indicator helps researchers in measuring the results, effectiveness, and impact of the research conducted. Indicators of the achievement of development research can be seen in Table 2.

Table 2. Development Research Achievement Indicators

No	Achievement Indicators	Sub Indicators of Achievement
	Research objectives	The achievement of the specific goals set in the research proposal is to develop AR learning media to improve creative thinking skills and digital literacy
	Media or Product Development	Completion of the prototype design of AR learning media
	Media trial	Implementation of individual trials, small group trials, field trials, and conduct pilot tests

No	Achievement Indicators	Sub Indicators of Achievement
		Review or improvement from media experts, practitioners, and subject matter experts
	Revisions based on feedback	Number of revisions or improvements from media experts, practitioners, and subject matter experts Number of revisions or improvements in individual trials, small group trials, field trials, and conduct pilot tests
	Media effectiveness	Improvement of creative thinking skills and digital literacy after implementation
	Process documentation	Availability of complete documentation of each stage of research
	Publication of research results	Submission of research results in Sinta-accredited journals
	User satisfaction level	Surveys or questionnaires to measure user satisfaction with the developed media

2.7. Research Design

Research design is an overview of research conducted when AR learning media is implemented to research subjects with quasi-experimental research using a Nonrandomized Control-Group Pretest-Posttest research design. The research design of the Nonrandomized Control-Group Pretest-Posttest uses two groups of research subjects, namely the experimental class and the control class (Leedy & Ormrod, 2015). The experimental class was learned with the implementation of AR learning media and the control class was learned with a package book. Both class groups were pretested and at the end a posttest was carried out with the same questions, namely creative thinking skills and digital literacy tests. The design of this study can be seen in Table 3, source: Leedy and Ormrod (2015).

Table 3. One Group Pretest Posttest Research Design

Subject	Pretest	Treatment	Posttest
Experiment	O1	X1	O2
Control	O1	X	O2

3. Results and Discussion

3.1. Study of the Validity Test Results of Augmented Reality-Based Science Learning Media

3.1.1. Study of the Validity Test Results of AR-Based Science Learning Media by Material Experts

The aspects assessed at the time of material expert validation are related to the feasibility of content, language, presentation and usefulness. A summary of the results of the material validation can be found as shown in Table 4.

Table 4. Material Expert Validation Results

No.	Indicator	Mean	Percentage	Category
1	Suitability of Material Description	5	100%	Valid
2	Material	5	100%	Valid
3	Presentation Support	5	100%	Valid
4	Language Qualifications	5	100%	Valid
5	Contextual Material	5	100%	Valid
Average Percentage of Validation Results		5	100%	Valid

The comments and suggestions given by the subject matter experts can be seen as in Table 5, based on the results of the validation of the subject matter experts, it is known that there are suggestions and comments given related to the development of learning media.

Table 5. Comments and Suggestions of Material Expert Validators

No.	Comments and Suggestions
1	Images of simple aircraft material clarified
2	Simpler drawings for easy understanding by students

The validity test of the e-module by a material expert aims to assess the correctness of the material that has been described in the AR learning media. The purpose of the material validation test is to obtain endorsement or approval from the validator of the material expert on the suitability of the material contained in the AR learning media with the needs (Pambudi & Windasari, 2022). AR learning media is categorized as

having good material if it is sorted based on chronology, topic, cause and effect, place, problem-centered, logical structure, and follows a spiral sequence (Ministry of National Education, 2008). The results of the validity test of AR learning media by subject matter experts were 100%, showing that AR-based science learning media with the Lee & Owens development model was very valid to be used (Akbar, 2013). Scoring the validity of the e-module is using a material expert validity test questionnaire.

According to Olvah et al. (2024) states that a decent AR learning media is a learning media that can be used for independent learning, has a clear purpose, a description of the subject matter is easy to understand, and has a good evaluation strategy. AR learning media can be categorized as meeting the accuracy of the material, namely meeting the aspects of facts, concepts, and procedures/methods (Indriani & Abidin, 2022). This means that the facts presented are effective in improving students' understanding, the concepts or theories presented do not cause many perceptions, and the methods presented are consistent and correct (BSNP, 2014).

3.1.2. Study of the Validity Test Results of AR-Based Science Learning Media by Media Experts

The aspects assessed at the time of validation of biology education practitioners are the presentation of learning, the attractiveness of the media, the ease of AR media to use, and the ease of AR media to understand. The summary data of the validation results of Biology Education practitioners can be found as shown in Table 6.

Table 6. Validation Results of Biology Education Practitioner Experts

No.	Indicator	Percentage	Category
1	Presentation of learning	100%	Very valid
2	Media attractiveness	98%	Very valid
3	Ease of AR media to use	100%	Very valid
4	Ease of AR media to understand	90%	Very valid

The comments and suggestions given by Biology Education practitioners can be seen as shown in Table 7.

Table 7. Comments and Suggestions of Biology Education Practitioners

No.	Comments and Suggestions
1	The development of AR media should be adjusted to the applicable curriculum standards
2	Make sure the 3D model in AR fits the subject matter i.e. a simple plane
3	AR should not only showcase models, but also encourage students to conduct exploration, virtual experiments, or scientific discussions

The completeness of AR-based learning media components includes appearance, usage aspects, content aspects, and design. AR is a technology that adds visuals, sounds, and computer-generated 3D models to the user's real-world environment (Watkraw & Sangsawang, 2023). The development of 3D-based AR media can facilitate student activities to improve students' creative thinking skills and digital literacy (Widiana et al., 2024). AR learning media will encourage students to think creatively by generating new ideas that are interactive to use AR learning media (Buditjahjanto & Irfansyah, 2023). This is in accordance with the statement made by (Arrasyafitri et al., 2024) that AR learning media can visualize abstract concepts and provide an interactive and engaging learning environment.

The development of AR learning media can also improve students' digital literacy. This is in accordance with research conducted by (Chabibah et al., 2024) which states that AR-based learning media will have an impact on students' digital literacy because students are invited to play an active role in using the application. AR learning media contains not only components of the learning process, but also additional components that can encourage students' creativity and imagination, increase active participation in the learning process, and encourage changes in student behavior (Unggul, n.d.). Learning processes that integrate learning media will train students to access, evaluate, and use available information effectively and develop a deeper understanding of the material in learning (Sholikhah et al., 2025).

One of the advantages of AR learning media is the attractive visual display because it can display 3D objects and their animations directly as if they appear in the real world and are equipped with information about 3D objects and their animations directly as if they appear in the real world and are complemented by information about 3D objects displayed in the form of text and audio (Putra et al., 2022). The preparation of AR media as a defense media has been declared suitable for use on the topic of simple aircraft material. The AR learning media developed contributes to learning, including: (1) The delivery of learning messages can be more standardized; (2) Learning can be more fun; (3) More interactive learning by applying learning theory; (4) The learning implementation time can be shortened; (5) The quality of learning can be improved; (6) The learning process

can take place anytime and anywhere as needed; (7) Students' positive attitude towards learning materials and learning processes can be improved; (8) The role of teachers has changed to positive (Fatimah et al., 2019).

The preparation of AR learning media in learning activities must pay attention to existing assessment standards, namely the feasibility of content or material in AR learning media related to learning objectives and language feasibility (BSNP, 2007). AR learning media has met existing assessment standards. This is evidenced by AR media that is developed in accordance with the feasibility of the content or the material and language used to make it easier to understand the learning material (Bahri & Akhmad, 2022). Students can easily understand the learning material if they use language that is not difficult to understand (Ariansyah et al., 2024). A language that is easy and not difficult to understand is in accordance with General Guidelines for Indonesian Spelling (PUEBI) (Ariansyah et al., 2024).

3.1.3. Study of the Validity Test Results of AR-Based Science Learning Media by Experts of Education Practitioners

The aspects assessed at the time of validation of biology education practitioners are the presentation of learning, the attractiveness of the media, the ease of AR media to use, and the ease of AR media to understand. The summary data of the results of the validation of Biology Education practitioners can be found as shown in Table 8.

Table 8. Validation Results of Biology Education Practitioner Experts

No.	Indicator	Percentage	Category
1	Presentation of learning	100%	Very valid
2	Media attractiveness	98%	Very valid
3	Ease of AR media to use	100%	Very valid
4	Ease of AR media to understand	90%	Very valid

The comments and suggestions given by Biology Education practitioners can be seen as shown in Table 9.

Table 9. Comments and Suggestions of Biology Education Practitioners

No.	Comments and Suggestions
1	The development of AR media should be adjusted to the applicable curriculum standards
2	Make sure the 3D model in AR fits the subject matter i.e. a simple plane
3	AR should not only showcase models, but also encourage students to conduct exploration, virtual experiments, or scientific discussions

3.2. Study of the Results of the Effectiveness Test of AR-Based Science Learning Media

3.2.1. Study of the Effectiveness Test Results of AR-Based Science Learning Media to Improve Digital Literacy

The results of the normality and homogeneity test of digital literacy data show that the data is distributed normally and homogeneously. Based on the results of the digital literacy test, the pretest data was 0.084 and the posttest data was 0.171. The value of the normality test > 0.05 so that the data is said to be distributed normally. Based on the results of the digital literacy homogeneity test in the pretest data is known to be 0.124 and the posttest data is known to be 0.935. The homogeneity test value > 0.05. Based on the results of the paired T test, it is known that digital literacy has a significance value of 0.000. The data shows a $p<0.05$ value. So it can be known that there is a difference between the pretest and the posttest of digital literacy. Based on the N-Gain test, it is known that the experimental class is 0.50 with the medium category and the control class is 0.30 with the low category. The results stated that there was an improvement in the experimental class that was taught using AR learning media compared to the control class that was only learned with a package book. Data on the results of the digital literacy pretest and posttest can be seen in Table 10.

Table 10. Digital Literacy N-Gain Scores, Experimental Class Scores, and Control Classes

Variabel	Class	N-Gain Score	Category
Digital literacy	Experiment	0.50	Tall
	Control	0.30	Keep

The results of research that have been conducted by researchers show that the application of AR-based science learning media can improve digital literacy. This can be seen based on the digital literacy gain score of the experimental class of 0.50 in the medium category, while the control class is only 0.30 in the low category.

This is because the control class does not use AR learning media and only uses package books. This statement is in line with research that has been conducted by (Jannah & Oktaviani, 2022) that AR-based science learning media can increase digital literacy.

AR learning media can train students' digital literacy. This is in line with research that states that AR learning media can stimulate students to learn independently and find problems and solutions to solve these problems according to real-life objects. Students are also skilled in accessing videos, music, images, on the developed AR media. These activities can give rise to students' digital literacy. In line with research conducted by Rosa Sinensis et al., (2023) and Listiana et al. (2024) that the stages of AR learning media can train students' digital literacy.

AR learning media is designed to facilitate the improvement of students' digital literacy. Students are able to sort through and independently find information relevant to the problem. The teacher presents illustrations in the form of phenomena in the students' daily lives and displays images according to real objects (Superior, n.d.). This can trigger students to find information that is relevant to the problem. Based on the results of the implementation carried out, students can answer questions that measure the indicators found. Students can identify problems and explanations related to simple aircraft material.

AR media also trains indicators using many sources. Based on the phenomena that have been presented, students are given the opportunity to be skilled in using AR learning media in the form of text, videos, music, simulations, and more (Carolina, 2022). Students are able to use AR learning media and are able to answer questions that measure indicators in the AR learning media developed (Agustiani et al., 2023). Students will find it easier to learn a material if the problem used is a phenomenon of daily life (Maulana et al., 2019). An important finding in this study is that students are active and enthusiastic in learning.

3.2.2. Study of the Effectiveness Test Results of AR-Based Science Learning Media to Improve Creative Thinking Skills

The results of the normality and homogeneity test of creative thinking skills data showed normal and homogeneous distributed data. Based on the results of the Normality test of creative thinking skills in the pretest data is known to be 0.090 and the posttest data is known to be 0.310. The value of the normality test > 0.05 so that the data is said to be distributed normally. Based on the results of the Homogeneity test of creative thinking skills in the pretest data is known to be 0.168 and the posttest data is known to be 0.695. The homogeneity test value > 0.05. Based on the results of the paired T test, it is known that creative thinking skills have a significance value of 0.000. The data shows a $p<0.05$ value. So, it is known that there is a difference between the pretest and the posttest of creative thinking skills. Based on the N-Gain test, it is known that the experimental class is 0.47 with the medium category and the control class is 0.20 with the low category. The results stated that there was an improvement in the experimental class that was taught using AR learning media compared to the control class that was only learned with a package book. The data on the results of the pretest and posttest of creative thinking skills can be seen in Table 11.

Table 11. N-Gain Scores: Creative Thinking Skills, Experimental Class Scores, and Control Classes

Variable	Class	N-Gain Score	Category
Creative Thinking Skills	Experiment	0.47	High
	Control	0.20	Low

AR-based science learning media is effective in improving students' creative thinking skills. The results of the research that have been carried out show that the application of science-based learning media can improve students' creative thinking skills. This can be seen from the results of the gain score of creative thinking skills in the experimental class of 0.47 in the medium category, while the gain score of the control class was only 0.20 in the low category.

The use of AR Learning Media that is interesting and interactive for students will encourage students' interest in learning. Student involvement in learning using AR learning media is necessary in training students' high-level thinking skills such as creative thinking skills (Rahmawati & Riyanto, 2023). The use of AR requires learning activities that are able to involve students to find out the answers to existing questions themselves. The use of AR in learning will help teachers to build interaction with students because the AR media used by teachers is a new experience received by students.

4. Conclusion

Conclusion of research & development of AR-Based Science Learning Media to Improve Creative Thinking Skills and Digital Literacy in Junior High School Students, namely AR-Based Science Learning Media to Improve Creative Thinking Skills and Digital Literacy in Junior High School Students Compiled using the Lee and Owens

development model has been validated based on validation results conducted by validators of material experts, media, and practitioners of Biology Education. AR-Based Science learning media to improve creative thinking skills and digital literacy in junior high school students is included in the practical category based on the results of the student response questionnaire assessment. AR-Based Science learning media to improve creative thinking skills and digital literacy in junior high school students is included in the effective category. The suggestion of the results of this research and development is that AR-based science learning media can be developed on other materials in grades 7, 8, and. Researchers can then continue to develop AR learning media that is integrated with the learning model. AR learning media can be developed again for other 21st century skills, such as: critical thinking skills, collaboration skills, communication skills, and various literacy and media AR learning can be developed in other subjects.

Author Contributions

All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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