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A Study of The Use of Augmented Reality in Learning: Impacts on Increasing Students' Critical Thinking Skills

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Abstract: The ability to think critically could be improved by using proper learning media. At present it is found that many students have very low critical thinking skills as a result of the ease of learning facilities provided by advances in information technology and computers for society 5.0. This paper aimed to investigate the impact of using Augmented Reality (AR) in learning on improving the critical thinking skills of vocational school-level students in Indonesia. The research method used Design Based Research (DBR) with the main stages of identifying and analyzing problems, designing solutions, repeating cycles in testing and improving product designs, as well as reflection to produce design principles and implementation. A total of 98 students from vocational schools using cluster random sampling techniques were used as samples for this research. Testing the effectiveness by conducting a sample paired test. The results obtained from the application of AR were an increase in students' abilities in aspects of analysis of 96.82%, inference of 79.77%, interpretation of 93.16%, explanation of 95,31%, evaluation of 69.09%, and self-regulation of 93.17%. Based on the results obtained, it can be concluded that the use of AR in learning can massively improve students' critical thinking skills. With these findings, AR can be recommended as one of the best technology choices that can be used widely in delivering learning materials to improve students' thinking skills in this century.

Keywords: Augmented Reality, Critical Thinking, Design-Based, Learning, Vocational School

1. Introduction

The industrial era 4.0 requires humans to live a life based on critical thinking. Critical thinking is one of the basic abilities that students must have today (Sulistyanto et al., 2023; Perdana et al., 2019; Sidiq et al., 2021). However, it turns out that from surveys and observations on a group of students, it has been found that the results of students' critical thinking skills are very low. This is shown by the student's ability to analyze only 34%, inference 32%, interpretation 31%, explanation 36%, evaluation 35%, and self-regulation 37%.

In some previous research, many learning media have been investigated within the framework of increasing students' high-order thinking skills (critical and creative thinking). The emergence of innovative technology has inspired instructional media designers the development of learning environments that facilitate progressive learning (Sulistyanto et al., 2019; Dalim et al., 2022; Chang et al., 2016). The implementation of innovative technologies such as Augmented Reality (AR) has become much easier to realize with the rapid advancement of wireless communication networks and mobile devices so technology-assisted learning has significantly benefited (Ozdemir, 2017).

Augmented Reality (AR) refers to a set of technologies and instruments capable of enhancing and perfecting human perception, thereby bridging the gap between real and virtual spaces. The merging of digital information with the real-world environment is subtly formulated by AR to provide students with opportunities to practice knowledge and skills (Wojciechowski & Cellary, 2013; Ozdemir et al., 2018). AR also practices real-world scenarios by providing an interactive learning environment through interactive activities (C. P. Chen & Wang, 2015).

Collaborative learning experiences can be enhanced by using AR systems (Zhou et al., 2008) and enable students' skills to be improved through innovative, interactive teaching of subject matter, and presenting information in 3-D format (H. K. Wu et al., 2013). In addition, students' motivation and cognitive learning can also be positively influenced by the AR system (Yoo, 2023). It is proven that students' spatial and psychomotor-cognitive skills can be developed with the help of AR (Alamsyaha et al., 2023). Enhanced student experiences are facilitated by AR by providing visual, auditory, or sensory cues and feedback by way of objects being mixed in a hybrid space where users can move around without constraint (Zhou et al., 2008). Furthermore, AR has been shown to have a positive impact on academic success in studies conducted through meta-analysis methods (Yılmaz & Batdı, 2016). However, it is unfortunate that limitations were found when the results of their research presented the effectiveness of AR applications in the learning process that combines different environments and times.

AR has the economic potential in meeting the needs of high-cost education (Gavish et al., 2015). A series of studies regarding the application of AR technology in education (C. M. Chen & Tsai, 2012; Han et al., 2015; Huang et al., 2016; Ibanez et al., 2014; Kamarainen et al., 2013; Ke & Hsu, 2015; Liou et al., 2016; Zhang et al., 2014) shows that AR applications have a real impact on student academic achievement.

On the other hand, the effectiveness of AR applications in the learning process with different variables (for example concerned to the characteristics of students' critical thinking abilities) has not been found in the literature so far. This is the gap opportunity from previous research. In connection with that, this research is considered to be contributing to the field in terms of these variables. In essence, in the field of education, there will be more benefits when using AR technology with various educational goals. For this reason, it is considered important to investigate the effect of AR applications on students' competence in critical thinking skills.

In the identification of the problem, in this study, a learning media was designed that applied the sophistication of AR technology. The learning media produced are then validated and tested for the feasibility of use on a limited scale. Finally, this media product is tested on a wide scale to determine the level of effectiveness in increasing students' critical thinking skills.

2. Method

Six aspects of critical thinking, namely interpretation, inference, explanation, analysis, evaluation, and self-regulation are used in this research. Design-Based Research (DBR) was applied in carrying out this research (Sulistyanto et al., 2022). The general research procedure included case studies which were categorized into collecting the data and software development (Augmented Reality=AR). The methodology in this study was carried out through several stages according to the four stages in the DBR. Literacy studies of various sources, such as books and articles that are appropriate to the research topic, are the techniques used in collecting initial data (Kiong et al., 2022). Extracting information was also pursued by way of observation and field surveys (Sulistyanto et al., 2023). Furthermore, for the system design stage in this research, Unified Modelling Language (UML) using case diagrams were used.

The AR application development model in this study was the Luther model. The development step began with concept analysis, namely analyzing user needs and system specifications to design applications to improve student's critical thinking skills based on AR. User requirements included two user access rights that require a login page, a learning material display page, a QR code scanning page, and an admin page. The second stage was application design. This stage was the stage to make the design of learning media applications that could improve students' critical thinking skills using AR technology. Program architecture, style, appearance, and material requirements for AR-based learning media applications included: 1) The flowchart showed the workflow of the entire application system to be made, explained the form of communication between the user and the system, and explained the flow of the system in describing 3-dimensional (3D) objects and 2-dimensional (2D) videos when markers were detected by the camera; 2) Navigation structure that explained how the application system worked; 3) Storyboard described the storyline or every scene in the application which was presented in the form of animated images.

Marker-based tracking is AR component that uses a two-dimensional object marker with a unique pattern to be read via a webcam or computer camera. Usually a white background with a thick black border. After the position and orientation of the marker are known by the AR application on the computer, it will proceed by creating a virtual 3D point (0,0,0) and 3 axes X, Y, and Z. The Art toolkit software library is needed to implement the marker-based tracking method. Video tracking is used by AR applications in calculating real camera positions and orientation patterns on paper in real-time.

Once the original position of the camera is known, the virtual camera can be positioned at the same point and a 3D object can be drawn on the marker.

2.1 Participants and Data Analysis

The AR application was designed to deliver computer network introduction material at the vocational high school level. The product draft was validated by two media validators and one material validator. The user sample was 98 students from vocational high schools in Indonesia who were collected using the cluster random sampling technique. In the usability test procedure and effectiveness testing, students were technically divided into two groups, namely experimental and control. The test was carried out using a sample paired test and the resulting data were analyzed using non-parametric analysis.

2.2 Application Design

AR application design could be represented by activity diagrams. The activity diagram displayed the AR menu starting with the user opening the learning media application. Then, the user selected the AR menu where the system automatically displayed several choices of computer network types. The user selected one of the materials, then the system directed it to the AR camera. When the system was displaying the AR camera, the user directed the camera at the target 2-D marker/image. Automatically, the system could display 3-D objects as learning materials. AR Menu Activity diagram was in **Fig. 1**.

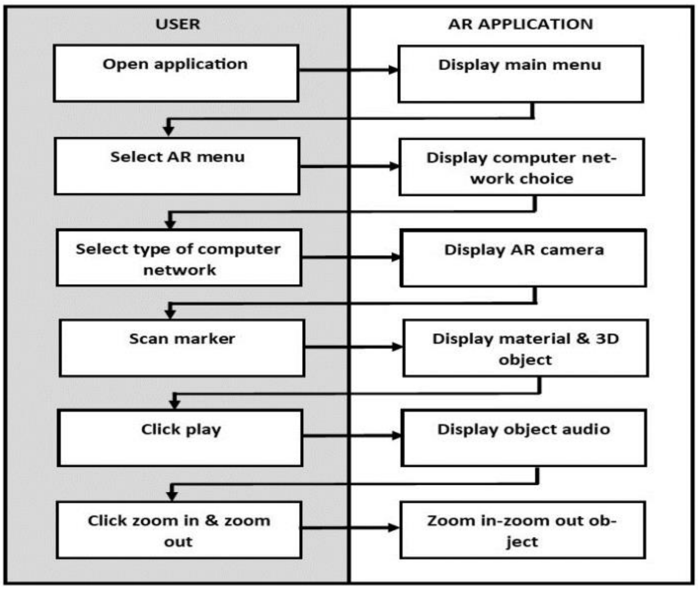

Fig. 1 AR menu activity diagrams

2.3 Research Instruments

Main instruments were used to carry out the procedures in this research. The instruments could be grouped into categories, namely identification and analyzing problem instruments, AR application and design instruments, validation-testing instruments, and instruments measuring the effectiveness of AR-based learning media in improving students' critical thinking skills. Descriptions of the types of instruments are presented in Table 1.

Table 1. Research instruments classification

No.	Stage of Research	Types of Instruments	Descriptions
1	Identifying and analyzing problems used needs analysis instruments	Survey of teachers' perceptions of critical thinking	Knowing the teacher's perception of critical thinking and students' initial critical thinking skills
		Instruments for analyzing the needs of teachers and students	Determine the types of needs of teachers and students to improve students' critical thinking skills
		Media requirements specification instruments	Determine media specifications needed by teachers and students
2	Design and solution	Blender and Unity tools	Engineering AR-based learning media
		Media & materials expert validation	Recommendation of application revision
		SUS	System for assessing the feasibility of AR media products
3	Repeating cycles in testing using assessment instruments	A set of quizzes to assess students' final thinking skills after the treatment	Determine and measure the increase in students' critical thinking skills after being treated with AR media
4	Reflection to produce design principles and implementation	Draft product	Refinement into an AR-based media product
		A set of questions and quizzes to determine critical thinking skills	Determining the improvement of critical thinking skills

In the manufacturing process, the stage of developing learning media used Blender 2.83.20.2 software, Unity 2018.4.25, and Vuforia. Learning media was developed according to the concept design using the materials that had been collected.

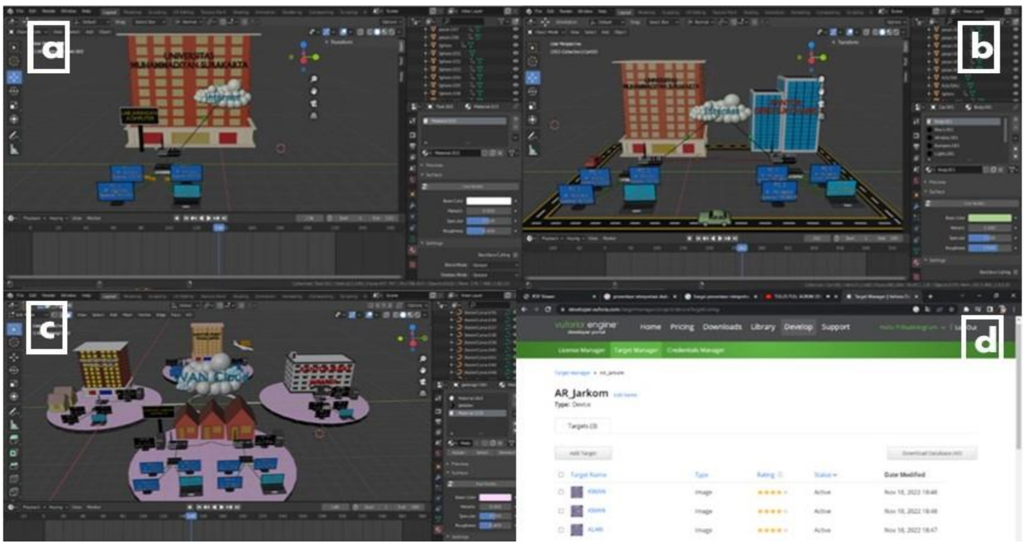

Fig. 2 The results of the display design on the media

Blender software was used to create three-dimensional (3D) objects and animations for each object in a series of computer network types. The resulting design of the display of AR-based learning media was shown in **Fig. 2**. **Fig. 2(a)(b)(c)** showing the appearance of computer network learning media objects which included Local Area Networks (LAN), Metropolitan Arena Networks (MAN), and Wide Area Networks (WAN). Besides, Vuforia was used to create a marker database so that it can be used in the Unity software to display 3D objects and their animations. Furthermore, **Fig. 2(d)** displays a page that stores the target markers used in AR. The target markers that are made include LAN, MAN, and WAN which each have a rating of 4. So that the markers can be used when the camera is pointed at the three markers.

Several measurement scales were used to determine the achievement of research targets. Eq. (1) applied to the normalized gain test (N-Gain) in measuring aspects of critical thinking ability after treatment.

$$Gain\ score = \frac{Post\ Test\ score}{Ideal\ score - Pre\ Test\ score} x100\% \quad (1)$$

Post-test Score: post-test scores result
Pre-test Score: pre-test scores result
Ideal Score: a maximum score that can be resulted
(Kashani-Vahid et al., 2017)

Category of the interpretation of the effectiveness of the gain score:

Gain score < 40	: Ineffective
40 ≤ gain score ≤ 55	: Less effective
56 ≤ gain score ≤ 75	: Effective enough
Gain score > 75	: Effective

(H. Wu & Leung, 2017)

3. Results and Discussion

3.1 Result Findings

This research aimed to design AR-based learning media to improve students' critical thinking skills, especially for students in vocational high schools. The results obtained were shown in **Fig. 3**. **Fig. 3(a)** is the display of the initial menu on the developed learning media. The menu featured information buttons, instructions, Core Competencies (KI) & Basic Competencies (KD), materials, AR, and quizzes. In the upper right corner, there is an exit button from the learning media.

The main features of learning media are on the AR menu page. **Fig. 3(b)** shows the screenshot when the AR camera is pointed at the LAN marker so that a 3D object of a computer network type in the form of a LAN appears. In this object, a building is described that has a computer network laboratory that has internet, switches, routers, and several computers with IP addresses. The LAN AR page has a button consisting of buttons to zoom in and out of the layer which is located in the upper left corner. The back button on the main menu is located in the upper right corner. The back button is used to return to the computer network type selection menu. There is also an information button that is used to display a description and a play button to play audio explaining the type of LAN network.

Fig. 3 Display results when AR is working

Fig. 3(c) shows the screenshot of the AR camera directed at the MAN network type marker. In this object, 2 inter-city buildings are presented that are connected to the internet where each building has a series of networks that are connected using a router. Computers in Building 2 can send and exchange data with computers in Building 1. The MAN AR menu page has buttons to zoom in and out of layers which are located in the upper left corner (+ and -). The main menu button is located in the upper right corner. There is also a Back button used to return to the computer network type selection menu, an information button to display an AR description, a play button that is used when clicked, and an audio explanation of the MAN network type appears.

Furthermore, **Fig. 3(d)** is a screenshot of the AR camera directed at the WAN network type marker. In this object, four places that are connected in the WAN Cloud are presented, including Java, Bali, DKI Jakarta, and Surabaya. Just like LAN and MAN networks, WAN networks have routers that connect each other between places according to the IP address settings.

AR-based learning media had been validated by two media experts, two material experts, and a feasibility test by prospective users with the result that the application was feasible to use. The next research step was testing media products on users of vocational high school students. According to the test scenario, students were grouped into the treatment group and the control group. The testing procedure begins with measuring students' initial abilities with a pre-test before implementing the learning process and at the end of learning with a post-test in both groups.

Table 4. The normality test results of the pre-test and post-test scores

Group		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Pre-test	Experiment	.152	50	.005	.936	50	.012
	Control	.171	50	.001	.921	50	.002
Post-test	Experiment	.207	50	.000	.896	50	.000
	Control	.222	50	.000	.896	50	.000

a. Lilliefors Significance Correction

The results of the normality test analysis of the pre-test and post-test scores of the experimental and control groups are shown in Table 4. With Kolmogorov Smirnov, the results of the data normality test analysis were at a significance of <0.05 in each. The conclusion is that the data distribution is not normally distributed. Meanwhile, Table 5 shows the results of the homogeneity analysis of the two groups from the pre-test and post-test scores.

Table 5. The homogeneity test results on the pre-test and post-test scores

		Levene Statistic	df1	df2	Sig.
Pre-test	Based on Mean	.053	1	96	.824
	Based on Median	.191	1	96	.663
	Based on Median and with adjusted df	.191	1	97.431	.663
	Based on trimmed mean	.070	1	96	.792
Post-test	Based on Mean	4.756	1	96	.033
	Based on Median	2.442	1	96	.123
	Based on Median and with adjusted df	2.442	1	89.972	.120
	Based on trimmed mean	4.952	1	96	.026

In Table 5, it can be seen that the pre-test results between the two groups had a significance value of 0,824 > 0,05 which indicates that the results of the pre-test scores are both homogeneous. This results stated that the two groups did not have much difference in variance because they had the same variance. On the other hand, the existence of a significance value of 0.033 < 0.05 from the homogeneity analysis results on the post-test results between the two groups stated that the two groups had different variances (non-homogeneous distribution) so it was concluded that there were differences in diversity.

Analysis of the experimental class and the control class then carried out a balance test to find out the balance of the abilities of the experimental class and the control class. Following the prerequisite analysis results which found that the data were not normally distributed. Regarding the results of the prerequisite tests, the non-parametric Wilcoxon Signed Rank Test (paired-test) and the Mann-Whitney U test (unpaired-test) are suitable to be applied. (Vong & Kaewurai, 2017). The results of the analysis were shown in Table 6.

Table 6. The analysis results of the balance test between the experimental and the control group

Test Statistics[a]

	Pretest
Mann-Whitney U	1108.400
Wilcoxon W	2392.400
Z	-.930
Asymp. Sig. (2-tailed)	.356

a. Grouping Variable: group

The analysis results in Table 6 were significance of 0.356 > 0.05 which states that there is no significant difference between the pre-test values in the experimental and control group. This concluded that there was no difference (balanced) between the two groups before any treatment was applied to the two groups.

Table 7. Results of the non-parametric Wilcoxon Signed Rank Test in two groups

Test Statistics[a]

	Pre test experiment-Post test experiment	Pre test control-Post test control
Z	-6.188[b]	-6.196[b]
Asymp. Sig. (2-tailed)	.000	.000

a. Wilcoxon Signed Ranks Test
b. Based on negative ranks.

Testing of the Wilcoxon Signed Rank Test gave results as conveyed in Table 7. Analysis using the Wilcoxon Signed Rank Test as shown in Table 7 produced a significance value of 0.000 < 0.05 in the comparison of the pre-test and post-test scores of the two groups. These results illustrated that the two groups have differences between the pre-test and post-test scores. Therefore it can be concluded that both groups have experienced changes in ability.

The next results were shown in Table 8, namely the analysis of the results of the post-test scores between the experimental and cotrol groups. The significance value of 0.000 < 0.05 is presented in Table 8 as an indication of differences in post-test score results for the two due to the experimental group receiving treatment.

Table 8. The results of the analysis of post-test scores between two groups

Test Statistics[a]

	Post test
Mann-Whitney U	32.000
Wilcoxon W	1307.000
Z	-8.427
Asymp. Sig. (2-tailed)	.000

a. Grouping Variable: group

Finally, an analysis was carried out on the difference in scores between the pre-test and post-test (gain) to recognize the effectiveness of AR-based learning media. The gain score for each aspect of critical thinking skills was shown in Table 9.

Table 9. The gain score comparison on the aspect of critical thinking skills in two groups

Group	Aspects of Critical Thinking Skills (%)					
	Interpretation	Inference	Explanation	Analysis	Evaluation	Self-regulation
Experiment	93.16	79.77	95.31	96.82	69.09	93.17
Control	63.91	42.54	64.67	61.81	38.93	66.32

The control class had a Gain score on critical thinking skills with a range of values between 38.93% to 66.32% and an average of 52.62% which was in the moderate category. On the other hand, the range of scores between 69.09% and 95.31% with an average of 82.20% was in the effective category found in the experimental class. Based on this fact, it can be concluded that the critical thinking skills of the experimental class improved better than the control class as a result of the implementation of AR-based learning media in the experimental class..

3.2 Discussion

In this research, it was necessary to test AR-based learning media products to determine their benefits and effectiveness (Santos et al., 2014). The results of testing the effectiveness obtained from media products will provide important insights and recommendations for teachers and instructional designers regarding the need to use learning media such as the product of this research to improve students' critical thinking skills.

Many research findings and current studies reported excellent effectiveness in carrying out the learning process by applying AR-based learning media when compared to conventional models. The effectiveness of AR-based learning media had been tested on several different test variable categories as has been done by (Chiang et al., 2014; Alamsyaha et al., 2023; Hsiao et al., 2016; Hwang et al., 2016). There are several reasons why the use of AR-based learning media can positively impact student academic achievement. For example, (Chiang et al., 2014) said that AR-supported learning media can present a pleasant learning atmosphere. Another study by (Vargas et al., 2020) demonstrated that AR could provide understanding, memory, concentration, interaction, and a more interesting learning environment compared to traditional learning environments. Furthermore, (Ozdemir, 2017) reported that concentration can be increased and subject understanding can be facilitated by using AR. In other research, it was stated that teachers can more easily and quickly convey concepts to their students who study learning materials supported by AR before their lessons (Hwang et al., 2016).

Based on the research that has been carried out at this time, it has also proven that the application of AR in learning media has a very positive effects on improving students' critical thinking skills. A series of facts obtained from the results of the tests that have been carried out prove that AR-based learning media is very effective in its role to improve students' critical thinking skills. The results of the analysis on the results of the post-test found a very significant difference in scores in the experimental group compared to the control group where the experimental group was generally higher in the percentage increase in six aspects of critical thinking skills.

From the results of this study, it also determined the comparison of the percentage increase between the experimental class and the control class, namely in the aspect of interpretation 93.16% (63.91%), inference 79.77% (42.54%), explanation 95.31% (64.67%), analysis 96.82% (61.81%), evaluation 69.09% (38.93%), and self-regulation 93.17%(66.32%). Based on the comparative data on the percentage increase, in general, it can be concluded that AR-based learning media is proven to be able to improve student's critical thinking skills. The results achieved strengthen the findings from research by (Nagao & Nagao, 2019; Bimba et al., 2017; Tsortanidou et al., 2017) and (Manuri & Sanna, 2019) which state that students' critical thinking skills can be improved by providing learning tools that follow natural learning styles and student needs.

4. Conclusion

This research had produced several important results related to the design of learning media supported by AR. The results of this research could be summarized as follows; 1) AR-based learning media had been successfully built in this research by applying the Design Based Research method and the Waterfall software development model. The goal of developing this media was to improve students' critical thinking skills at the vocational school level. However, in the follow-up, this learning media application could also be used in other school clusters; 2) AR-based learning media had proven to be very effective in the learning process so it is recommended that it can be used by teachers in teaching and instructional activities in the classroom. The presentation of subject matter in a more interesting way and in a pleasant learning atmosphere makes students more intense in learning, which is a positive impact resulting from AR media. Creating a conducive and enjoyable atmosphere and learning conditions also play a role in directing and motivating students in improving critical thinking skills; 3) The aspect of independence in learning was one of the characteristics that had been successfully raised by using AR-based learning media. The independent character in learning that was formed was believed to have a positive impact on increasing student self-efficacy so that efforts to improve critical thinking skills are easy to implement; 4) AR-based learning media was very well applied broadly to any learning by making slight modifications according to the needs and learning conditions. This modification of learning media has the opportunity to generate new ideas for further research in the field of AR; 5) AR-based media should be applied to subjects that contain too abstract and complex material concepts.

5. Co-Author Contribution

There is no conflict of interest in this article. First author carried out the fieldwork, prepared the literature review, and overlook the writeup of the whole article. The other authors performed application testing, analysed the findings, wrote the research methodology, did the data entry, carried out the statistical analysis, and interpretated of the results.

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