Augmented Reality as a Media for Distance Learning in the Digital Era: Contribution in Improving Critical Thinking Skills

Nurul Lailatul Badriyah*, Munawir Yusuf, and Agus Efendi

***Abstract*—As a result of the COVID-19 pandemic, education has undergone a transformation in the learning methods it has carried out so far, from face-to-face to virtual face-to-face or better known as distance learning. Distance learning is a way of independent learning using technology. Usually, this learning method is considered less effective in developing critical thinking skills. Therefore, this study aims to measure the effectiveness of one of the technologies used for distance learning, namely smartphone-based Augmented Reality (AR) in improving critical thinking skills. The subjects involved in this study were second grade vocational high school students in Surakarta with a total sample of 120 students. Furthermore, the true experiment design research method of the Pretest-Posttest Control Group Design was used and the data were collected by studying the observation syntax, while data analysis techniques were conducted by using One-Way ANOVA statistical test. As for the results of this study, namely Surakarta State Vocational School X obtained an average test result in a class that used augmented reality media which was 71.4 points, higher than the class that did not use AR learning media, namely 51.03. The same results were also shown at Surakarta State Vocational School Y, where the class that used augmented reality (AR) media obtained an average test score of 69.47, which was greater than the class that did not use it, that was only 45.67. These results indicate that the use of smartphone-based augmented reality technology is quite effective in developing students' critical thinking skills in distance learning.**

***Index Terms*—Augmented Reality (AR), distance learning, vocational students, smartphone**

I. Introduction

Technology needs have increased massively since entering the industrial era 4.0. With technology, people fulfill their information needs. Even more than that, technology is used as a tool to help modern society in completing various tasks [1]. The need for technology has also increased sharply with the onset of the COVID-19 pandemic. As a result of the pandemic, there has been a significant increase in the use of technology in the education sector [2]. The reason for this increased need is the shift in the learning system from traditional to online or distance learning, which heavily relies on technology. This modern learning system includes portfolio collection through the web, animated videos, online quizzes, online test instruments, and more [3, 4]. During distance learning, students actively and independently use technology to learn.

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Nurul Lailatul Badriyah is with Sebelas Maret University, Surakarta, Central Java, Indonesia.

Munawir Yusuf and Agus Efendi are with Educational Technology Master Study Program, Faculty of Teaching and Education, Sebelas Maret University, Indonesia.

*Correspondence: lailanurul04@gmail.com (N.L.B.)

Distance learning conducted independently by students is less likely to improve critical thinking skills. Yet, this theoretical understanding is refuted by research results [5], as it has been suggested that independent learning with the use of technology in education is more likely to foster the development of students' critical thinking skills. Qureshi *et al.* [4] has also previously mentioned that distance learning can facilitate the development of critical thinking skills in students. However, it is important to consider several factors in distance learning. The main thing that needs to be considered in distance learning is the existence of social interaction among students, teachers and fellow students, as it plays a crucial role in enhancing the learning experience [6]. Meanwhile, one of the supporting components for distance learning is the need for extensive digital literacy for educational practitioners. However, there are still many teachers with lack of information related to digital technology that can be used for learning [7]. In the field, there are many choices of technology and media that can be used for the learning process. This is evidenced by the establishment of the Digital Learning Resource (DLR) to support educators in using technology during the learning process [1, 2]. In line with Berduygina [1], research results from Kashina *et al.* [8] state that digital technology resources must be used in education. It turns out that there is an impact on student development due to the use of technology or digital media [9, 10]. This impact can be directed towards stimulating student abilities that are mandatory for vocational graduates in the 21st century. These abilities include critical thinking skills, which encompass creative thinking and problem-solving skills [11, 12]. Critical thinking skills are important assets for vocational students. This is because vocational high school students are being prepared to enter the workforce or industry after graduation.

One of the technologies that educators can use during distance learning is Augmented Reality [13]. It is important to note that Augmented Reality (AR), an application that combines the real world with virtual objects in two and three dimensions, is projected onto the real environment simultaneously. AR is the integration of virtual objects (in two or three dimensions) into the real environment through technology, and these virtual objects are then projected in real-time [14, 15]. Augmented reality is the projection of computer-generated materials, such as text, images, and videos, into the human perspective in the real world. Simply put, augmented reality can be defined as the simultaneous addition of virtual objects to real-world objects, creating a seamless integration between the two [16].

Several studies have concluded that augmented reality also has the potential to be used as a learning medium in Science, Technology, Engineering, and Mathematics (STEM)

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education, as well as in sport science education [17, 18]. By using augmented reality in engineering education, it can help to visualize engineering materials that are difficult to understand. According to Moorhouse *et al.* [19], through augmented reality, students can comprehend and visualize concrete versions of abstract concepts. Therefore, students' abilities will increase, and learning becomes more relevant from the content displayed using augmented reality [20, 21]. Based on this, it is now possible to use augmented reality as a distance learning medium that can develop critical thinking skills for vocational students [22].

As it is known, critical thinking skills are one of the abilities that are highly required for individuals to compete in the 21st century [23]. It is important to note that critical thinking is not only a matter of reflection, drawing conclusions, and synthesizing information, but also enables individuals to make reasonable judgments both in the classroom and in everyday life [24, 25]. Therefore, conceptually, critical thinking means skilled and active interpretation and evaluation of observations and communication activities, information processing, as well as the ability to argue [26, 27]. Critical thinking is also defined as an ability to evaluate someone's thoughts based on interpretation, analysis, evaluation, inference, and explanation in order to make decisions that consider concepts, methodologies, criteria, and contexts [28, 29]. This makes critical thinking an important competency that students must master, as it enables them to become more competitive and accustomed to making arguments in their everyday lives.

Therefore, this study will investigate the effectiveness of mobile augmented reality as a distance learning medium in improving students' critical thinking skills. As is well-known, Distance Learning is a learning process that allows teachers and students to be in different locations [30, 31]. Distance learning does not involve meeting students in person, but with the application of e-learning, they can still collaborate and work together to solve problems. The ability of students to collaborate from different places can help solve social problems, satisfy their learning needs, and motivate them to continue using online learning [32, 33]. Through discussion, students can gain new knowledge and improve their thinking skills by being actively engaged in the learning process. The use of technology in learning can also change students' perspectives and increase their understanding of the material presented in e-learning [34, 35].

Referring to various empirical findings above, it has been identified that the use of smartphones can affect students' academic performance in terms of their cognitive, practical, and affective aspects. The novelty of this study is about the implementation of mobile learning in augmented reality format for learning in vocational high schools. Therefore, this study aims to empirically test the effect of augmented reality on the critical thinking skills of vocational high school students.

II. METHOD

A. Research Design

This study employs a true experimental design, specifically the pretest-posttest control group design [36], which includes a control group (not using AR) and an experimental group (using AR). Samples are selected from each group using Cluster Random Sampling method.

B. Participant and Data Collection

The sample for this research consisted of vocational school students in Surakarta, specifically from Surakarta State X and Y Vocational High Schools who were enrolled in the Department of Building Information and Programming Design (DPIB) and were selected using random sampling. The study included 120 students in the secondary grade, aged between 15–17 years. Among the total students, 93 (78%) were male and 27 (22%) were female.

The data collection techniques used were pretest-posttest questionnaires and observation instruments for learning syntax implementation [37]. It was conducted for 12 weeks (3 months) during the odd semester, from July to September 2021. Data analysis techniques used the One-Way ANOVA statistical test, which involved testing for normality (using Shapiro Wilk test) and homogeneity (using Levene test). The experimental design can be more clearly seen in the following figure:

Fig. 1. Research design.

Description:
EG: Experimental group
CG: Control group
O1: Experimental group pretest
O2: Control group pretest
O3: Experimental Group Posttest
O4: Control group posttest
X: Treatment with AR media
P: Not treated

C. Research Procedure

First, the preparation of the syntax of learning critical thinking inquiry model, which consisting of 5 phases adapted to the learning material of Road and Bridge Construction. The preparation of syntax was based on the book *The Miniature Guide to Critical Thinking Concepts and Tools* [38]. The following are learning activities for students using mobile AR (shown it in Fig. 2):

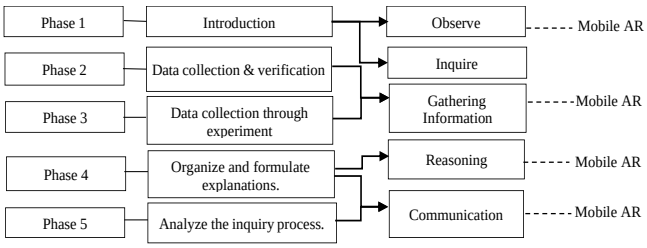

Fig. 2. Phases of learning activities with mobile AR.

The level of critical thinking test instrument was prepared with 10 questions. The questions were analyzed for validity

(rxy≥0.40), reliability (r=0.90, α=0.05), difficulty (P≤0.30), and differentiation (D≤0.50). Based on the results of these analyses, the questions were deemed valid, reliable, difficult, and had good differentiation. The critical thinking questions were adopted and developed from the Illinois Critical Thinking Essay Test, with the following question grids:

TABLE I: INDICATOR OF CRITICAL THINKING SKILL

No	Aspects	Critical Thinking Indicators	QuestionNumber
1	Focus (Ability to express opinions)	The process of identifying and formulating answers appropriately	4
		Addressing discrepancies between statementsand facts	2
2	Supporting Reasons (Basis for making a decision)	Able to show evidence for his answer	1
		Can answer according to prior knowledge.	3
		Provide decisions and answers according to the situation and conditions	8
3	Reasoning (ability of displaying evidence, arguments and alternative solutions)	Formulate conclusions based on facts and accompanied by collaborating evidence	5
		Can critically accept opinions and reject opinions from other people's conclusions.	6
4	Organization (Ability of constructing sentences & answers)	Able to define terms and considerdefinitions correctly	7
5	Conventions (ability of using language)	Determine rhetorical strategies in a persuasive manner. Also useful for us to be aware of the rhetorical strategies of others so as not to be easily deceived	10
6	Integration (ability to answer correctly according to the question)	Understand the content and check the quality of their own thinking	9

Both the Experimental Group (EG) and the control group (CG) studied Road and Bridge Construction. The only difference was that the experimental class used AR media while the control class did not use AR mobile media. The AR mobile media was in the format of an Android APK that had been developed by researchers using Blender 3D, Vuforia SDK, and Unity 3D applications. The feasibility of the AR mobile media had received validation from 6 experts of expert judgment.

It should be underlined by readers, that the augmented reality media that has been developed has gone through the stages of needs analysis, therefore in terms of the suitability of subject matter and student characteristics it has been highly considered and is certain to be suitable for students. This media will contain learning information on the topic of road and bridge construction which is expected to be a source of learning during learning activities, but this research is limited and focuses on looking at the effect of AR media on critical thinking skills as stated research objectives.

III. RESULTS

During the trial, each group had six learning sessions. The experimental group used Augmented Reality (AR) media while the control group did not.

The purpose of having six sessions for each group was to determine the extent of the effect of using AR media on improving students' critical thinking skills. After the sessions, pretest and posttest data on the student's critical thinking skills were collected and tested for normality. The normality test is a prerequisite that must be performed before further testing [39]. The results of the normality prerequisite test using Shapiro-Wilk with a significance level of Sig.>0.05 are presented in Table II below:

TABLE II: NORMALITY TEST RESULTS

		Kolmogorov-Smirnov[a]			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Surakarta State Vocational School X	Experiment Class	0.133	30	0.185	0.969	30	0.511
	Control Class	0.169	30	0.028	0.951	30	0.182
Surakarta State Vocational School Y	Experiment Class	0.113	30	0.200*	0.979	30	0.803
	Control Class	0.121	30	0.200*	0.969	30	0.518

*. This is a lower bound of the true significance.

The average significance value for Surakarta State Vocational School X was 0.511>0.05 for Experiment Class and 0.182 > 0.05 for Control Class. The average significance value for Surakarta State Vocational School Y was 0.803 > 0.05 for Experiment Class and 0.518>0.05 for Control Class (Sig.>0.05). These results indicate that the data on student critical thinking test results in all classes are normally distributed. To ensure the validity of the analysis, the normally distributed data was then tested for homogeneity, which tests whether the variances of the groups are equal. The results of the homogeneity test are presented below:

TABLE III: HOMOGENEITY TEST RESULTS

Test of Homogeneity of Variances				
	Levene Statistic	df1	df2	Sig.
Surakarta State Vocational School X	0.146	1	58	0.704
Surakarta State Vocational School Y	0.540	1	58	0.465

The results of the Levene test for homogeneity in Table III indicated that the data from Surakarta State Vocational School X had a significance value of 0.704 > 0.05, and the data from Surakarta State Vocational School Y had a significance value of 0.465 > 0.05, indicating that the data was homogenous. Afterward, the data was tested using one-way ANOVA, which utilized an independent sample t-test assisted by the IBM Statistics SPSS version 25 application. The test results are presented in the table below:

TABLE IV: T-TEST RESULTS

	Levene's Test for Equality of Variances		t-test for Equality of Means						
	f	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
								Lower	Upper
Surakarta State Vocational School X	0.146	0.704	6.451	58	0.00	19.367	3.002	13.357	25.376
Surakarta State Vocational School Y	0.540	0.465	6.451	58	0.00	26.800	3.110	20.574	33.026

It can be observed from Table IV above that the t-test results yielded a significance value of 0.000. Since the significance level of 0.000 is less than 0.05, it can be concluded that there is a significant difference between the control class and the experimental class. To determine which class is superior, the following statistics can be examined from the test results:

TABLE V: COMPARISON OF CONTROL CLASS AND EXPERIMENTAL CLASS RESULTS

Descriptive Statistics						
		N	Mean Pretest	Mean Posttest	Difference In Average Score Value	Std. Deviation
Surakarta State Vocational School X	CG	30	48.53	51.03	2.50	15.109
	EG	30	48.30	71.4	23.10	12.585
Surakarta State Vocational School Y	CG	30	40.15	45.67	5.52	12.596
	EG	30	40.62	69.47	28.85	11.481
Valid N (listwise)		120				

IV. DISCUSSION

In line with the research objectives, this study aims to investigate the effectiveness of mobile learning through an augmented reality (AR) application in improving the critical thinking skills of secondary vocational students in the subject of road and bridge construction. The experimental results of this study demonstrate that students who used mobile AR learning media in distance learning had higher critical thinking skills than those students who did not use mobile AR. These findings are consistent with previous research by [40, 41], which have also shown that AR technology can enhance students' thinking skills.

Students use Mobile AR, an application for Android smartphones that displays abstract concepts of road and bridge construction materials in 3D. With its advantages, Mobile AR can be effectively used to improve engineering education. Based on previous research, AR has the potential to enhance students' cognitive abilities [42, 43]. In comparison to other teaching methods, the use of AR technology has been proven to improve STEM learning outcomes [44, 45]. In this study, evidence is provided through the statistically analyzed acquisition of critical thinking scores. The difference in pretest scores between the control and experimental groups was insignificant. However, after the experimental class received treatment, the critical thinking scores of both control and experimental class students demonstrated a significant difference, with the experimental class achieving notably better results. This study's evidence of improvement is supported by the graph in Fig. 3, which depicts a significant increase in the average score of students who utilized mobile AR.

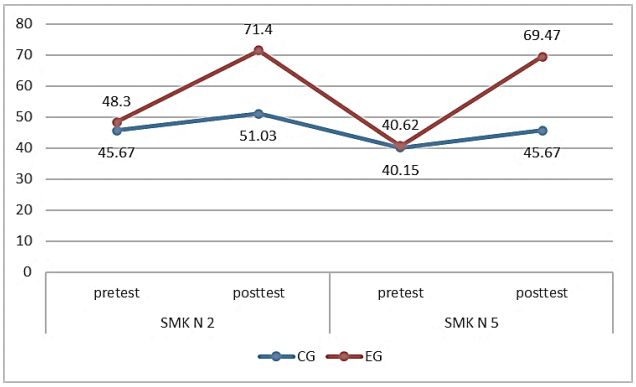

Fig. 3. Significant difference between Control Group and Experiment Group.

The findings of this study are particularly noteworthy when comparing the learning outcomes of the control and experimental classes that used the same teaching method. The use of AR technology-based media in one of the classes led to significantly better academic achievement. Through interactivity with augmented reality, students are stimulated, as noted in previous research [46], and their cognitive systems

are activated [47]. This interactive experience with AR technology also fosters curiosity and inspires students to explore further information. Augmented reality has been shown to create innovative learning experiences for students in previous studies [48, 49]. These findings suggest that the use of AR technology can have a positive impact on student learning outcomes.

The use of mobile augmented reality generates stimulating experiences that encourage vocational school students to ask more questions of their teachers. These observations were made by experts who monitored the study's learning process. Previous research have also demonstrated that augmented reality media can facilitate student interactivity in the classroom, as virtual objects provide information that supports students' reasoning and enables them to visualize concepts [50, 51]. This process of thinking and developing is enhanced through instructions that are aligned with the learning objectives. As a learning medium, augmented reality technology is consistent with Kemp and Dayton's definition of learning media, which is to present information and provide instructions to students [52]. Additionally, even when learning is done remotely, technology can help teachers create an interactive classroom [53, 54].

Students' critical thinking can develop during distance learning because the support of Mobile AR learning media cannot be separated from the pedagogical side that exists in the media. Mobile AR developed by researchers, can be operated without using a Wi-Fi network. It is easy to install and use independently and interactively for students. Mobile AR used by students besides being interactive also contains instructions for students. The instructions have been adapted to the instruments and learning design applied in the classroom [55, 56]. In this study, the learning design used is inquiry. The characteristics of interactive inquiry are considered to be in line with the nature of Mobile AR that has been developed [57]. With the support of AR mobile media with inquiry design, it will create a learning experience for students during distance learning.

Based on several relevant research findings and synthesis results, it is shown that Augmented Reality (AR) technology can contribute positively to improve the critical thinking abilities of vocational high school students. This is undoubtedly due to the characteristics of AR media, which can provide visual representations of course material, making it easier for students to understand both conceptual and practical subjects. However, this study is still limited to measure the influence of AR-based smartphone learning media on the critical thinking abilities of second-grade vocational high school students, while disregarding other factors that may affect the results. It is possible that there are internal or external factors of the students that also contribute to improve critical thinking abilities, apart from the use of augmented reality technology during the learning process.

V. Conclusion

The results of this experimental research allow it to be concluded that mobile AR developed by researchers is effective as a medium of distance learning to enhance the critical thinking skills of second grade of vocational high school. From the results of this, it was also identified that learning designs that utilize mobile AR as a distance learning medium can actually contribute positively in efforts to improve students' critical thinking skills.

Based on the results of the Sig significance t-test 0.05, the critical thinking ability of second grade students in Road and Bridge Construction subjects improved. The difference between 0.00 and 0.05 indicates that there is a difference. In Surakarta State Vocational School X itself, the average test outcome in the class that uses augmented reality media is 71.4 points, higher than the class that does not use AR learning media, with 51.03 points. The same result was also shown in Surakarta State Vocational School Y. Classes that used augmented reality media obtained an average test score of 69.47, which is greater than the class that did not use it, with score of 45.67.

Mobile AR also provides new experiences, especially for students studying road and bridge construction materials. The submission of material filled with abstract concepts is easier for students to understand using mobile AR. Mobile AR is one of the innovative learning media used as a support for learning processes.

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author Contributions

Nurul Lailatul Badriyah: Conceptualization, design, data acquisition, data analysis, interpretation, writing, drafting manuscript. Munawir Yusuf: critical revision of manuscript, supervision, final approval. Agus Efendi: data analysis, interpretation, securing funding, critical revision of manuscript, supervision, final approval.

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