Development of E-Book Integrated Augmented Reality Based on STEM Approaches to Improve Critical Thinking and Multiple Representation Skills in Learning Physics

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***Abstract*—This study aims to develop an E-book Augmented Reality (AR) based on STEM approaches on renewable energy material. This E-book AR can be accessed on smartphones to improve students' critical thinking and multiple representation skills. The development adopted the Analyze, Design, Development, Implementation, and Evaluation (ADDIE) model. The study used pre-test post-test control research design on 93 students of class 10 at one of the junior high schools in Kerinci, Indonesia. The students were divided into three trial classes: X, the experiment class, and classes Y and Z, the control class. Class X learns using E-book AR, class Y uses E-book pdf, and Class Z uses textbooks. The E-book AR and test instruments provided have been validated by six validators. Based on the results of the analysis, it was found that E-book media was suitable for improving students' critical thinking and multi-representation skills in renewable energy. The result showed that media feasibility assessments by expert lecturers, practitioners, and colleagues scored very well. In addition, the E-book used is also effective in improving critical thinking skills and multi-representation. This is indicated by the acquisition of class X, who learned to use E-book AR and have gained value in the high category compared to the class Y and Z. In addition, the partial eta square value in class X contributed 78.7%, higher than class Y 55.5%, and class Z 53.1%. As well as obtaining the effectiveness of its use in the medium effect for critical thinking category and large effect category for multi-representation skill. Learning using E-book AR is more effective and positively impacts students in learning physics, especially in renewable energy subjects.**

***Keywords*—augmented reality, critical thinking, E-book, multi-representation, STEM**

I. Introduction

The tremendous development of technology has influenced all aspects of life, including education. Students are more engaged in learning when recent technology is involved. In this era of technological development, students are required to have a variety of abilities, one of which is the ability to think critically. Critical thinking involves making decisions and becoming part of higher-order thinking skills [1, 2]. These critical thinking skills help students solve complicated problems [3]. Besides, students must also have problem-solving skills. This ability can be trained with learning using representation. Representations can be divided into visual representations (tables, pictures, graphics, and diagrams), symbolic representations (mathematical symbols), and verbal representations [4–6].

According to previous studies, students' critical thinking skills tend to be low because they are less active in formulating concepts independently [7]. In addition, the results of the Indonesian National Examination in the last four years, from 2015 to 2019, find that energy material has the lowest percentage [8]. It can be interpreted that energy subject one of physics is complex for students; it affects quiet student understanding [9, 10]. Apart from that, the results of initial research at schools conducted interviews with students found that energy material was difficult for students. This can also be seen from the effects of students' school exams, which showed that the average score was not optimal in energy material. The students' difficulties are due to the energy concept, a fundamental physics concept that includes abstract concepts. In contrast to the ideas of force (pull or push), work and energy are pretty abstract, so transferring learning from one context to another is very difficult [11]. Students find it challenging to qualitatively interpret the basic principles related to the work-energy concept. Students' difficulties in this material are that they cannot differentiate energy in scientific contexts and everyday life and determine the system and environment of energy business processes [12]. Apart from that, students do not understand the basic concepts of the material correctly [11] . Furthermore, it was explained that students' difficulties in this material occurred on several topics, such as difficulty understanding the relationship between work, mechanical energy, and energy work [10, 13]

Previous studies found that difficulties in learning physics, especially in renewable energy subjects, were caused by students' low representation skills [14], low analytical thinking, and evaluation [15]. Student representation skills, including verbal, pictorial, and mathematical, are still low. The representation abilities of students are still low, namely 21.1% verbal representation, 26.1% image representation, and 18.4% mathematical representation [16]. Student representation in verbal representation was 43%, 32% in mathematical representation, and 25% in pictorial representation [17]. Apart from that, students' multiple representation abilities in physics material are still low, with a percentage of 71.86%. Students have difficulty making graphs and making verbal conclusions well. Apart from that, students in the low category have a pattern of learning difficulties in understanding language, understanding basic concepts, analyzing images, determining symbols, arranging equations, and calculating [18, 19]. Due to this low ability, it is necessary to improve learning in the form of appropriate learning models or media to motivate students so that students' conceptual understanding and critical thinking abilities can increase, especially regarding renewable energy material.

Developing students' thinking skills and knowledge of concepts can be done using appropriate media or teacher teaching materials [20].

One form of teaching materials that can be used following current technological developments is electronic books (E-books). The digital form of a printed book containing various integrated knowledge, broad knowledge, and discussion is packaged in E-books [21]. E-books consist of digital text, images, or audio accessed via computers or other electronic devices such as tablets, smartphones, and Android [22].

E-books can be integrated with Augmented Reality (AR) technology. AR can replace learning books in schools in virtual form. Several studies reveal that AR can improve achievement, students' attitudes toward subjects, motivation, interaction, and the desire to help students improve their understanding of learning content [23, 24]. In the 21st century, students are required to be experts in digital technology. Integrating AR technology into E-books in learning physics using Android applications to improve students' critical thinking and multi-representation. In addition, the E-book makes it easier for students because it can be accessed at any time by students.

STEM education is an interdisciplinary approach connected to the real world through problem-based learning [25]. STEM education is a scientific learning choice that supports generations to be ready for challenges and helps advance 21st-century skills today [26, 27]. Several studies have produced research results where the use of the STEM approach can overcome student problem-solving problems [28–31], increase critical thinking skills [32], critical thinking skills and scientific literacy [33], the ability to think creatively [34], solving mathematical problems [35, 36], can foster high technological and engineering literacy in students [37], as well as students' ability to understand concepts and problem-solving [38]. Therefore, it is necessary to develop E-book integrated AR technology based on the STEM approach for renewable energy material to improve students' critical thinking and multi-representation skills.

Researchers assume that using STEM-based E-books and those created with the help of Augmented Reality positively improves students' critical thinking and multiple representation skills. Apart from being based on several previous studies, critical thinking is a skill that requires students' ability to solve problems. Problem-solving abilities can be improved through multiple representations. The multiple representations used are visual, verbal, and mathematical representations. This is related to the approach that will be used, namely the STEM approach and visual abilities that can be assisted by demonstrating material using Augmented Reality.

Previous studies have been conducted on STEM topics, E-books, or Augmented Reality. Research by Jesionkowska, which examined the use of AR with a STEAM approach, found that the learning process by combining STEM and AR made students more active, gained more learning experience, and provided a more holistic and exciting education [39]. Almuharomah *et al.* also conducted research by creating a STEM-based physics module integrated with local wisdom. The study found that using a STEM approach improved students' thinking at school [34]. Furthermore, Usta and Ultay *et al.* also researched AR with a STEM approach, which found that AR animation was exciting and fun, abstract concepts were easy to present, and that STEM education was one area where Augmented Reality could be used effectively [40]. Various benefits have been found in previous relevant research. Still, no development has been found in the form of an electronic book linked to Augmented Reality and made using a STEM approach. So, the research that researchers will carry out is a development of previous research, namely developing a physics E-book based on STEM and assisted by Augmented Reality and looking at its effect on improving students' critical thinking and multiple representation abilities.

Based on the background that has been explained, the research questions in this study is: 1) What is the feasibility of a physics E-book developed based on expert validation assessment? 2) How effective is the use of physics E-books on renewable energy material to improve students' critical thinking and multi-representation skills? So, this research aims to produce a STEM-based physics E-book with the help of Augmented Reality that is feasible and effective for improving students' critical thinking and multiple representation skills.

II. Methods

This research adopts the ADDIE development model. This model consists of five steps: analysis, design, development, implementation, and evaluation. This research aimed to develop an E-book integrated with AR technology on renewable energy material to improve students' critical thinking and multiple representation skills [41]. This research is a process of making or improving a new product [42].

The description of the research steps is:

1) Analyze: The Analyze stage is the initial analysis stage to determine the difficulties experienced in learning activities. This analysis stage is used to obtain the required information to support the development of STEM-based E-book products assisted by Augmented Reality (AR). At this stage, needs, material, and student analyses are carried out. Needs analysis is carried out to adapt user needs to the media to be developed. At this stage, interviews and initial observations were conducted on teachers and research schools.
2) Design: The Design Stage consists of activities to design the E-book product that will be created. Researchers will design the instruments and learning media that will be used.
3) Development: The development stage is a stage in media development. Expert validation will revise the media, and limited trials will be conducted. The results of this stage produce valid E-books and data collection instruments to be implemented in the classroom.
4) Implementation: The Implementation Stage carries out the implementation of the product being developed. The products developed will be implemented in classes at schools that implement the Independent Learning curriculum. At this stage, data was obtained on improving students' critical thinking and multi-representation skills and data on the effectiveness of AR-assisted STEM-based E-book media development.
5) Evaluation: The evaluation stage is the stage of tabulation

and analysis of research data. The final research results and conclusions are obtained at this stage, namely how to increase students' abilities and the effectiveness of AR-assisted STEM-based E-books.

The research design can be seen in Fig. 1.

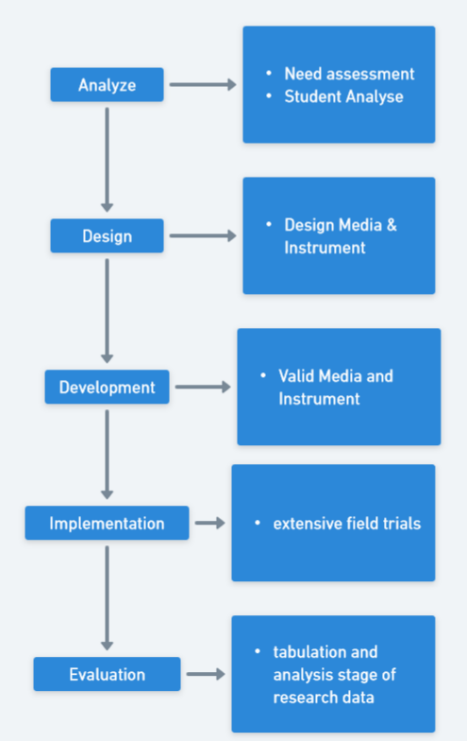


Fig. 1. Research design.

The effectiveness testing used a pretest-posttest control group experimental design. Three classes were established by using the cluster random sampling technique. The class design in this study is presented in Table 1, with the same pre-test and post-test questions for all classes.

Table 1. Pretest-posttest control group design

Class	Pre-test	Treatment	Post-test
X	O_1	X_1	O_2
Y	O_1	X_2	O_2
Z	O_1	X_3	O_2

Note:
O_1 = Pre-test critical thinking skills and multi-representation;
O_2 = Post-test critical thinking skills and multi-representation;
X_1 = Learning using physics E-book based on STEM assisted by AR;
X_2 = Learning using E-books in pdf format;
X_3 = Learning using books in schools and with the lecture method

The research was conducted in a state junior high school in Kerinci, Indonesia. The participants of this study were three classes in senior high school on science subjects studying renewable energy. The research participant was selected using the cluster random sampling technique, namely, collecting samples through a population in a random way in groups of students in classes without focusing on the level of that population.

Data collection instruments in this study include test and non-test instruments. The test instrument is essay questions to measure critical thinking and multiple representation skills. Besides, the non-test instrument uses a questionnaire, observation, and interview sheets. All data collection instruments have been validated in advance by expert validators and declared valid before use. Each instrument item test represents each indicator of critical thinking and multi-representation. The test instrument used has gone through the limited trial stage beforehand. It has been declared valid and reliable based on the value of the validity, reliability, and difficulty index of the questions using the QUEST application.

E-book AR was validated by six validators, including two expert validators, two physics teachers as practitioners, and two colleagues as peer reviewers. The score conversion for validation results is shown in Table 2.

Table 2. Classification of expert validation score

Score Intervals	Score Category
1.00–1.75	Very Not Good
1.76–2.50	Not good
2.51–3.25	Good
3.26–4.00	Very good

Before giving treatment, students are given pre-test questions, and at the end of learning, students are given post-test questions. The critical thinking and multi-representational test instruments provided will be analyzed first using the QUEST software program to determine the reliability of the questions and then validated using the V-Aiken equation, namely;

$$V = \frac{\sum S}{n(C-1)} \quad (1)$$

The interpretation of the value of V is presented in Table 3.

Table 3. Interpretation of V-Aiken results

Score Range (V)	Validity Level
$V \leq 0.4$	Weak Validity
$0.4 - 0.8$	Moderate Validity
$V \geq 0.8$	High Validity

Furthermore, the research analysis results were analyzed using the SPSS 25 program. At this stage, a two-group test or "two group Multivariate Analysis of Variant (MANOVA)" was carried out to determine differences in the increase in critical thinking and multi-representation of students in the research class. At this stage, the normality test, homogeneity test, n-gain analysis, and effect size analysis were carried out.

The data analysis techniques used to determine the effectiveness of media use are the normality test, homogeneity, N-Gain analysis, and effect size analysis. The description of the data analysis technique used is as follows.

A. *Normality Test*

The normality test was conducted to determine whether the samples were normally distributed. Normality testing using SPSS 25 based on the Kolmogorov-Smirnov test. The test was carried out using the condition that if the Sig value <0.05, the sample comes from a normally distributed population.

B. *Homogeneity Test*

Homogeneity test to see whether the two groups are homogeneous or not. A significant level guideline of $\alpha = 0.05$ is used to determine homogeneity. If the significance obtained is $>\alpha$, then each sample's variance is the same, meaning it is homogeneous and vice versa.

C. *Media Effectiveness*

Effect size analysis is used to see how much influence learning uses STEM-based physics E-books assisted by

Augmented Reality to improve students' critical thinking skills and multi-representation. The size effect is produced by calculating Cohen's f value from the transformation of the eta square (η^2) value with the following equation:

$$f = \sqrt{\frac{\eta^2}{1-\eta^2}} \quad (2)$$

In addition, the increase in students' abilities can also be seen through an increase in student scores on the pre-test and post-test scores and by looking at the N-gain scores.

III. Result and Discussion

A. Analysis Stage

The first stage in this research is the analysis stage. There are several activities in this analysis, namely (1) material analysis, (2) literature analysis, and (3) student and learning environment analysis. The material analysis identifies competencies or skills students must learn, including core competencies and basic competencies, materials, assessment instruments, and indicators [43]. At the literature analysis stage, the researcher completes the literature review related to the research and analyses relevant research to support the product development process. Next is to analyze students. The student analysis stage aims to discover the problems faced during learning. At this stage, observation activities are carried out during the implementation of learning. This observation aims to analyze students or obtain information about learning devices, methods, and attitudes during learning. In addition, interviews were conducted with teachers supporting the subject of physics to analyze the needs of teachers and students in learning.

Based on the results of initial observations and interviews with students and teachers, it is known that learning media is mostly through whiteboards and occasional practice questions using Android to attract more students' attention. Apart from that, sometimes the use of Android is only limited to looking for additional material. Teachers realize that using Android is very effective in learning because it is a helpful technology. However, its use is still not optimal because there are no Android applications for physics material owned by teachers or students, especially those who use Augmented Reality. Initial observations also found that students looked active when studying. It was seen that students were enthusiastic about getting the best grades when completing quiz questions given by the teacher. However, when we look at students' learning achievements in energy material, it turns out that they are still not optimal. Students also said they were interested in learning and using learning media that contained good audio and kinetic aspects and excellent visuals. So, teaching media with kinesthetic aspects in the form of experiments, audio aspects that have sound in the form of material explanations and videos, and visual aspects presented in the form of Augmented Reality will be developed.

B. Design Stage

The next stage is the design stage. At this stage, the project planning is done. Information collected from the analysis, related to the theory and learning design models, is intended to explain the learning that will be carried out.

The media design stage begins with creating media development designs and flowcharts. Media development design is a matrix arrangement containing the media development design itself. A flowchart describes the flow in operating media in the form of an Android application, which has been developed to make it easier to read the operational flow. The flowchart in this research can be seen in Fig. 2.

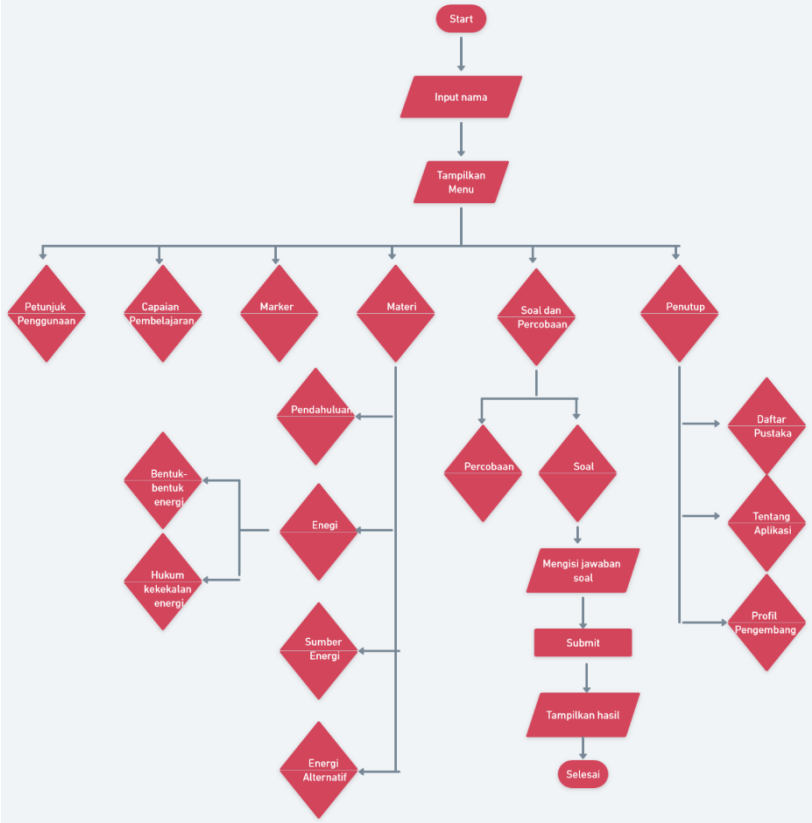


Fig. 2. E-book development flowchart.

The next step is preparing the content of the media that will be created. In this research, development begins by collecting the components of the E-book content in the form of material, images, videos supporting the material, and 3D Augmented Reality designs displayed in the E-book. Apart from that, he also designs color composition and media design in E-books.

This research created a physics E-book media on renewable energy material to improve students' critical thinking and multi-representation skills, which was developed by creating an E-book in the form of an Android application.

So, a connecting matrix is needed between critical thinking indicators and multiple representations with energy material. The matrix of indicators for critical thinking skills and multi-representation is developed in this E-book, as shown in Table 4.

Table 4. Indicator matrix of critical thinking and multiple representation skills

	Indicator	**The treatment given in the E-book**			
		Energy	**Forms of Energy**	**Law of Conservation of Energy**	**Energy Limitations**
Critical Thinking Skills	Identifying problems (Recognize the existing problem)	Showing problems regarding the energy distributed by the water wheel. Students identified the issues that occur in the problem.	Show a simple experiment on the form and change of energy. Students identify what conditions of energy change.	Students identify problems in simple experiments about the conservation of mechanical energy.	Issues related to energy limitations concerning Indonesia's population growth are presented. Students identify the relationship between these two things.
	Formulate problems (Looking for a solution to the problem)	Students can formulate the amount of energy channeled to the water wheel.	Students can develop uses and how energy can change.	Students develop the relationship between speed, height, and mass contained in mechanical energy.	Students develop ways to deal with the problem of limited energy and its relation to energy use in everyday life.
	Give logical arguments (Offers design solutions to existing challenges, as well as data collection and information compilation)	Students can give their arguments about the energy that is channeled to the water wheel.	Students provide arguments about what happens to energy changes.	Students give their ideas about the relationship between height, speed, and mass in the experiment on the conservation of mechanical energy.	Students provide a solution design for the energy potential found in the surrounding environment.
	Analyze and make decisions (Create conclusions about the formulation of problems and solutions that have an impact on everyday life)	Students provide decision answers regarding the amount of energy channeled to the problem.	Students can analyze and provide conclusions based on the energy change experiments.	Students can provide conclusions about the conservation of mechanical energy experiments carried out.	Students make decisions on solutions from the energy potential in the surrounding environment.
Multiple representations Skills	Determine and operate mathematical equations in solving problems.	An example of an image of renewable energy in everyday life is the water wheel. Students are presented with mathematical operations in solving these problems.	Showing issues regarding energy changes that occur in the water wheel, students use mathematical equations to solve problems.	Presented a simple experiment on the conservation of mechanical energy, students can determine the mathematical equations used in difficulties in solving problems regarding the conservation of energy.	Showing the issue of the relationship between the impact of energy use and population growth in Indonesia. Students explain the relationship between the two things verbally.
	Understand, explain, and write down concepts and principles and solve problems by writing verbally.	An example of an image form of renewable energy in everyday life is presented. Namely, the water wheel and a verbal explanation of the concept are given in solving the problem.	Students explain what happened to the water wheel and give their conclusions verbally.	Students interpret the pictures of the experimental results to find out the concept and write it verbally.	
	Represent data or information using charts, graphs, or tables.	An example of an image form of renewable energy in everyday life is presented, namely a water wheel, and its structure is presented, accompanied by a description of the problem in graphic form, which is represented in a mathematical form.	Students present graphical data again in questions about energy changes in the water lock.	Students represent the experimental data back into graphical form and draw conclusions explaining the concepts in the experiment.	Participants cannot find data in graphs or tables and express their findings again by writing them verbally.

C. Development Stage

At this stage, it is done by validating the product that has been developed. This study involved six validators. To determine their feasibility, expert lecturers, practitioners, and peer reviewers validated Media products developed and learning tools used in research. The items that will be used to measure students' critical thinking and multiple representation skills have also been declared feasible and have passed the empirical test stage to determine the validity and reliability of the questions. The media validation results can be seen in Table 5, and the validation results of the question items in Table 6.

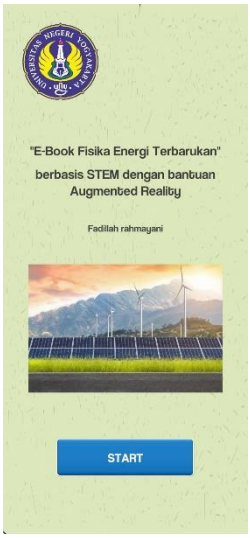
Table 5. Media feasibility assessment

Aspect	Average Score	Category
Serving Components	3.50	Very good
Content Eligibility	3.33	Very good
Language	3.47	Very good
Aspects of Visual Communication	3.41	Very good
Software Engineering	3.67	Very good
Average	3.44	Very good

Table 6. Content validity analysis of critical thinking skills and multi-representation instruments

	Question Items	Validity Coef (V)	Category
Critical thinking	1	0.89	Valid
	2	0.83	Valid
	3	0.83	Valid
	4	0.89	Valid
	5	0.78	Valid
	6	0.78	Valid
	7	0.89	Valid
	8	0.83	Valid
Multi-representation	1	0.83	Valid
	2	0.89	Valid
	3	0.89	Valid
	4	0.78	Valid
	5	0.89	Valid
	6	0.78	Valid

Based on the results of the validator data analysis in Table 5, it was found that the E-book developed was in a very good category, so it was very feasible to apply and try out in the classroom. The design of E-book AR can be seen in Fig. 3.

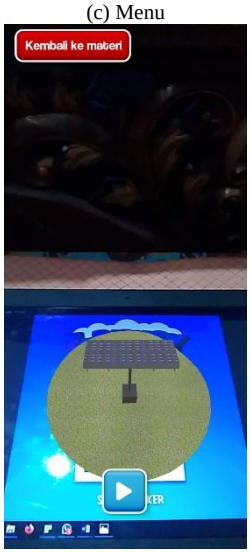


(a) Cover

(b) Login menu

(c) Menu

(d) Quiz



(e) AR Solar Energy

(f) AR Windmill Energy

(g) AR Water wheel Energy

(h) AR Geothermal Energy

Fig. 3. Design E-book with augmented reality.

The product's initial design, Design I, was first validated by expert lecturers, practitioners, and peer reviewers. Suggestions and comments at this stage will be used as a basis for conducting Revision I so that Draft II is produced. Design II is used to do limited trials on students and empirical test questions. After the problem has been solved, an evaluation will be carried out to assess whether there is an improvement in the product so that Design III is produced. Design III will

be used in field trials. After the extensive trial phase is carried out, it will be continued at the Evaluation stage to evaluate the achievement of the product that has been implemented so that it will produce a product that is ready for dissemination. The product being developed is a physics E-book in the form of an Android smartphone application. The product is made in the form of an Android application so that students can always use it without being limited by space. It can be used at any time and easily carried by students. The developed application can be accessed offline or without an internet network, but you must use the internet network for experimental activities.

The android application made in the form of a physics E-book is a learning media that can be used as teaching material in studying renewable energy material. Renewable energy was chosen to follow according to the independent learning curriculum. This E-book has videos, articles, and experiments on renewable energy materials to help students understand the subject. The E-book has a menu of instructions, markers such as 3D component barcode scans, learning materials, learning videos, assignment collection points, virtual and non-virtual quizzes and experiments, and a cover containing a bibliography, applications, and developer profiles. The user manual menu includes instructions for using the application. The marker comprises a 3D component scanned barcode image that will be used when using Augmented Reality assistance. There are sub-sub-materials on the material menu, including introduction, energy, energy sources, alternative energy, and the impact of limited energy. AR technology will be displayed in the explanation of alternative energy materials. There are several forms of applying alternative energy in everyday life, such as water, wind and solar energy, and geothermal energy. This AR visualization is also equipped with audio explanations of each material so that students can take advantage of the audio and visual senses of students in learning the material. Every other sub-material is equipped with energy materials and several additional questions.

The test question instrument was also used in empirical trials to determine the reliability of critical thinking questions and multiple representations. Empirical tests were carried out on 276 students. An empirical test analysis was conducted using the QUEST computer program. Item analysis was carried out to determine the reliability value of critical thinking skills and multiple representations seen in the summary of item estimate and summary of case estimates sections. An overview of the item estimates is used to see whether the items used match the Rasch model being tested. This value is also called sample reliability. Meanwhile, the summary of case estimates is the reliability value for the test created. The results of the reliability values are in Table 7.

Table 7. Instrument reliability result

Reliability	Nilai	Category
summary of item estimate	0.75	Fit
summary of case estimates	0.71	Reliable

Based on Table 7, it can be seen that the results of empirical trials on critical thinking and multiple representations show a summary of item estimates with a value of 0.75 and a summary of case estimates with a value of 0.71 in the reliable category. So, it is concluded that the question items are reliable and can be used.

After analyzing the product and test question instruments and declaring them valid and reliable, the research can proceed to the next stage: carrying out extensive trials or implementation in the classroom.

D. Implementation Stage

The implementation stage was carried out in 3 classes, as shown in Table 1. Class X learning used E-book AR, class Y learning used E-book PDF, and Class Z learning used textbook. A student response questionnaire was also given to assess students' media use in this broad trial. The results show a positive response and are in the very good category. The Study activities can be seen in the following figure.

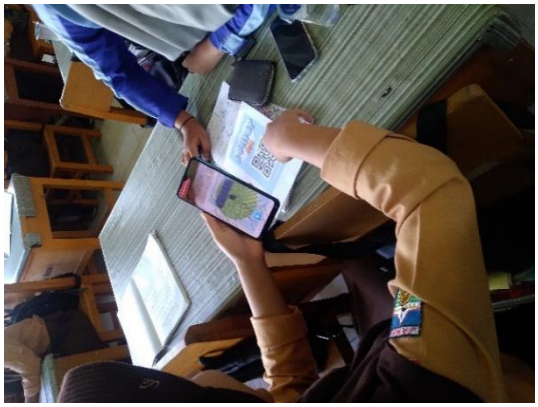


Fig. 4. Learning activities in Class X.

Fig. 5. Learning activities in Class Y.

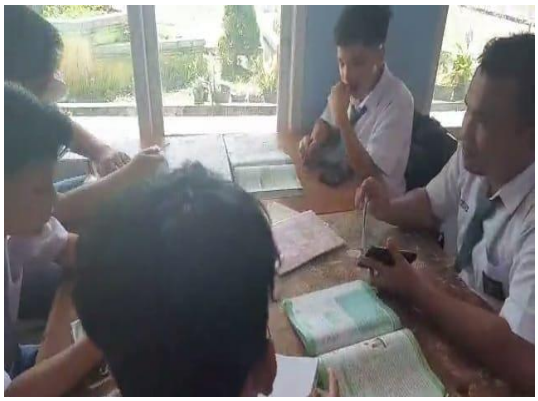


Fig. 6. Learning activities in Class Z.

Learning activities are carried out in two meetings. Learning is carried out in the research class using the developed media, namely class X, using the STEM approach. The phases of the STEM learning model include: 1) The Reflection Phase, where students plan and formulate

problems with existing knowledge by actively involving all students. 2) Research Phase: at this stage, students investigate ideas, theories, and laws from various related sources that can be used as guidelines in designing and creating solutions to unknown problems. In this phase, there are also asking questions (science) and defining questions (engineering). 3) In the Discovery Phase, choosing the optimal solution that suits your needs is made using the results of group discussions. At this stage, technology is also used to learn (Technology) and analyze and interpret data findings (Mathematics). 4) In the Application Phase, students develop and design solutions.

The methods used in the learning design are simulations, discussions, presentations, and question and answer. The learning plan developed consisted of two meetings. The 1st meeting discussed the material Introduction to Energy, and the 2nd meeting discussed the Alternative Energy material. The simulation was carried out when collecting experimental data in groups. Discussions occur when students conduct experimental activities to obtain conclusions on experimental problems. Presentations were made when students communicated the results of the discussions that had been carried out and continued with questions and answers when students responded to the results of the shared group discussions.

When learning using the E-book AR based on the STEM approach, it was found that students are more enthusiastic about using learning applications. AR technology is a new experience for students, so they become active and passionate about learning integrated AR technology. Also, high enthusiasm by students makes them more interested, easy to understand, and helps them remember Renewable Energy material.

E. Evaluation Stage

The evaluation stage aims to evaluate or reassess the achievement of the research carried out as the final stage of development. After the evaluation stage, an E-book product will be produced and categorized as feasible for learning. The data from the implementation stage will be analyzed at the evaluation stage. The data is about data on improving students' ability to think critically and multi-representation. The data on critical thinking and multi-representation skills for each class can be seen in Table 8.

Table 8. Mathematical representation ability test results

	Class	Pre-test	Post-test	N-gain	Category
Critical thinking	X	46.0	85.1	0.70	High
	Y	45.6	78.6	0.58	Medium
	Z	47.0	72.8	0.44	Medium
Multiple representations	X	36.3	82.3	0.71	High
	Y	44.3	67.7	0.44	Medium
	Z	39.8	59.1	0.30	Medium

Table 8 shows the critical thinking skills of class X, with a score of 0.70 in the high category, and class Y and Z of 0.58 and 0.44, respectively, which are included in the medium category. Meanwhile, in multi-representational skills, class X was 0.71 in the high category, class Y was 0.44, and class Z was 0.30 in the medium category. Based on these results, it can be interpreted that using E-book AR scores higher than class Y and Z.

Furthermore, an effectiveness test was carried out to see the increase in students' critical thinking and multi-representation skills of students after experiencing treatment. This test uses the Manova test, where the previous data was first tested for normality and homogeneity. The results of the normality and homogeneity tests can be seen in Table 9.

Table 9. Data normality test results

Data	Shapiro-Wilk		
	Statistics	df	Sig.
Pre_X_CT	0.969	31	0.502
Pre_Y_CT	0.941	31	0.090
Pre_Z_CT	0.958	31	0.261
Post_X_CT	0.947	31	0.131
Post_Y_CT	0.936	31	0.065
Post_Z_CT	0.968	31	0.461
Pre_X_MR	0.953	31	0.192
Pre_Y_MR	0.937	31	0.066
Pre_Z_MR	0.941	31	088
Post_X_MR	0.940	31	083
Post_Y_MR	0.938	31	075
Post_Z_MR	0.948	31	0.136

Note:
CT=Critical thinking;
MR=Multiple representation.

Based on Table 9, it is known that the Sig value is > 0.05. So, it can be said that the samples in each population group are normally distributed. The result of the homogeneity test is also shown in Table 10.

Table 10. Homogeneity test results

Treatment	F	df_1	df_2	Sig.
Pre-test CT	1.795	2	90	0.172
Post-test CT	2.788	2	90	0.177
Pre-test MR	2.562	2	90	0.083
Post-test MR	1.603	2	90	0.207

Table 10 shows that the value of Sig > 0.05 is known. So, it can be said that the sample is homogeneous. Furthermore, the Manova test was carried out, and it was found that there was a significant difference between media use and its effect on critical thinking and multi-representation skills, as indicated by the acquisition of Sig <0.001. The results of the Manova test were carried out using Hotelling's Trace test using SPSS 25 software. The results of the Manova test can be seen in Table 11.

Table 11. Manova test results

Within Subject	Effects	Value	F	Sig.
time	Hotelling's Trace	6.649	295.878	< 0.001
Time*Class	Hotelling's Trace	0.333	7.331	< 0.001

Furthermore, to determine the effective contribution of the treatment given to each class to the increase in critical thinking and multi-representational skills, a test was carried out using SPSS 25 software through a Partial Eta Squared value. The results of the analysis can be seen in Table 12.

Table 12. The effective contribution of students' abilities

Class	F	Sig	Partial Eta Squared
X	164.729	< 0.001	0.787
Y	55.512	< 0.001	0.555
Z	50.35	< 0.001	0.531

Partial Eta Squared values for classes X, Y, and Z were 0.787, 0.555, and 0.531, respectively. So, it is known that Class X, who is learning to use E-book AR, contributed 78.7% more than Class Y, 55.5%, and Class Z, 53.1%. Furthermore,

Effect Size analysis was carried out to determine the influence of the media on increasing critical thinking and multi-representation skills, as shown in Table 13.

Table 13. Effect size calculation results

No	Variables	Eta Square	Cohens' f	Interpretation
1	critical thinking	0.145	0.145	Medium effect size
2	multiple representations	0.279	0.279	Large effect size

Based on the effect size analysis, it is known that the STEM-based physics E-book media assisted by Augmented Reality affects critical thinking skills in the medium effect size category and multi-representational skills in the Large effect size category.

In addition, the results of the study found that the use of STEM-based android applications with the help of Augmented Reality increased learning outcomes for students, as seen from the N-gain scores of the experimental class in the high category. This is in line with research by Usta [40] that the use of animation is intriguing and fun, and by using animation, abstract concepts are easily presented, displayed, and conveyed to students. This study found that STEM education is an area where Augmented Reality can be used effectively. Research also shows that using E-books with the help of Augmented Reality is more attractive to students' learning interests. This is because AR media is something new for students. Students look enthusiastic about learning using E-books with the help of AR. In addition, this E-book is more interesting because it is equipped with videos, materials on renewable energy, additional articles for students to read, and experiments carried out on their respective Android smartphones. This is in line with research [44] that shows that high student learning interest makes students' curiosity even more elevated and makes students more interested in learning and using media so that students' thinking skills also increase.

IV. Conclusion

Based on the results of data analysis, it can be concluded that the STEM-based physics E-book learning media assisted by Augmented Reality is categorized as feasible to use for improving critical thinking and students' multi-representational abilities on renewable energy material. This is based on the media feasibility assessment by expert lecturers, practitioners, and colleagues, obtaining a score in the very good category. Evaluation by students through student responses received scores in the very good category.

Furthermore, the STEM-based physics E-book learning media assisted by Augmented Reality effectively improves the critical thinking and multi-representational abilities of high school students. This is based on the n gain value of the multi-representation ability of class X in the high category and class Y and Z in the medium category. Also, the partial value of eta square media in STEM-based physics E-books assisted by Augmented Reality can improve the ability critical thinking and multi-representational of 78.7%, which have superior grades than class Y and Z with contributions of 55.5% and 53.1%.

Suggestions for using STEM-based physics E-book products assisted by Augmented Reality that have been developed are STEM-based physics E-book products assisted by Augmented Reality on renewable energy materials to improve students' critical thinking skills, and students' multi-representation can be used by teachers and students in other schools as media. Reference learning because it has been tested for feasibility, limited trials, and extensive field trials. For further research as a brief overview of the future, because the E-book product in this research can only be used on devices with the Android system, the product can then be developed as an application for all smartphone systems, including iOS. However, before it is developed further, more detailed observations of the sample are needed to minimize limitations in the field. Further research can develop STEM-based physics E-book products with the help of Augmented Reality for other physics materials.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Fadillah Rahmayani and Heru Kuswanto developed the concept of this research. Fadillah Rahmayani carried out research, data analysis, and design. Heru Kuswanto is responsible for monitoring and validation. Fadillah Rahmayani implemented research and development. Anggi Datiatur Rahmat carried out review and Editing. Anggi Datiatur Rahmat and Heru Kuswanto contributed to the discussion, facilitation of AR-related experiences, and discussion of technical activities. All authors contributed to writing the article and read and approved the final version of the manuscript.

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References

[1] S. D. Putri, "Development of physics learning tools based on critical thinking skills in problem-based learning," *Al-Biruni Physics Education Scientific Journal*, vol. 6, no. 1, pp. 125–135, Apr. 2017. doi: 10.24042/jpifalbiruni.v6i1.648 (in Indonesian)

[2] Darhim, S. Prabawanto, and B. E. Susilo, "The effect of problem-based learning and mathematical problem posing in improving student's critical thinking skills," *International Journal of Instruction*, vol. 13, no. 4, pp. 103–116, 2020. doi: 10.29333/iji.2020.1347a

[3] Mundilarto and H. Ismoyo, "Effect of problem-based learning on improvement physics achievement and critical thinking of senior high school student," *Journal of Baltic Science Education*, vol. 16, no. 5, pp. 761–780, 2017.

[4] A. P. Aliyanti, O. R. U. Putri, and Z. Zukhrufurrohmah, "Analysis of students' symbolic representation errors in solving high order thinking skill questions," *AKSIOMA: Journal of the Mathematics Education Study Program*, vol. 8, no. 3, 382, Dec. 2019. doi: 10.24127/ajpm.v8i3.2265 (in Indonesian)

[5] D. Y. Ningtyas, Y. Fuad, and A. Lukito, "Representational ability of mathematics education students in solving calculus problems," *Journal of Creative-Innovative Mathematics*, vol. 10, no. 1, pp. 27–36, Jun. 2019. doi: 10.15294/kreano.v10i1.17334 (in Indonesian)

[6] R. Rohana, E. F. P. Sari, and S. Nurfeti, "Analysis of the mathematical representation capability of linear equations with two variables," *AKSIOMA: Journal of the Mathematics Education Study Program*, vol. 10, no. 2, 679, Jul. 2021. doi: 10.24127/ajpm.v10i2.3365 (in Indonesian)

[7] F. H. Sutrisno, S. K. Handayanto, E. Supriana, and R. Laksmisari, "How does the students' critical thinking ability in geometry optics?" *USEJ*, vol. 7, no. 2, 2018.

[8] P. P. Pendidikan. (March 2023). National examination results report. *Education Evaluation Center of the Ministry of Education and Culture*. [Online]. 28. Available: https://hasilun.puspendik.kemdikbud.go.id/#2019 (in Indonesian)

[9] S. Kassiavera, A. Suparmi, C. Cari, and S. Sukarmin, "Student's understanding profile about work-energy concept based on multirepresentation skills," in *Proc. American Institute of Physics Inc.*, Dec. 2019. doi: 10.1063/1.5141673

[10] L. Rivaldo, M. R. A. Taqwa, A. Zainuddin, and R. Faizah, "Analysis of students' difficulties about work and energy," in *Proc. Institute of Physics Publishing*, Jul. 2020. doi: 10.1088/1742-6596/1567/3/032088

[11] Z. Mustofa, S. Sutopo, and N. Mufti, "High school students' understanding of concepts about work and mechanical energy," *Pend National Semester Pros. UM Postgraduate Science*, 2016, pp. 519–528. (in Indonesian)

[12] Y. S. Pramesti, H. Mahmudi, and I. Setyowidodo, "Analyzing students' understanding of work-energy concept," in *Proc. Institute of Physics Publishing*, May 2020. doi: 10.1088/1742-6596/1521/2/022016

[13] S. Nurjanah and Sunarto, "Analysis of difficulties in solving physics problems on work and energy material for class X students of taman karya jetis vocational school yogyakarta," *Scientific Journal of Physics Education*, vol. 5, no. 2, pp. 21–26, 2018. doi: https://doi.org/10.30738/cjipf.v5i2.4161 (in Indonesian)

[14] I. Wahyuni and H. D. Pramadanti, "Analysis of students' data interpretation ability in learning business and energy material," *Journal of the Medan State University Physics Alumni Association*, vol. 7, no. 2, 2021. doi: https://doi.org/10.24114/jiaf.v7i2.25664 (in Indonesian)

[15] L. Roza and N. Nilah, "Analysis of analytical thinking and evaluation skills in physics learning on work and energy topics," in *Proc. the SNF2020 National Physics Seminar*, vol. 9, no. 11, pp. 75–82, 2020. doi: 10.21009/03.SNF2020 (in Indonesian)

[16] N. H. Dienyati, I. Komang Werdhiana, and U. Wahyono, "Analysis of students' concept understanding based on multirepresentation in class XI business and energy material at sman 1 banawa tengah," *Online Creative Journal*, 2020, vol. 8, no. 1. (in Indonesian)

[17] L. Y. Kurniasari and W. Wasis, "Analysis of multi-representation capabilities and their relation to understanding physics concepts," *Jurnal Pijar Mipa*, vol. 16, no. 2, pp. 142–150, Mar. 2021. doi: 10.29303/jpm.v16i2.2404

[18] A. Dimas, A. Suparmi, S. Sarwanto, and D. A. Nugraha, "Analysis multiple representation skills of high school students on simple harmonic motion," in *Proc. American Institute of Physics Inc.*, Sep. 2018. doi: 10.1063/1.5054535

[19] E. Erniwati *et al.*, "Analysis of difficulty of science learning-based multi-representation," *Journal of Physics Education, Muhammadiyah University of Makassar*, vol. 8, no. 2, pp. 263–278, 2020. doi: 10.26618/jpf.v8i3.3924 (in Indonesian)

[20] C. D. Putri, I. D. Pursitasari, and B. Rubini, "Problem based learning integrated with STEM in the covid-19 pandemic era to improve students' critical thinking skills," *Journal of IPA and IPA Learning*, vol. 4, no. 2, pp. 193–204, Dec, 2020. doi: 10.24815/jipi.v4i2.17859 (in Indonesian)

[21] K. A. Us, P. Uin, S. Thaha, S. Jambi, M. Iai, and N. Batanghari, "Use of e-learning, E-books, e-journals and islamic education information systems at sriwijaya university palembang," *Innovatio: Journal for Religious-Innovation Studies*, vol. 19, no. 1, pp. 43–64, 2019. (in Indonesian)

[22] D. Mentari and A. Ruyani, "Development of E-book learning media based on the results of 2-d electrophoresis research to measure students' creative thinking abilities," *PENDIPA Journal of Science Education*, vol. 2, no. 2, pp. 131–134, 2018. (in Indonesian)

[23] K. H. Cheng, "Surveying students' conceptions of learning science by augmented reality and their scientific epistemic beliefs," *Eurasia Journal of Mathematics, Science and Technology Education*, vol. 14, no. 4, pp. 1147–1159, 2018. doi: 10.29333/ejmste/81811

[24] C. Mehmet, "The effect of augmented reality and mobile application supported instruction related to different variables in 7th grade science lesson 8," *Psycho-Esucational Research Reviews*, vol. 10, no. 2, 2021, pp. 298–313.

[25] T. Torlakson, "Innovate a blueprint for science, technology, engineering, and mathematics in california public education," *California: Californians Dedicated to Education Foundation*, 2014.

[26] A. Permanasari, "STEM Education: Innovation in science learning," *Prosiding SNPS*, pp. 23–34, 2016. (in Indonesian)

[27] R. S. Pertiwi, Abdurrahman, and U. Rosidin, "The effectiveness of STEM worksheets for training students' creative thinking skills," *Journal of Physics Learning*, vol. 5, no. 2, pp. 11–19, 2017. (in Indonesian)

[28] F. S. Kartini, A. Widodo, N. Winarno, and L. Astuti, "Promoting student's problem-solving skills through STEM project-based learning in earth layer and disasters topic," *Journal of Science Learning*, vol. 4, no. 3, pp. 257–266, Jul., 2021. doi: 10.17509/jsl.v4i3.27555

[29] A. Isatunada and S. Haryani, "Development of science learning tools using the STEM approach to train Problem solving ability and students activeness in global warming material," *Jurnal Pendidikan Sains Indonesia*, vol. 9, no. 3, pp. 363–375, Jul., 2021. doi: 10.24815/jpsi.v9i3.19599

[30] M. Adnan, A. Ayob, O. E. Tek, M. N. Ibrahim, N. Ishak, and J. Sheriff, "Empowering Malaysia's human capital development at the children's level: A study of the feasibility and integrability of STEM education in the PERMATA national curriculum," *Malaysian Journal of Society and Space*, vol. 12, no. 1, pp. 29–36, 2017. (in Indonesian)

[31] D. Khoerunnisa, A. I. Amiroh, N. D. Nurshalihah, and F. M. Putri, "Analysis of the implementation of stem-based learning to facilitate mathematical problem solving abilities in the new normal era," *ALGORITMA Journal of Mathematics Education (AJME)*, vol. 3, no. 2, pp. 169–181, 2021. doi: 10.15408/ajme.v3i2.23248 (in Indonesian)

[32] S. Çinar, N. Pirasa, N. Uzun, and S. Erenler, "The effect of STEM education on pre-service science teachers' perception of interdisciplinary education," *Journal of Turkish Science Education*, vol. 13, no. Specialissue, pp. 118–142, 2016. doi: 10.12973/tused.10175a

[33] R. Oktavia, "Science, technology, engineering, mathematics (STEM) based teaching materials to support integrated science learning," *IPA Education Universe*, vol. 2, no. 1, pp. 32–36, 2019. (in Indonesian)

[34] F. A. Almuharomah, T. Mayasari, and E. Kurniadi, "Development of a STEM physics module integrated with local wisdom 'Beduk' to improve junior high school students' creative thinking abilities," *Periodical Scientific Physics Education*, vol. 7, no. 1, p. 1, Feb. 2019. doi: 10.20527/bipf.v7i1.5630 (in Indonesian)

[35] A. L. Tan, Y. S. Ong, Y. S. Ng, and J. H. J. Tan, "STEM problem solving: Inquiry, concepts, and reasoning," *Sci Educ (Dordr)*, vol. 32, no. 2, pp. 381–397, Apr., 2023. doi: 10.1007/s11191-021-00310-2

[36] C. D. Putri, I. D. Pursitasari, and B. Rubini, "STEM integrated problem based learning in the covid-19 pandemic era to improve students' critical thinking skills," *Journal of IPA and IPA Learning*, vol. 4, no. 2, pp. 193–204, Dec. 2020. doi: 10.24815/jipi.v4i2.17859 (in Indonesian)

[37] P. S. Adiwiguna, N. Dantes, and I. M. Gunamantha, "The influence of the stem-oriented problem based learning (Pbl) model on the critical thinking ability and scientific literacy of class V elementary school students in group I gusti ketut pudja," *PENDASI: Indonesian Journal of Basic Education*, vol. 3, no. 2, 2019. doi: https://doi.org/10.23887/jpdi.v3i2.2871 (in Indonesian)

[38] M. Laforce, E. Noble, and C. Blackwell, "Problem-based learning (PBL) and student interest in STEM careers: The roles of motivation and ability beliefs," *Educ Sci (Basel)*, vol. 7, no. 4, Dec. 2017. doi: 10.3390/educsci7040092

[39] J. Jesionkowska, F. Wild, and Y. Deval, "Active learning augmented reality for steam education—a case study," *Educ Sci (Basel)*, vol. 10, no. 8, pp. 1–15, Aug. 2020. doi: 10.3390/educsci10080198

[40] N. D. Usta, N. D. Usta, and N. Ültay, "Augmented reality and animation supported-STEM activities in grades K-12," *J. Sci. Learn 2022*, vol. 5, no. 3, pp. 439–451, 2022. doi: 10.17509/jsl.v5i3.43546

[41] R. M. Branch, *Approach, Instructional Design: The ADDIE*, New York: Springer Science and Business Media, vol. 53, no. 9, 2009.

[42] N. Alfianika, *Indonesian Language Teaching Research Methods*, Yogyakarta: Deepublish, 2018. (in Indonesian)

[43] F. Rahmayani, M. Hendri, and D. P. Rasmi, "Need analysis for developing a STEM-based student worksheet application," *Jurnal Pendidikan Sains (JPS)*, vol. 9, no. 2, 137, Aug., 2021. doi: 10.26714/jps.9.2.2021.137-145

[44] R. P. Artiwi, Asrizal, Desnita, and Y. Darvina, "The influence of the physics enrichment E-book dissertation news and facts assignment on the critical and creative thinking skills of class X students at SMA N 2 field," *Pillar of Physics Education*, vol. 13, no. 2, pp. 289–296, 2020. (in Indonesian)