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Development of Augmented Reality-Based and Artificial Intelligence-Assisted E-Modules on Global Warming Materials to Improve Critical Thinking Skills of High School Learners

Dwi Purnomo Aji[1], Hamdi Akhsan[2*], Leni Marlina[1]

[1] Master of Physics Education, Sriwijaya University, Palembang, Indonesia.
[2] Physics Education Department, Faculty of Teacher Training and Education, Sriwijaya University, Indonesia.

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Corresponding Author:
Hamdi Akhsan
hamdiakhsan@fkip.unsri.ac.id

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Abstract: The background of this research is the low level of critical thinking skills in students and the importance of technology utilization in the learning process. To deal with students' low critical thinking skills can be done by utilizing technology in the packaging of teaching materials in the form of e-modules based on Augmented Reality and Artificial Intelligence Assisted on Global Warming Material. This development procedure uses the Akker model in three stages: analysis, design, and evaluation, with 179 students involved. The findings of this study indicate that the products made have reached the valid category with an average value of the electronic validity of the module from the five aspects of 94.3%. Then, the final average of the results of student responses to the use of e-modules on global warming material amounted to 3.45 with a convenient product category. From the results of the N-Gain test using SPSS version 22.0, the results obtained are for the N gain value of 0.71 ≥ 0.70. So, it can be said that using electronic modules based on Augmented Reality and Artificial Intelligence on global warming material at SMA Negeri 3 Sekayu is adequate to improve students' critical thinking skills.

Keywords: Artificial intelligence; Augmented reality; Critical thinking skills; Electronic module; Global warming

Introduction

In the 21st century, Education for Sustainable Development (ESD) plays a vital role in facing the challenges of globalization in the world of education (Kopnina, 2020). The application of ESD in Indonesia is reflected in the revitalization of Curriculum 13 (K-13) into an Independent Curriculum. Students can explore their abilities and know their interests in implementing an independent curriculum; this also has an impact on the teacher, namely the teacher where the teacher is more accessible to vary and know the interests and talents of students to maximize student learning outcomes (Maisyaroh et al., 2024; Setyaningsih et al., 2024). In the implications of the independent curriculum in Indonesia, thinking skills, especially critical thinking skills, are essential during the learning process (Orhan, 2023). The level of critical thinking skills in Indonesian school students still needs to be higher. This fact is evidenced in a study that revealed the percentage level of students' critical thinking skills, especially for physics learning materials, especially the topic of global warming, was low (Akhsan et al., 2020b, 2020a).

Factors that cause low critical thinking skills are caused by the teacher's monotonous role during the classroom learning process. In teaching and learning activities, the teacher is the main factor in developing students' critical thinking skills (Chairatunnisa et al., 2023). The teacher's strategy in preparing the learning model determines the success in achieving learning objectives and achieving critical thinking skills at a high level for students (Basak & Yucel, 2024; Demir, 2022).

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The lack of variety in learning models results in students getting used to memorizing and a lack of curiosity in the student learning process; the habit of memorizing by students makes critical thinking skills not improve and will remain at a low level (Lestari et al., 2024). In addition to other problems, technology in the learning process still needs to be improved. Using technology in the learning process is an effort to enhance students' critical thinking skills (Gürsan et al., 2023; Rachmadtullah et al., 2023). In other cases, the cause of low critical thinking skills is using teaching materials and modules that are still conventional or only using package books. So that learning becomes non-interactive (Tampubolon & Sipahutar, 2024).

The solution to the problem of students' low critical thinking skills is using technology and teaching materials in electronic modules (Gürsan et al., 2023; Pitorini, 2024). Electronic modules have proven effective in improving students' thinking skills at low and higher education levels (Dewi, 2020; Kustantia et al., 2023). Then, using augmented reality technology in electronic modules can provide interactive learning for students. This impacts increasing students' enthusiasm for learning and curiosity (Dewi, 2020; Saidin et al., 2024). Augmented reality is a technology that offers an interactive experience in understanding virtual objects in a real-world environment by applying computer simulation content through 3D images, videos, and interactive features (Akhsan, Yusup, et al., 2023; Demircioglu et al., 2023). In learning natural science and physics, augmented reality technology has a positive impact on improving students' critical thinking skills. This is because augmented reality provides an authentic experience in the learning process (I. A. Rizki et al., 2024; Syawaludin et al., 2019). On the other hand, augmented reality technology can be combined with artificial intelligence technology to make electronic modules. Artificial intelligence is a technology that can answer the questions we give; in the learning process, the use of artificial intelligence has a positive impact on improving students' critical thinking skills (Lintner, 2024).

Based on literature studies and previous research results, using electronic modules based on problem-based learning combined with Socratic Dialogue has proven effective in improving students' critical thinking skills (Pitorini, 2024). Electronic modules combined with augmented reality technology create something positive to develop critical thinking skills in students (Dewi, 2020). Electronic books also provide benefits that are no less good in dealing with the low essential skills of thinking that occur in students (Pradina & Suyatna, 2018). In the learning process, using augmented reality technology is proven to provide good results for students to achieve good critical thinking skills (Akbaş, 2021; Syawaludin et al., 2019). This is an effort to face the challenges of the 21st century, where the use of augmented reality technology is needed in the learning process to produce students with critical thinking skills (Anwar et al., 2022). In addition, artificial intelligence technology creates interactive learning by creating critical thinking skills for students (Barana et al., 2023). From the many studies, there has yet to be a combination of augmented reality technology and artificial intelligence in electronic modules. In contrast, these two technologies produce a positive impact and provide good results in improving the critical thinking skills of each student.

The novelty of the research is in the form of innovations combining augmented reality technology and artificial intelligence in electronic modules to create critical thinking skills in each student. Therefore, the development of electronic modules based on augmented reality technology and artificial intelligence can answer the problem of students' low critical thinking skills and provide contributions, especially in Indonesia's education field. This research is also a graduate research program issued by BIMA Kemendikbud Ristek with research contract number 0018.021/UN9/SB1.LP2M.PT/2024.

Method

The research method used is development research (Maulana et al., 2022; A. Rizki et al., 2021), which aims to produce a product with certain stages; the product is an augmented reality-based E-Module and artificial intelligence-assisted global warming material that is valid, practical and effective for improving the critical thinking skills of high school students. Researchers use the development model to make teaching material products using the 4D model. The 4D development model by Thiagarajan (Agustin et al., 2020) was chosen because it offers systematic steps, flexibility, learner focus, and integrated evaluation. This model is oriented toward the development of a product. This 4D model consists of 4 stages, namely: the defining stage (Define), the planning stage (Design), the development stage (Development), and the dissemination stage (Disseminate). The research flow is seen in Figure 1.

Defining Stage

Researchers conducted several activities at this stage, such as analyzing student needs and school facilities. Analyzing student needs, namely learning, and determining content, indicators, and learning objectives. Needs analysis is carried out to find problems in related subjects through surveys of research implementation. In addition, researchers will also

design instruments that will be used to see the validity, practicality, and effectiveness of the products developed to improve critical thinking skills. Furthermore, facility analysis is carried out to determine the availability of facilities and infrastructure that teachers will use in carrying out research. Some studies use analysis as an initial stage before developing a product. Activities at this defining stage are carried out with the focus of the main objective is to determine the condition of the school and the main problems in learning physics on global warming material at school (Akhsan, Irfan, et al., 2023), as well as to determine the right solution by the problems and conditions of the school. Then, a literature study was conducted as has been done (Aji et al., 2024) to obtain the results of previous research. This has been done by Naf'atuzzahrah et al., (2024) and Tanjung et al. (2024) in using augmented reality technology.

Planning Stage

The next stage is design. At this stage, there are four steps in developing instruments: selecting learning media, selecting formats, and initial planning. The design stage in this study focuses on activities, namely designing initial product content, designing product components, determining the software to be used, designing flowcharts and storyboards, and collecting sources and materials for learning media content. This planning stage aims to design how the e-module will be developed. Then, the researcher carried out the production activities of the first draft of the augmented reality-based E-module and artificial intelligence-assisted global warming material that had been previously designed. The process of making the cover, preface, table of contents, concept map, introduction, module electronic identity, learning outcomes, material description, the flow of learning objectives, description of learning materials, instructions for using modules, learning materials, learning activities one and two, summative assessment, glossary, bibliography, and author's history. At this stage, augmented reality-based E-module products and artificial intelligence-assisted global warming material will be produced. In addition, researchers will also design instruments that will be used to determine the validity, practicality, and effectiveness of augmented reality-based E-modules and artificial intelligence-assisted global warming materials.

Development Stage

The third stage is development, which is divided into expert appraisal (product validation to experts) and development testing (product design trials). Draft 1, produced at the design stage, will be evaluated by validity testing at the expert appraisal stage to determine the feasibility level of the product developed based on expert judgment. The expert appraisal stage involves construct, media, language, and content expert validation. Researchers used five validators, namely 4 Sriwijaya University Physics Education Masters Lecturers and 1 Physics teacher at SMA Negeri 3 Sekayu. Suppose it has been accepted by the validator and declared valid. In that case, the e-module based on augmented reality and assisted by artificial intelligence on global warming material is tested (development testing) to determine the practicality and effectiveness of improving students' critical thinking skills in high school. In this study, the expected effectiveness is the development of augmented reality-based E-Modules and artificial intelligence-assisted global warming material to improve students' critical thinking skills in high school students.

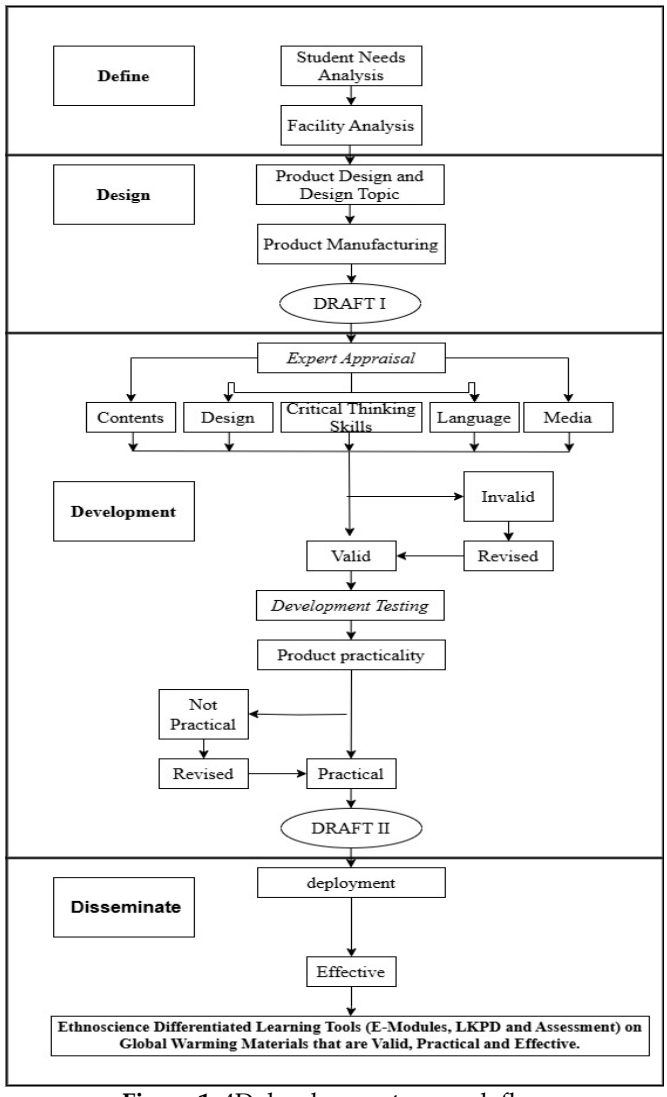

Figure 1. 4D development research flow

Dissemination Stage

The dissemination stage aims to disseminate augmented reality-based E-modules and artificial intelligence-assisted global warming materials. This

stage is the stage of spreading the global warming E-module developed on a wider scale. Each student will later conduct training in the use of the worldwide E-module that has been developed. At the end of the activity, researchers will see the effectiveness of the E-module that has been created so that we will get an augmented reality-based global warming E-module and artificial intelligence to improve students' critical thinking skills in high school that are valid, practical, and effective.

Data Collection Technique

Valid data is obtained from the validation results of 3 expert lecturers by the validator filling out the validation sheet with the categories "YES" and "NO." Practical data is obtained from the results of product trials on students; after using e-modules assisted by AR and AI on global warming material, students are asked to fill out a practicality sheet with a Likert scale and provide comments, suggestions, and responses. It is practical, as seen from the N-Gain value of students before and after using the product.

Data Analysis Technique

The analysis of product validity was carried out using a validation sheet given to the validator with a value category of 1 for "YES" and 0 for "NO." by using the formula:

$$\text{Percentage (P)} = \frac{\text{many scores of "yes" answers}}{\text{many aspects observed}} \text{ X } 100\% \qquad (1)$$

By making decisions about the validity regarding content feasibility, *language*, design, critical thinking skills, and augmented reality media and assisted artificial intelligence developed, namely if the percentage gain ≥ 50%, it is classified as valid. On the other hand, if the percentage is ≤ 50%, it is classified as invalid (Turan-güntepe & Abdüsselam, 2022). The product practicality analysis uses a Likert scale to determine the extent of the product's practicality. It looks at student responses as E-module users loaded with suggestions and comments. The assessment criteria refer to Table 1.

Table 1. Assessment Criteria (Murniati et al., 2023)

Scale Answer	Category
Strongly Agree	4
Agree	3
Disagree	2
Strongly Disagree	1

The final score is processed using the following equation:

$$R = \frac{\sum_{i=1}^{n} Vi}{n} \qquad (1)$$

Description:

R = Average value

$\sum_{i=1}^{n} Vi$ = Score of the assessment results of the i-th learner

n = Many data

After processing, the average value results are obtained, which will then be matched with the practicality level category in Table 2. Table 3 The effectiveness analysis was carried out using SPSS version 22.0, looking at the normalized N-gain value according to (Hake, 1998). The gain calculation results were then interpreted using the classification, as in Table 3.

Table 2. Categories of Practicality Level (Murniati et al., 2023)

Scale Answer	Category
3.26-4.00	Very Practical
2.51-3.25	Practical
1.76-2.50	Not Practical
1.00-1.75	Very Not Practical

Table 3. Gain Criteria (Hake, 1998)

Average Normalized Gain	Criteria
$(g) \geq 0.70$	High
$0.30 \leq (g) < 0.70$	Medium

Result and Discussion

Results of the Define Stage

The results of observations, interviews, and distribution of needs analysis lift to 179 class X students at SMA Negeri 3 Sekayu. Of the 179 students, only 161 students responded to the AR and AI-based e-module needs analysis questionnaire on global warming material with the results obtained, namely: 53.90% difficulty in defining the concept of global warming material, 47.10% difficulty solving global warming material problems, 55.90% difficulty analyzing global warming material questions 52.90% and difficulty when focusing on solving global warming material questions. This indicates low critical thinking skills. Then, the results of an interview with one of the class X physics teachers stated that the low essential thinking skills were caused by the low use of technology in the learning process and the lack of teaching materials available, especially on global warming material. The observation shows that class X physics learning on global warming material only uses a textbook. As for the use of technology, students are allowed to bring cell phones to school.

Results of the Planning Stage

Product development begins with developing global warming material; global warming material is designed as complete as possible by prioritizing the novelty, completeness, and correctness of the material content. After the material is developed, it is entered into the electronic module application. In the electronic module design, the cover, preface, table of contents, concept map, introduction, electronic module identity, learning outcomes, material description, the flow of learning objectives, description of learning material, instructions for using the module, learning material, learning activities one and two, summative assessment, glossary, bibliography, and author's history. Then, the design will be done using color combinations made of global warming material. Followed by making AR and AI that will be included in the electronic module. The results at this stage are in the form of initial products, namely electronic modules already based on AR and AI on global warming material.

Development Phase Results

The initial product obtained in the design process is then reviewed to determine whether the product is suitable from several aspects, such as material, construction, language, and AR and AI technology. This activity holds discussions with teammates and peers who understand electronic modules and AR and AI technology. This is done to maximize product development from a different and broader perspective. Then, the results of this stage were tested for validity by five validators, namely 4 Sriwijaya University Physics Education Masters Lecturers and 1 Physics teacher at SMA Negeri 3 Sekayu.

AR and AI-based electronic modules on global warming material carried out product validation. The initial product was validated by five validators, namely 4 Srivijaya University Physics Education Masters Lecturers and 1 Physics teacher at SMA Negeri 3 Sekayu, to determine the level of validity of AR and AI-based electronic module products on global warming material. The validation results can be seen in tables 4, 5, 6, 7, 8, and 9.

Table 4. Material Validation Results

Aspects	Assessment Indicator	Many instruments	Total Score	Maximum Score	Validation Result
Material	The suitability of the material with learning outcomes (CP), learning objectives (TP), and the profile of Pancasila students (P3) in the independent curriculum	3	3	3	100%
	The accuracy of the learning material	2	2	2	100%
	Up-to-date learning material	3	3	3	100%
	Benefits for insight and encourages curiosity	4	4	4	100%
	Clarity of information	4	4	4	100%

The results of material validation, with an average score of 100%, are in the valid category.

Table 5. Language Validation Results

Aspects	Assessment Indicator	Many instruments	Total Score	Maximum Score	Validation Result
Language	Readability	2	2	2	100%
	Conformity with correct Indonesian language rules	3	3	3	100%
	Use of language effectively and efficiently	2	2	2	100%

The results of language validation, with an average score of 100%, are in the valid category.

Table 6. Critical Thinking Skills Validation Results

Aspect	Assessment Indicator	Many instruments	Total Score	Maximum Score	Validation Results
Critical Thinking Skills	Material / Content	8	8	8	100%
	Construction	7	7	7	100%
	Language	7	7	7	100%

Critical thinking skills validation results with an average score of 100% are in the valid category.

Table 7. Design Validation Results

Aspects	Assessment Indicator	Assessment Indicator	Total Score	Maximum Score	Validation Result
Design	Order of presentation	1	1	1	100%
	E-Module cover and content design	3	3	3	100%
	Font usage (type and size)	2	1	2	50%
	Layout	2	2	2	100%

The design validation results, with an average score of 87.5%, are in the valid category.

Table 8. Results of Media Validation of AR and AI-Based E-Modules

Aspects	Assessment Indicator	Many instruments	Total Score	Maximum Score	Validation Result
Media	Learning Process	2	2	2	100%
	Skill Development	3	3	3	100%
	Accuracy of Language and Sentence Usage	9	8	9	88.8%
	Has Benefits, Purpose, and Identity	4	3	4	75%
	Accuracy of writing usage	3	3	3	100%
	Accuracy of image usage	2	1	2	50%
	Appropriateness of video usage	4	4	4	100%
	Accuracy of color selection	2	2	2	100%
	Attractiveness of appearance/layout	4	3	4	75%
	Software engineering	7	7	7	100%

The AR and AI-based e-module media validation results, with an average score of 88.8%, are in the valid category.

Table 9. Average Results of AR and AI-Based E-Module Validation on Global Warming Material

Validation Aspect	Percentage	Validity Category
Material	100%	Valid
Language	100%	Valid
Design	87.5%	Valid
Critical Thinking Skills	100%	Valid
AR and AI media	88.8%	Valid

The average result of the electronic validity of AR and AI-based modules on global warming material from the five aspects is 95.3% with a valid category.

Figure 2. Module electronics overview

Figure 3. AI features in module electronics

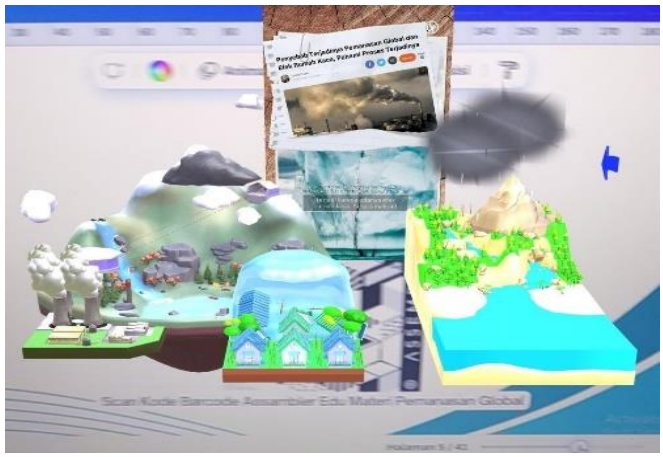

Figure 4. AR features on module electronics

The validation results of the five aspects are as follows: An electronic module based on AR and AI technology on valid global warming material is already in the product-valid category. This means that the product can be tested at the next stage. AR and AI-based electronic module products on valid global warming material can be seen in Figures 2, 3, and 4.

The product is an electronic module based on AR and AI technology on global warming material that has been proven valid. It will then be tested on three SMA Negeri 3 Sekayu students with low, medium, and high skill levels. This is intended to see if the product can be used at different skill levels and to determine its practicality. The results of the one-to-one trial can be seen in Table 10.

Table 10. Results of Student Responses to the Use of AR and AI-Based E-Modules on Global Warming Material

Student Code	Response Score	Maximum Response Score	Average Response Score	Level of Practicality
DW	37	44	3.36	Very Practical
PA	36	44	3.27	Very Practical
SS	40	44	3.63	Very Practical

The results obtained in the one-to-one trial, namely from two students with different abilities, gave a positive response. This is evidenced by student's reactions to the fact that AR and AI-based electronic module products on global warming material are efficient.

Five groups were formed from five different classes, each consisting of four students, comprising 20 students from five different classes. Students were asked to use the developed electronic module. The results can be seen in Table 11.

Table 11. Results of Student Responses to the Use of AR and AI-Based E-Modules on Global Warming Material

Group Code	Response Score	Maximum Response Score	Average Response Score	Level of Practicality
K1	38	44	3.45	Very Practical
K2	40	44	3.63	Very Practical
K3	42	44	3.81	Very Practical
K4	36	44	3.27	Very Practical
K5	34	44	3.09	Practical

The final average of student responses to using AR and AI-based e-modules on global warming material is 3.45, with a convenient product category.

The results obtained at this stage are: It is known that the five groups, consisting of four students from five different classes, stated that the AR and AI-based electronic module products on global warming material are in the very practical category in their use.

Results of the Dissemination Stage

Dissemination of AR and AI-based electronic modules on global warming material was carried out to all X-grade students at SMA Negeri 3 Sekayu, totaling 179 students. The dissemination is done to see the effectiveness of the product that has been made, done by giving 12 evaluation questions before and after the use of AR and AI-based electronic modules on global warming material. The results of the pre-test and post-test can be seen in Figures 5.

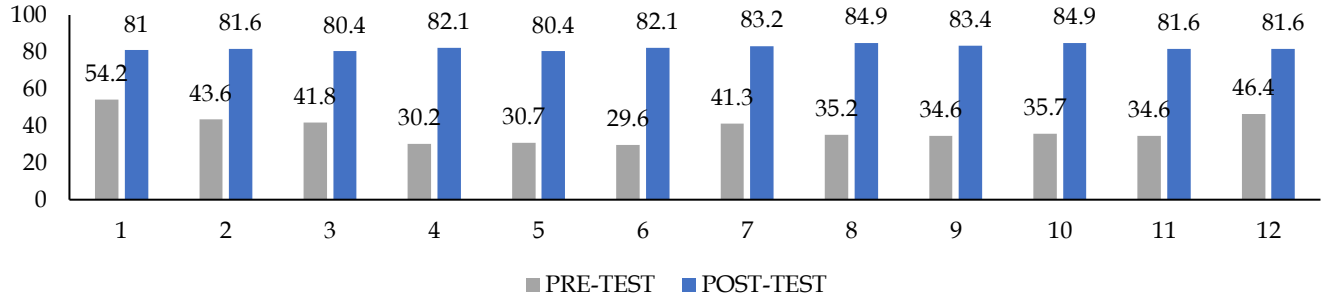

Figure 5. Results of pre-test and post-test distribution of the use of AR and AI-based e-modules on global warming material

N-Gain test was carried out using SPSS version 22.0. The test results of AR and AI-based electronic module product distribution on global warming material were seen from the average value per item of pre-test and post-test questions. The results of the N-Gain value can be seen in Table 12.

The results of the N-Gain test using SPSS version 22.0 are for the N gain value of 0.71 ≥ 0.70. So, it can be said that the use of AR and AI-based electronic modules on global warming material at SMA Negeri 3 Sekayu is at an adequate level to improve students' critical thinking skills.

Table 12. Results of N Gain Using AR and AI-Based E-Modules on Global Warming Material

	N	Minimum	Maximum	Mean	Std. Deviation
N Gain	12	.59	.77	.7080	.05395
Valid N (listwise)	12				

Discussion

The research team conducted a needs analysis of the SMA Negeri 3 Sekayu school. Interviews were conducted with physics teachers at SMA Negeri 3 Sekayu. The results of interviews with class X physics teachers stated that the low critical thinking skills were caused by the low use of technology in the learning process and the lack of teaching materials available, especially on global warming material. From the results of observations, it is evident that the X physics class only uses the package book to learn about global warming material. As for the use of technology, students are allowed to bring cell phones to school. Then, a student needs analysis questionnaire was distributed using Google Forms with a Likert scale to determine the initial description of students at SMA Negeri 3 Sekayu. The results obtained: Of 179 students, only 161 students responded to the AR and AI-based e-module needs analysis questionnaire on global warming material with the results obtained, namely: 53.90% difficulty in defining the concept of global warming material, 47.10% difficulty solving global warming material problems, 55.90% difficulty analyzing global warming material questions 52.90% and difficulty when focusing on solving global warming material questions. This indicates low critical thinking skills. This is because the situation states that students' critical thinking skills are still in the low category (Aji, Akhsan, & Marlina, 2024; Aji, Akhsan, Marlina, et al., 2024).

After analyzing and knowing the situation, needs, and what sources are needed, researchers can only design products in the form of electronic modules; making products begins with developing global warming material; global warming material is designed as completely as possible by prioritizing the material content's novelty, completeness, and correctness. After the material is developed, enter it into the electronic module application. In the electronic design of the module, the cover, preface, table of contents, concept map, introduction, the electronic identity of the module, learning outcomes, material description, flow of learning objectives, description of learning material, instructions for using the module, learning material, learning activities one and two, summative assessment, glossary, bibliography, and author's history. Then, the design will be done using color combinations by global warming material, followed by AR and AI, which will be included in the electronic module. The results at this stage are in the form of initial products, namely electronic modules already based on AR and AI on global warming material. The use of AR and AI technology, according to Dewi (2020), has proven effective in electronic modules as an effort to improve students' thinking skills at both low and higher education levels.

The initial product that has been designed is then re-evaluated to determine whether the product is appropriate from several aspects, such as material, construction, language, and AR and AI technology. In this activity, discussions were held with teammates and peers who understood electronic modules and AR and AI technology. This is done to maximize product development from a different and broader perspective. Then, an evaluation is carried out by an expert review or experts in their fields. The evaluation was carried out by three experts in AR and AI media, material, language, design, and critical thinking skills. Validation in the field of material that validators have carried out gets an average percentage of 100% with a valid category. The same thing happened to the results of the language validation that was carried out. The electronic module language shows promising results with an average percentage of 100%; this states that the language in the electronic module is in the valid category. For the validation of AR and AI media in the electronic module that has been made, the results show that the average percentage is 88.8%, so the electronic module media is valid. Electronic module product design also shows positive results, namely 87.5% with a valid category.

The module's electronic design is essential to attract students' interest and provoke students' curiosity in the learning process. As for the validation of critical thinking skills, it shows very expected results, namely 100% with a valid category. From the five validation results of 5 validators, the average result of AR and AI-based electronic module products on global warming material is 95.3% with a valid category. Therefore, the AR and AI-based electronic module on global warming material is valid for continuing at the practicality and effectiveness testing stage. According to Ly et al. (2024), in product development, it is said that products that can be tested are products that have gone through the validation stage and are declared valid by the validator.

Products that have been declared valid by validators will be tested. However, the trials carried out are still small in scale for individuals and groups. This study tested the electronic module on 3 class X students at SMA Negeri 3 Sekayu with high, medium, and low critical thinking skills. All three students with essential thinking skills responded well and stated that the electronic module was efficient. Then, to further ensure that the product is practical, it was tested on five groups from 5 different classes, each consisting of 4 students, so the total is 20 students from 5 different classes. The five groups' overall results show that the final average of student responses to using AR and AI-based e-modules on global warming material is 3.45, with a convenient

product category. According to Ayunda et al. (2024), the level of practicality is essential in product development. This is because the correctness and ease of the product are fundamental things that must be owned by the development of new products, especially electronic modules that utilize technology.

The end of product development in the form of AR and AI-based electronic modules on global warming material is product dissemination. If the product that has been developed has passed and meets the validity and practicality requirements, then an effectiveness test will be carried out. The effectiveness test will see whether the product that has been developed can answer the problem objectives, namely the low critical thinking skills of students on global warming material. After conducting a comprehensive test, the average results of 179 students from 5 class X at SMA Negeri 3 Sekayu who answered 12 multiple choice questions on critical thinking skills were known at the pre-test value of 38.1 and for the post-test value of 82.3. So, the results obtained are for the N gain value of 0.71 ≥ 0.70 with a convenient category. So, it can be said that using AR and AI-based electronic modules on global warming material at SMA Negeri 3 Sekayu effectively improves students' critical thinking skills.

The advantages of this research are that electronic modules have proven to be effective in improving students' thinking skills (Dewi, 2020; Kustantia et al., 2023). Then, using augmented reality technology in electronic modules can provide interactive learning for students. This impacts increasing students' enthusiasm for learning and curiosity (Dewi, 2020; Saidin et al., 2024). Already using augmented reality technology that offers an interactive experience in providing an understanding of virtual objects in a real-world environment by applying computer simulation content through 3D images, videos, and interactive features (Akhsan, Yusup, et al., 2023; Demircioglu et al., 2023). Then, it has been combined with artificial intelligence technology to make electronic modules. Artificial intelligence is a technology that can answer the questions we give; in the learning process, the use of artificial intelligence has a positive impact on improving students' critical thinking skills (Lintner, 2024).

Conclusion

The development of AR and AI-based electronic modules on global warming material is an effort to deal with the low level of students' critical thinking skills. On the other hand, using AR and AI technology is an effective solution because it provides interactive, imaginative, and authentic learning. This study shows that the products made have reached the valid category with an average value of the electronic validity of AR and AI-based modules on global warming material from the five aspects of 95.3%. Then, the final average of student responses to using AR and AI-based e-modules on global warming material amounted to 3.45, with a very practical product category. Moreover, from the results of the N-Gain test using SPSS version 22.0, the results obtained are for the N gain value of 0.71 ≥ 0.70. So, it can be said that using AR and AI-based electronic modules on global warming material at SMA Negeri 3 Sekayu effectively improves students' critical thinking skills. So, in this study, researchers succeeded in developing AR and AI-based electronic modules on global warming material that are valid, practical, and effective. This breakthrough and innovation is expected to be maintained and applied in learning activities at school to reduce students' low critical thinking skills on global warming material. Then, the researcher hopes for similar developments with different materials so that AR and AI-based electronic modules are not only focused on global warming material.

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