Effectiveness of Augmented Reality-Based Learning Media for Engineering-Physics Teaching

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Abstract—This study aimed to determine the effect of augmented reality-based learning media and cognitive ability as well as their interaction on student learning outcomes in engineering-physics teaching. The results of the study revealed that augmented reality-based learning media improved student learning outcomes for activity-centered models and exploratory tutorial models. Furthermore, cognitive ability had a positive effect on learning outcomes, and the learning outcomes of students with high cognitive abilities were better than those of students with low cognitive abilities. Augmented reality-based learning media developed by an exploratory tutorial model proved effective for all students, while those developed by an activity-centered model was effective only for students who had high cognitive abilities.

Keywords—augmented reality, cognitive ability, learning outcomes

1 Introduction

Technical and vocational education (TVE) aims to generate graduates who are ready to enter the world of work or further their study to a higher level of education [1]. The rapid development of science and technology has forced educational institutions to respond appropriately so that their graduates have guaranteed quality. If the quality of the graduates is low, it will be difficult for them to obtain a job, and many TVE graduates who have worked for quite some time have had to be laid off due to being unable to adapt to technological development [2]. Therefore, TVE must be able to generate graduates with superior qualifications and adaptive competencies who can follow and play an active role in line with rapid technological development.

Indonesia has paid great attention to TVE as an effort to improve the quality of its human resources. This attention is manifested in the form of curriculum development, availability of learning facilities, and quality improvement of teaching staff [3]. However, there are challenges in achieving this goal, because many factors can determine the quality of TVE graduates. The North Sumatra Province of Indonesia has experienced problems related to low-quality graduates [4]. Although several efforts have been made, the learning outcomes still have not reached the target. In the electrical engineering study program, low student learning outcomes are typically caused by weak competencies in engineering and physics, which form the basis for achieving professional competence [4], [5]. This problem is experienced not only by TVE graduates in the province of North Sumatra, Indonesia, but also in other areas, as indicated in the research results [1], [6-8]. This problem should be immediately solved so that the decreasing quality of TVE graduates can be stopped, as it has resulted in an increase in unemployment.

The problem related to students' low ability in engineering-physics must be resolved immediately. This ability determines the professional competence achievement of TVE graduates. Shortcomings in teaching and learning due to the absence of learning media must be addressed appropriately. Engineering-physics requires media that visualize abstract concepts more concretely so that students can understand them easily [7], [8]. The presentation of theoretical and conceptual lecture material in engineering-physics subjects will not be effective without using the correct learning materials and media [8].

Along with the current technological development, many augmented reality-based learning media have been developed, and the selection of media for teaching engineering-physics should be based on the suitability of the concepts and characteristics of the media with the learning content. Several relevant studies can serve as references in that augmented reality-based media have proven to be effective in learning physics [8], [9], basic electronics [10], industrial engineering [11], and basic electrical engineering [12].

In addition to learning media, cognitive ability also determines student learning outcomes. Deldoost et al. [13] and Sinha et al. [14] revealed the effect of cognitive ability on student learning outcomes, particularly in the TVE fields of study. Andrew [15] discovered that cognitive abilities significantly affected student success in mathematical competencies. Referring to the theoretical and empirical facts, it is very clear that success in learning engineering-physics is affected by learning multimedia accuracy and students' cognitive abilities.

This study aimed to analyze the effect of augmented reality-based learning media and cognitive ability on student learning outcomes in engineering-physics. There were three main problems revealed through hypothesis testing: (1) the effect of augmented reality-based learning media (activity-centered model and exploratory tutorial model) on learning outcomes; (2) the effect of cognitive ability (high ability and low ability) on learning outcomes; and (3) the effect of interaction in using augmented reality-based learning media and cognitive ability on learning outcomes. The results of the study determined which treatment was the most effective in improving learning outcomes using an augmented reality-based learning media model in a group of students based on their levels of cognitive ability. Findings from this study were useful for solving the problem related to low learning outcomes in engineering-physics. The findings also served as the basis for students to achieve professional competence in the field of electrical engineering, which led to TVE graduates' quality improvement.

2 Literature review

Learning can be classified into three main phases, namely, input, process, and output. The process stage focuses on student learning activities where the content of the teaching materials, methods, media, and learning resources play important roles in determining the effectiveness of the learning process [16]. Media, as important components in the learning process, need to be developed in terms of the context of the lessons and the students' characteristics as well as the multimedia design theory. The low category is related to the theory of memory systems and cognitive processes with references to Paivio's dual-coding theory and Baddeley's working memory model. Furthermore, the high category refers to the principle of multimedia design, which is based on relevant concepts and theories, including cognitive load theory from Sweller and the cognitive theory of multimedia learning from Clark and Sweller [17].

The production of effective multimedia that improve learning outcomes should be in line with the required design principles, especially the principles of coherence, spatial of time, redundancy, modality, and segmentation [16],[18]. To prepare the learning media, the correct model can be used according to the lessons and the students' characteristics [19]. The structure of engineering-physics learning media preparation in this study was developed with two models, namely, the activity-centered model and the exploratory tutorial model [20]. The activity-centered model emphasizes students' activities as the core that utilizes the concept in problem-based learning. This model conditions students to perform learning activities to solve problems and find solutions as learning outputs. The exploratory tutorial model, on the other hand, follows the rules of tutorial learning that build student learning independence by providing accessible teaching materials based on students' interests and abilities. The media content in these two models is built based on augmented reality, which visualizes objects and events in the form of animations and virtual simulations similar to their real forms [19].

AR-based media were selected and developed to solve the problems related to students' low learning outcomes in engineering-physics. The students' thinking ability will not be optimal in absorbing information if the information load is too large to be processed simultaneously, which is known as cognitive load. Intrinsic, extrinsic, and germane cognitive load in the learning process can be reduced by using appropriate instructional media [17]. Learning multimedia also can be used to present teaching materials in the forms of visual, auditory, video, and animation that make it easier for students to understand the lessons, increasing the effectiveness of their thinking [16]. The success of learning that utilizes augmented reality-based multimedia has been proven in various published studies [11].

Cognitive ability is a person's ability to think, such as reasoning, perception, memory, verbal and mathematical abilities, and problem solving [13]. This ability is needed in thinking for problem solving in the field of science, including skills in arithmetic calculations, verbal analogies, reading comprehension and review, arithmetical sequences, and spatial relationships related to visualizing objects in three dimensions. This ability also can be applied to solve problems with 3D animation visualization based on cognitive abilities for correct data analysis [13],[14]. A person's cognitive ability is different from others, which includes differences in age, gender, and intelligence [15]. This ability can be developed to help improve higher-order thinking skills in an effort to achieve optimal performance in the field of machine learning and artificial intelligence [21].

Student learning outcomes in engineering-physics affect TVE graduates' professional competence achievement, particularly in the electrical engineering study program. Engineering-physics contains the basic concepts and theories needed to master professional competencies, such as atomic theory, static and dynamic electricity, electricity generation, semiconductors, electronic circuits, energy, and electric power [12]. Engineering-physics, with a fairly broad scope of discussion material, has become a prerequisite for several skill subjects that determine students' success in achieving TVE professional competence.

A number of studies have discussed the teaching and learning of physics and basic engineering and their relation to study competence. Learning media based on augmented reality and virtual reality have proven to be quite influential in improving students' learning outcomes in various fields of expertise, such as physics [8], [22] and geoeducation [23], [24]. Research results also have proven the increasing effectiveness and efficiency of learning using learning media in the fields of science, technology, engineering, and mathematics [25], [26] and engineering processes [27]. In addition to media, the effect of cognitive ability on student learning outcomes also has been proven in research related to learning physics and math [15], [24]. Cognitive abilities, which include arithmetic abilities, verbal analogies, and 3D object visualization, have been proven to affect student learning outcomes in STEM learning [26]. The results of these studies indicate the magnitude of the effect of multimedia learning and cognitive ability on student learning outcomes in the field of STEM. This study analyzed more specifically the effect of augmented reality-based learning media and the levels of cognitive ability and their interaction on student learning outcomes in engineering-physics lessons that served as the basis for achieving professional competence in TVE. The results of this research are expected to be a learning innovation and a solution to improve the competence of student learning outcomes.

3 Research method

This research was conducted at the State University of Medan in Indonesia at the Faculty of Engineering, with a quasi-experimental approach. The learning model used augmented reality-based media as an independent variable, divided into two groups, namely activity-centered augmented reality (AR_{-AC}) and exploratory tutorial augmented reality (AR_{-ET}), and learning outcomes as the dependent variable. Cognitive abilities as moderator variables were divided into two groups, namely, high cognitive ability (CA_{-H}) and low cognitive ability (CA_{-L}).

The study used a 2 x 2 factorial design with a sample size of 106 respondents, comprising 49 respondents in the CA_{-H} group and 57 in the CA_{-L} group. The media feasibility test referred to the multimedia design criteria of Alessi and Trollip [28]. The instrument for measuring cognitive ability adapted the critical thinking ability test from

Watson Glaser, while the learning outcome test instrument was developed referring to the curriculum after going through validity, difficulty index, discriminating power, and reliability tests. There were three hypotheses tested in this study: (1) there are differences in student learning outcomes due to the types of augmented reality-based learning media, (2) there are differences in student learning outcomes based on the levels of cognitive ability, and (3) there are interactions between types of augmented reality-based learning media with cognitive ability toward student learning outcomes. Data analysis was conducted descriptively and inferentially using two-way ANOVA after fulfilling the test requirements [29].

4 Results and discussion

This research was conducted in engineering-physics subjects covering the following topics: (1) atoms, (2) electromagnetics, (3) static and dynamic electricity, (4) electricity generat, (5) electronic components, and (6) electrical circuits. The lessons were arranged in the form of augmented reality-based learning media, grouped into two types, namely, AR$_{.AC}$ and AR$_{.ET.}$ AR$_{.AC}$ learning media had the characteristics of preparing teaching materials that focused on students' independent learning activities, while AR$_{.ET}$ focused on preparing learning materials in parallel and was open for students to choose according to their interests and abilities without requiring any sequences.

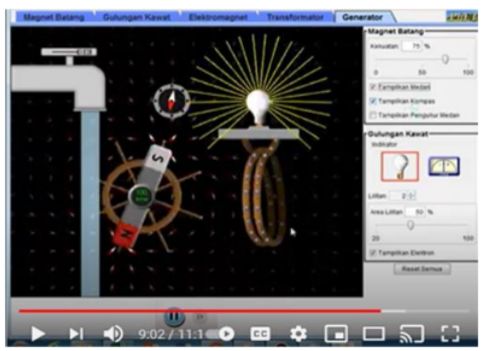

Fig. 1. AR media of magnet system

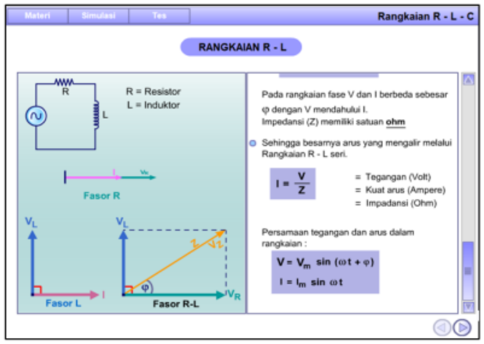

Fig. 2. AR media of RL circuits

The study used a sample of respondents who were divided into two groups, namely, those learning using media based on the AR.$_{AC}$ and AR.$_{ET}$ types. Members of each learning group were tested for their cognitive ability, namely, CA.$_{L}$ and CA.$_{H}$. A test of learning outcomes was carried out after the implementation of learning, and the gain score (∂) was the difference between the posttest and pretest scores. The results of the data analysis are shown in Figure 3.

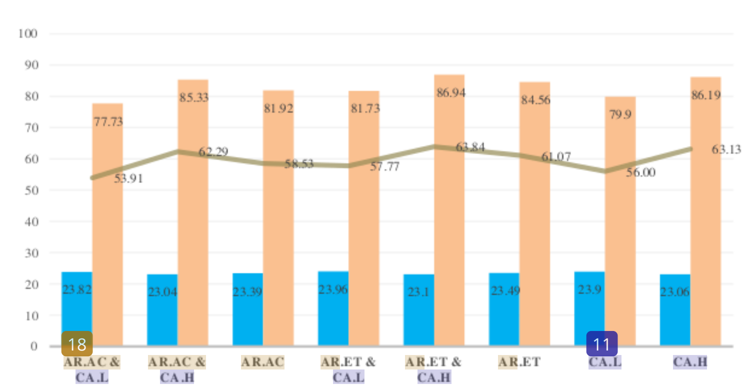

Fig. 3. Mean scores of pretest and posttest

The increase in learning outcome scores was quite large in the student group. The difference in score (∂) from the posttest and pretest was largest for the (AR.$_{ET}$ & CA.$_{H}$) group, which was 63.84, followed by the (AR.$_{AC}$ & CA.$_{H}$) group, at 62.29. This means that cognitive ability has a positive effect on increasing the score of learning outcomes both in the group using AR.$_{ET}$ media and the group using AR.$_{AC}$ media. This fact has been reinforced by the difference in the mean score for the learning outcomes of the $CA_{.H}$ group (63.13), which is higher than that of the $CA_{.L}$ group (56.00). The data analysis of student learning outcomes based on learning groups and levels of cognitive ability is displayed in Table 1.

Table 1. Descriptive Statistics of Learning Outcomes

Group	Cog.Ability	N	Minimum	Maximum	Mean	Std. Deviation
$AR_{.AC}$	$CA_{.L}$	22	68	83	77.73	3.74
	$CA_{.H}$	27	75	90	85.33	3.57
	Total	49	68	90	81.92	5.25
$AR_{.ET}$	$CA_{.L}$	26	72	88	81.73	4.36
	$CA_{.H}$	31	78	92	86.94	3.02
	Total	57	72	92	84.56	4.50
Cog.Ability	$CA_{.L}$	48	68	88	79.90	4.52
	$CA_{.H}$	58	75	92	86.19	3.35
	Total	106	68	92	83.34	5.02

Table 1 shows that there are differences in the learning outcomes of students based on the learning media used. Students who use $AR_{.ET}$ media are superior, with a mean score of 84.56, compared to the students who use $AR_{.AC}$ media, with a mean score of 81.92. Furthermore, the influence of cognitive ability was high; the group of high cognitive ability students had an average score of 86.19, while the group of low cognitive ability students had an average score of 79.90.

In general, the data in Table 1 reveal different learning outcomes in each group, but to prove its significance, further testing must be conducted using a two-way ANOVA. The normality test using the Kolmogorov-Smirnov Z technique was met, followed by the homogeneity test. The results from Levene's test of equality of error variances obtained $F_{(3:102)}=0.177$, with a coefficient greater than $(0.157>0.05)$. This meant that the variance between groups was identical (homogeneous). With the fulfillment of the analysis requirements, a comparative analysis was subsequently conducted with two-way ANOVA, and the results obtained are shown in Table 2.

Table 2. Tests of Between-Subjects Effects

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1268.424[a]	3	422.808	31.321	.000
Intercept	718242.005	1	718242.005	5.319	.000
ML	205.098	1	205.098	15.189	.000
CA	1071.175	1	1071.175	79.326	.000
ML * CA	37.637	1	90.602	7.689	.007
Error	1377.350	102	13.503		
Total	738868.000	106			
Corrected Total	2645.774	105			

Dependent Variable: Learning Outcomes
a. R Squared = .479 (Adjusted R Squared = .464)

Table 2 shows that the F value was greater than the table requirements in all aspects. This demonstrated that the influence of all independent variables, namely, augmented reality-based learning media and cognitive ability, both had a positive effect on learning outcomes. The F value 31.32 on the corrected model and Sig. <0.05 confirmed that the model designed was valid. Furthermore, the results of the analysis can be interpreted as follows:

1. AR media-based learning had a positive and significant impact on student learning outcomes in engineering-physics subjects.

   - Learning assisted by media of the activity-centered augmented reality type ($AR_{.AC}$) was able to improve learning outcomes with a mean score of 81.92 and a standard deviation of 5.25.
   - Learning assisted by media of the exploratory tutorial augmented reality type ($AR_{.ET}$) was able to improve learning outcomes with a mean score of 84.56 and a standard deviation of 4.50.
   - Overall, AR media-assisted learning improved learning outcomes with a mean score of 83.34 and a standard deviation of 5.02.

2. Students' cognitive ability had a positive and significant effect on learning outcomes achieved in engineering-physics subjects.

   - The low cognitive ability students ($CA_{.L}$) achieved learning outcomes with a mean score of 79.90 and a standard deviation of 4.52.
   - The high cognitive ability students ($CA_{.H}$) obtained a mean score of 86.19 and a standard deviation of 3.35.

3. There was a significant interaction effect between learning using augmented reality-based media and students' cognitive ability levels. Overall, the students with high cognitive ability ($CA_{.H}$) obtained an average score of 86.19, which was higher than that of the students with low cognitive ability ($CA_{.L}$), who had an average score of 79.90. If analyzed based on the interaction with the learning model, the students with high cognitive ability ($CA_{.H}$) were able to achieve high learning outcomes in $AR_{.AC}$ and $AR_{.ET}$ media-assisted learning models with mean scores of 85.33 and 86.94, respectively. However, this was not the case with students with low cognitive ability ($CA_{.L}$), whose learning outcomes with $AR_{.ET}$ multimedia-assisted learning obtained a mean score of 81.73 but a mean score of 77.73 with $AR_{.AC}$ media-assisted learning.
4. The results of the study proved that $AR_{.ET}$ media-assisted learning was effective for students in all groups. However, $AR_{.AC}$ media were more effectively used by students with high cognitive ability ($CA_{.H}$), and were less effective for students with low cognitive ability ($CA_{.L}$).

Based on the results of this study, it can be revealed that augmented reality-based media in learning contributed significantly to student learning outcomes, especially in the fields of science and technology. Many abstract and conceptual events as learning content must be presented to students, but these events are not effective if done in conventional ways. The findings from this study proved that there was a positive effect of using media on engineering-physics learning outcomes. These findings also supported the results from previous studies conducted [7], [19] regarding the contribution of multimedia to improving learning in the field of science. This research also was in line with research that succeeded in improving engineering-physics learning outcomes through multimedia modules [9], [22] and research that substantiated the superiority of multimedia with animation and simulation in learning science and technology [24]. The advantages of multimedia in the teaching and learning process in improving student achievement also are determined by the structure of their content preparation that takes into account design principles [16] and is in accordance with cognitive theory in line with students' thinking [17].

The presence of augmented reality makes a significant contribution to education, especially in terms of multimedia learning. The results from this study indicated an increase in student learning outcomes in engineering-physics lessons, with an average score of 83.34. The results were in line with other studies using augmented reality-based learning media that succeeded in improving learning outcomes in the electronic and electrical fields [10], [30], physics [8], and industrial engineering [11]. The findings from this study also strengthened the results from previous studies that proved the advantage of augmented reality media in improving learning outcomes in the fields of science and technology according to the demands of the industrial revolution 4.0 [31].

Specific analysis of each group of respondents also was conducted based on the interaction of learning models and cognitive ability. The analysis showed that there were differences in learning outcomes based on the levels of cognitive ability. In general, augmented reality media, both $AR_{.AC}$ and $AR_{.ET}$, had a significant positive effect on student learning outcomes compared to other models of multimedia. Likewise, based on the levels of cognitive ability, the learning outcomes of $CA_{.H}$ students were higher than those of $CA_{.L}$. If analyzed based on the interaction of learning models with cognitive ability, the $AR_{.ET}$ model was effectively used by the $CA_{.H}$ and $CA_{.L}$ student groups. Nevertheless, the $AR_{.ET}$ model was effective for the $CA_{.H}$ students and less effective for the $CA_{.L}$ students. This indicated that cognitive ability was more dominant in determining student learning outcomes in augmented reality media-assisted learning. The findings from this study supported the results from previous research on the effect of cognitive ability on learning outcomes in physics learning and basic electronics [6-10], mathematical competencies [15], and STEM learning [26]. Cognitive ability also has been shown to have a positive effect on complex thinking skills and even has a significant and positive contribution to achievement in various fields [13]. Referring to the results from this study, cognitive ability was an important factor as one of the variables that affected students' achievement not only in physics but also in STEM.

The model of learning material preparation in multimedia also affected the level of students' understanding of the material being studied. $AR_{.AC}$ learning media with task block design enabled the students to learn independently, as it required the students to use their high-order thinking skills and tenacity. Therefore, the results from this study fundamentally proved that $CA_{.H}$ students succeeded in achieving high learning outcomes, while $CA_{.L}$ students were not able to achieve optimal results. It was different from the exploratory tutorial type ($AR_{.ET}$) that provided lesson materials in parallel and could be accessed freely. $AR_{.ET}$ learning media with a parallel and open structure of teaching material proved that students were able to obtain optimal results in the $CA_{.H}$ and $CA_{.L}$ groups. Based on the findings from this study, it is recommended that students with low cognitive abilities use $AR_{.ET}$ media, while students with high cognitive abilities use $AR_{.ET}$ and $AR_{.AC,}$ because they are equally effective for these students.

5 Conclusion

Learning media have an important role in the learning process, especially for learning conceptual and abstract learning materials. The presence of augmented reality makes the role of learning media more significant because it is able to visualize an abstract event into concrete with the use of artificial intelligence programs. Learning engineering-physics has posed a problem in terms of learning outcomes, particularly for low-achieving students. This research proved that augmented reality-based learning media improved student learning outcomes and served as the right solution to overcome problems in engineering-physics teaching. Learning material preparation should be adapted to the structure of students' thinking to increase teaching and learning effectiveness, as well as students' cognitive ability as a determining factor for their achievement in engineering-physics. The findings from this research were obtained with the following conclusions:

1. Learning media based on augmented reality, both $AR_{.AC}$ and $AR_{.ET}$, was proven to be effective in improving learning outcomes.
2. Cognitive ability had a positive and significant effect on learning outcomes in engineering-physics, in the sense that the students with a high cognitive ability ($CA_{.H}$) managed to obtain higher learning outcomes than those with low cognitive ability ($CA_{.L}$), both with $AR_{.AC}$ and $AR_{.ET}$ assisted learning.
3. There was a significant interaction between the augmented reality media-assisted learning model and the students' cognitive reality level, in which the $CA_{.H}$ group was effective in learning with the use of $AR_{.AC}$ and $AR_{.ET}$ media, but for the $CA_{.L}$ group, it was effective only with the use of $AR_{.ET}$ media, while it was ineffective with the use of $AR_{.AC}$ media.

Referring to the findings of this study, it is expected that lecturers teaching engineering-physics subjects should use the learning media of exploratory tutorial augmented reality ($AR_{.ET}$). This model was effective in improving student learning outcomes to a high level of achievement. In addition, the $AR_{.ET}$ media also proved to be effective for use by all groups of students, both those with high and low cognitive abilities. With the success of improving learning outcomes in engineering-physics lessons, it is hoped that students' competence and expertise in the field of electrical engineering also will improve to advance graduates' competence, making them ready to compete as expected by stakeholders.

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