Design and Analysis of Multimedia Mobile Learning Based on Augmented Reality to Improve Achievement in Physics Learning

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***Abstract*—The incorporation of mobile technology is necessary for physics teachers to improve students' learning experience. Therefore, this research aimed to develop and analyze mobile learning based on Augmented Reality for physics education in Senior High School. The research employed a mixed-methods approach, which consisted of two stages. First, the use of the research and development (R&D) employing the Instructional Design Analyze, Design, Development, Implementation and Evaluation (ID ADDIE) Model's, which comprised a series of steps for analysis, design, development, implementation, and evaluation. The second stage is using empirical analysis with limited classes. The validity of the learning device was assessed using an instrument that included aspects of planning, pedagogy, content, and technique. The results of the validation indicated high scores, with an average of 0.91 for planning, 0.94 for pedagogy, 0.96 for content, and 0.90 for technique, thus confirming the validity and reliability of the mobile learning approach for physics education. The empirical analysis conducted revealed a high level of reliability, with an alpha value of 0.82, which resulted in the determination that the mobile learning approach was valid and reliable for physics education. The second stage of the research was the experimental method. Two classes were randomly selected among six classes of student's grade XI of SMA Pekanbaru, A class was designed as the experimental group, while another served as the control group which both groups consisted of 34 students which was selected based on homogeneity and normality test results. The results of the experiment indicated that multimedia mobile learning based on Augmented Reality can have a positive impact on students' achievement in physics.**

***Index Terms*—Design, analysis, multimedia, mobile learning, learning physics achievement, Augmented Reality**

I. Introduction

Physics is a branch of science that investigates natural phenomena [1], and most of the material is abstract and difficult to describe with certainty [2]. According to Chiappetta [3], science encompasses a way of thinking, a method of investigation, and a collection of knowledge. Furthermore, sciences can be classified into two categories: micro and macro sciences, based on the size of the objects they study [4].

The formation of a positive attitude towards the study of physics involves the development of belief, curiosity, imagination, reasoning, and self-awareness [5]. The results of the 2019 National High School Physics Examination, administered to both public and private school students, revealed a low level of mastery, with only 45.23% of students answering questions on mechanics, waves, optics, thermodynamics, magnetism, and modern physics correctly. This represents a decrease from the previous year's results, when 44% of students performed well, and is even lower compared to the proficiency levels demonstrated by 48.67% of students in 2017. One of the most challenging topics for students was wave physics, with only 44.67% of students correctly answering questions in 2017, a decline to 40.61% in 2018, and an improvement to 44.42% in 2019. Wave physics consistently exhibited the lowest achievement among all topics, with a decrease from 44.67% in 2017 to 40.61% in 2018. However, there was a noticeable improvement in 2019, with 44.42% of students demonstrating proficiency in this area.

The results of the national exam on high school physics, which revealed a low level of achievement among students, indicate the need for an investigation into the difficulties faced by students in their study of physics. The low percentage of correct answers suggests a lack of understanding of the material taught, as many students are only able to solve problems with the aid of examples provided by their teachers.

This research aims to address the difficulties that students encounter in comprehending the concepts of physics, particularly in the area of mechanical waves. This is in line with the findings that physics material can be abstract and challenging to grasp, as evidenced by Depdiknas [5]. A comprehensive literature review has been conducted and it was found that AR can provide 3-dimensional images and integration with objects, as highlighted in [6, 7]. The objective of this research is to answer the following research question:

1) How to develop multimedia mobile learning based on AR for the material on mechanical waves?
2) What is the level of validity of multimedia mobile learning based on AR for the material on mechanical waves?
3) What is the level of reliability of multimedia mobile learning based on AR for the material on mechanical waves?
4) Can multimedia mobile learning based on AR enhance students' learning and cognitive skills?

II. Literature Review

According to Muhammad [8–10], one of the reasons for the difficulties faced by students in understanding physics material is its abstract nature, in line with opinion [11]. However as reported in researches [11–14], Augmented

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Reality (AR) media enhances the learning experience by combining two-dimensional and three-dimensional animated images in a more realistic manner [15]. This media has the potential to offer a new perspective and mode of learning, making it a promising educational tool [16].

Previous studies have investigated the use of three-dimensional techniques in learning. For example, Virvou and Katsionis's research [17], explored the effectiveness of games in the learning process and found that virtual reality games can be highly motivating and enhance educational outcomes. Similar developments have also been conducted by Gosalia [18], who developed three-dimensional animations for e-learning games.

According to Ismayani [19], the term AR was first coined by Thomas Caudell and David Mizel in 1990 while working at Boeing. AR was defined as the integration of virtual images into the real world. It is a technology that combines computer-generated objects, two-dimensional or three-dimensional, in a natural environment around the user in real-time. The experience displayed helps users to come up with new ideas to adapt to the real world [19].

AR is a technology that combines the real world with the virtual [15]. Azuma [20] defined the term as a combination of real and virtual objects, which can run interactively in more realistic situations. There is integration between objects in three dimensions that are integrated into the virtual or real world.

AR is a technology with interactive properties in more real-time space and is in the form of three-dimensional animation that combines the real world with the virtual. In its use [21, 22], AR requires the aid of electronic devices such as smartphones or tablets with the Android operating system to functions. Its accessibility and ease of use through mobile devices make it a valuable asset for not only teachers but also students in the field of education [23].

Based on a literature review period 2015–2022, it was found that the use of AR as a fun learning media [24] can improve student learning skills, promote independence and engagement [25], increase literacy knowledge [26], general learning and flexibility [24]. Meanwhile, Nasir *et al*. [1] and Isty *et al*. [23] stated that teachers and students can conduct their experiments with the help of AR applications to strengthen their understanding of concepts. The previous researches [1–2] found that AR can strengthen students' understanding of concepts and personality. In line with [3, 7, 27–37], AR can improve learning and cognitive skills [24–26], personal skills and social skills [1, 28, 38].

According to Nasir, AR education has the potential as one of the emerging technologies [8] with great pedagogical potential and are increasingly recognized in line with [1, 7, 9, 39–44]. AR mobile learning-based systems are focusing more on games or simulations [8, 19, 26, 45]. The capabilities of mobile devices, features, properties, such as portability, and social interactivity, simplify reality by bringing in material things. Therefore, the information does not directly affect the user who does not interact directly with the real-world communication, such as streaming video [46].

The Indonesian government, through the Ministry of Research, Technology, and Higher Education in 2017, reported that the number of smartphone users in Indonesia reaches 25% of the total population or 65 million people, [47]. Meanwhile, on its website, the Ministry of Communication and Information of Indonesia wrote a report on the digital marketing research company. Emarketer in 2018 [48, 49] stated that the number of active smartphone users was more than 100 million people. The completeness of smartphones with sophisticated operating systems provide users with extensive access in the form of data and information as well as various multimedia contents and interesting applications, including their potential to be used in developing AR.

III. Research Method

The research is a combination of development and experimentation with the ADDIE ID model. It consists of five stages: Analyze, Design, Development, Implementation, and Evaluation. This study focuses on two crucial stages: development of learning media (augmented reality) and the experimental stage. The research procedure and method for developing augmented reality multimedia mobile learning is showed in Fig. 1.

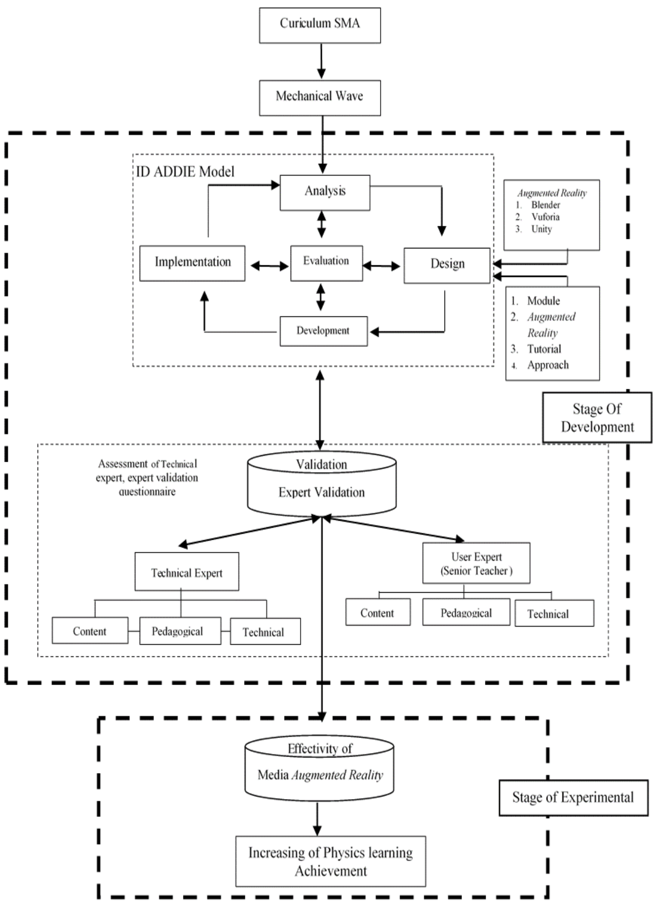

Fig. 1. Research procedure.

Fig. 1 shows the two-phase research. The first phase involved the development of AR-based multimedia learning using the ADDIE instructional model. The second phase was an experimental study to evaluate the impact of multimedia learning on physics achievement.

A. Multimedia Mobile Learning Development Procedure

The development of multimedia mobile learning by instructional design ADDIE Model's (ADDIE ID Model's) is given in Fig. 2, which is based on Augmented Reality as shown in Fig. 3,

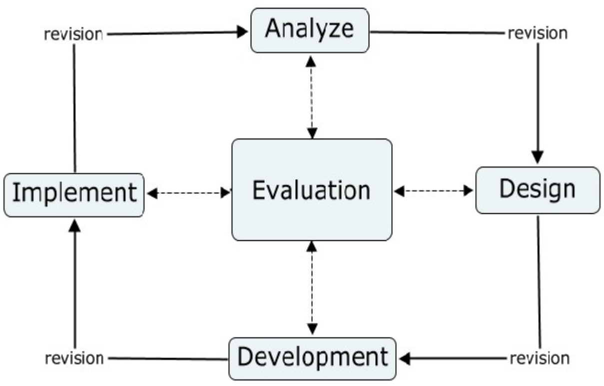

Fig. 2. ADDIE instructional design for multimedia mobile learning development procedure [50].

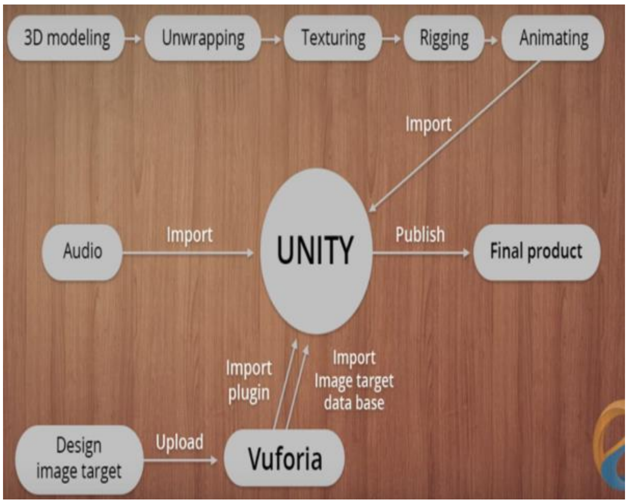

Fig. 3. Procedure for developing augmented reality.

1) Analysis phase (analyze)

The analysis stage focuses on identifying the problem and developing AR learning media. It includes several sub-studies, such as needs and task analysis, which can be described as follows:

a) Needs analysis

The purpose of the needs analysis is to determine the problems or difficulties and characteristics of high school students in learning about Mechanical Waves in physics, as outlined in the previous background. This stage includes a review of previous research results to identify the problems and their underlying causes.

b) Task analysis

Task analysis is carried out to define the topic and content of AR as a learning media that suits the needs.

This analysis consists of several steps, including the following:

1) Material Structure Analysis

It analyzes the core and basic competencies under the development of fundamental problems.

2) Analysis of Learning Objectives

Learning objectives are based on the main problems developed under the core and basic competencies in the 2013 Curriculum.

3) Concept Analysis

It includes making the main concepts that should be in AR learning media. The development of AR learning media is intended to be more coherent and systematic.

2) Design Phase

At this stage, the research designed the learning media according to their needs.

3) Development

This stage is an activity of making learning media. All the steps and components designed are carried out at this development stage to form a complete product per the plan.

4) Implementation

The learning media has been completed at this stage, and its use will be tested. The project is conducted to determine the consistency of the learning media with previous plan.

5) Evaluation

The evaluation stage focuses on identifying any deficiencies and errors in the ADDIE development learning media stage. Based on the evaluation results, the product can be revised to create the desired learning media.

The next step after the five stages is to test the validity of the learning media product. This validation is conducted by experienced physics education experts who act as lecturers. The aim of this validation is to obtain recognition of the feasibility of the learning media. If the learning media is found to be valid, it will be revised and finalized to produce the final product.

B. Mobile Learning Experimental Procedure

Experimental research was conducted to assess the impact of multimedia mobile learning on students' learning and cognitive skills. According to Creswell [51], a Quasi Experiment was carried out. This type of experimental research, known as Quasi Experiment, has a nonequivalent control group design, as shown in Table I.

TABLE I: EXPERIMENTAL DESIGN

Expr	T_1	X	T_2
Ctrl	T_3	-	T_4

T1: Experimental class pre-test results
T2: Experimental class post-test results
T3: Control class pre-test results
T4: Control class post-test results
X: Treatment

The population is students of Gride XI, consisting of six groups given normality and homogeneity tests. The normality and homogeneity test results are shown in Tables II and III, and two groups are randomly selected as the sample. The experimental group consisted of 34 students, with 15 boys and 19 girls, whereas the control consisted of 34 students, with 17 boys and 17 girls.

TABLE II: THE NORMALITY TEST OF SIX GROUPS OF STUDENT GRADE XI RESULT

Grid-X1	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
1	0.091	39	0.200*	0.968	39	0.319
2	0.113	41	0.200*	0.970	41	0.350
3	0.164	39	0.010	0.958	39	0.157
4	0.100	35	0.200*	0.986	35	0.927
5	0.164	39	0.010	0.958	39	0.157
6	0.153	33	0.049	0.963	33	0.317

a: Lilliefors Significance Correction
*: This is a lower bound of the true significance

TABLE III: THE HOMOGENITY TEST OF SIX GROUPS OF STUDENT GRADEXI RESULT

	Levine Statistic	df1	df2	Sig.
Based on Mean	0.904	5	220	0.479
Based on Median	0.734	5	220	0.599
Based on Median and with adjusted df	0.734	5	206.071	0.599
Based on trimmed mean	0.906	5	220	0.478

The instrument used for data collection is a validation sheet of educational game learning media adapted from the instrument made by Retnawati [52] and the validation assessment items can be seen in Table IV.

TABLE IV: VALIDATION ASSESSMENT INSTRUMENT TO DETERMINE THE SCORE GIVEN BY THE VALIDATOR TO EACH INDICATOR OF THE QUESTIONNAIRE (R)

No.	Item
Aspect -1 : Design	
1.	The design of the learning media screen is attractive or appropriate
2.	The letters used are appropriate or easy to read
3.	Images in the media according to the content
4.	The images used help students' to understanding
5.	The images used help with learning
6.	The colours used are suitable for reading
7.	The sound used is appropriate or not disturbing
8.	The buttons or signs used are easily recognizable
9.	The positioning of text, graphics, video and markers is Consistent
10.	Software instructions and user guide is Complete
Aspect -2 : Pedagogy	
11.	Teaching competencies are clearly written
12.	Teaching competencies can be achieved
13.	Competency formulation becomes a guideline for media users
14.	Topics according to competencies
15.	Presentation of topics attracts students' attention
16.	The information conveyed is easy to understand
17,	This media encourages students to think creatively
18.	Presentation the material is organized and easy to follow
19.	Examples and exercises given are in accordance with the material
20.	Learning methods are suitable for multimedia learning
Aspect -3 : Content	
21.	Learning materials are in accordance with the Curriculum K-13
22.	Learning materials are in accordance with the competence
23.	Learning materials are appropriate to the level of students' abilities
24.	Learning materials are appropriate de for students' basic knowledge
25.	Lesson materials contain an educative value
26.	Lesson materials are accompanied by exercises
27.	Exercises according to the topic of the lesson
28.	Lesson materials are accompanied by formative tests
29.	Lesson materials are accompanied by summative tests
30.	Formative tests and summative tests according to lesson materials
Aspect - 4 : Technical	
31	Users can control the learning process
32.	Media has many branches to other parts
33.	Users do not get stuck while browsing the media
34.	The journey of presenting media content is easy to follow
35.	There is more than one acquisition of information
36.	Users can easily find the information they need
37.	Users can exit the media whenever they want
38.	Software easy to use (operate)

The questionnaire assessment category uses a Likert Scale [51] which is presented in Table V

TABLE V: CATEGORY OF SCORE ASSESSMENT [51, 53, 54]

Category	score
Strongly Agree	5
Agree	4
Disagree	3
Don't Agree	2
Strongly Don't Agree	1

Determine the calculated validity value using the following Aiken's V [54] formula:

$$V = \frac{\sum s}{n(c-1)}$$

V = Rater's Fit Index
s = Average score - the lowest score in the category
c = Number of Categories
n = Number of Raters

Determining the category of Aiken's V coefficient in Table VI.

TABLE VI: THE VALUE OF V AIKEN COEFFICIENT AND CATEGORY [51, 53, 54]

Value of V Aiken	category
$0{,}80 < V \leq 1.00$	valid (very high)
$0{,}60 < V \leq 0.80$	valid (high)
$0{,}40 < V \leq 0.60$	valid (sufficient)
$0{,}20 < V \leq 0.40$	invalid (low)
$0{,}00 < V \leq 0.20$	invalid (very low)

From the calculation of the results, an item or device can be categorized based on its index. Furthermore, when the index is equal to 0.4, 0.4–0.8 and greater than 0.8, it is stated to be less valid, moderate validity, and very accurate [52, 54, 55], respectively, in line with Anggraini *et al*.'s researches [56]. Therefore, learning media is declared valid and feasible to use when the assessment indicators on the validity instrument have Aiken's V validity coefficient value >0.4 [56].

IV. RESULT AND DISCUSSION

A. Result of Development of Research Stage

This result is based on the Instructional Design ADDIE Model, which includes the Analysis, Design, Development, Implementation, and Evaluation stages.

The analytical phase found that the need for this research arose from students' poor understanding of physics concepts, as evidenced by their low scores on the National Exam. In 2019, only 45.23% of students at State and Private SMA levels answered Physics questions correctly. This is lower than in 2017 (48.67%) and higher than in 2018 (44.00%). The lowest scores were in wave material, with 44.67% correct answers in 2017, declining to 40.61% in 2018, then rising to 44.42% in 2019. This suggests that using multimedia and mobile learning methods could improve students' performance in Physics.

Results of the designing stage as shown in Figs. 4–11

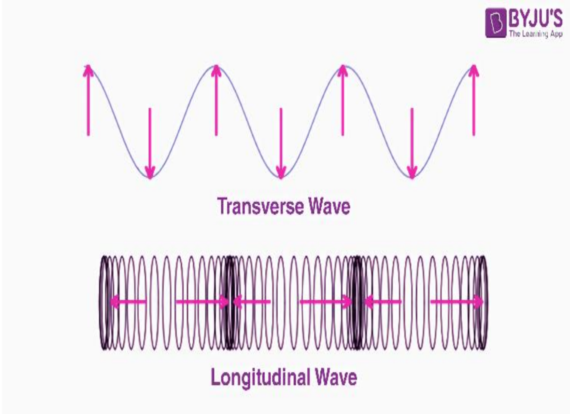

Fig. 4. Mechanical wave display in conventional view [57].

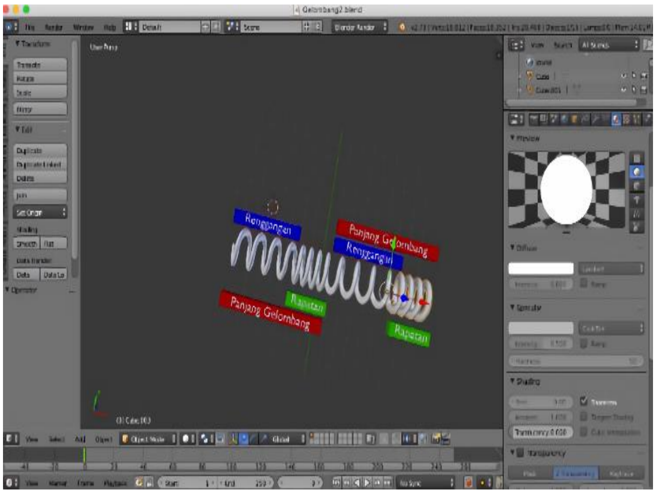

Fig. 5. Creating process "marker" of a mechanical wave in 3D view usage Blender.

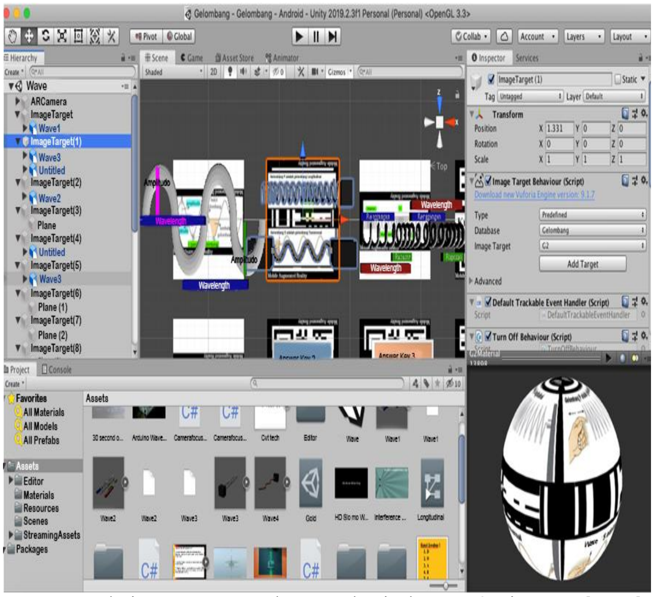

Fig. 6. Rendering process "marker" mechanical waves 3D in unity through Vuforia like as Fig. 3 stage process.

Meanwhile, to be able to see the appearance of the mechanical waves in the form of Augmented Reality, a system was designed as shown in Fig. 8. The system described in Fig. 8 is compiled to form an application (APK) and installed on a cellphone as shown in Fig. 9.

The application as described in Fig. 9 is called multimedia mobile learning based on Augmented Reality application. This study is called Multimedia Mobile Learning based on Augmented Reality (AR)

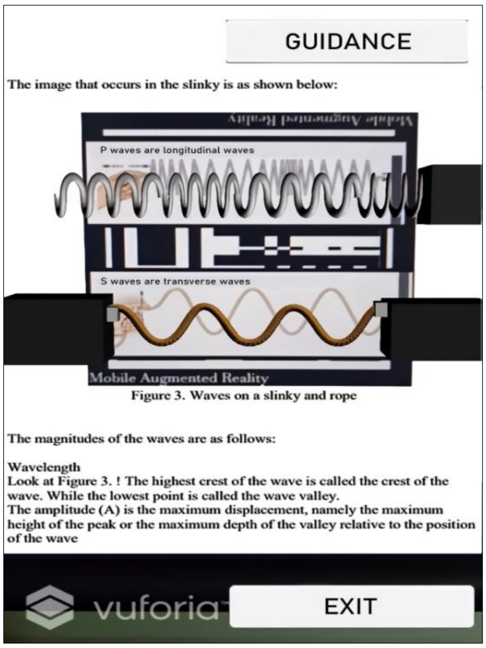

Fig. 7. A mechanical wave in augmented reality view.

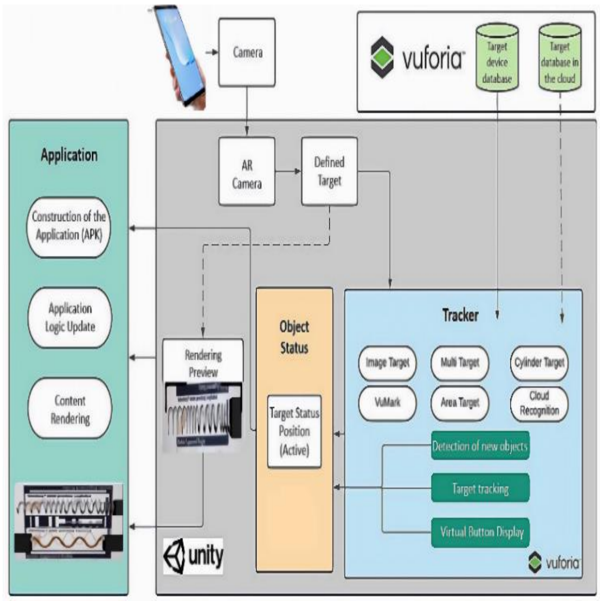

Fig. 8. Stage and process appearance of the mechanical waves in the form of augmented reality.

Fig. 9. Shortcut of application of multimedia mobile learning based on augmented reality (APK) display in smartphone.

Fig. 10. Display of multimedia mobile learning main menu.

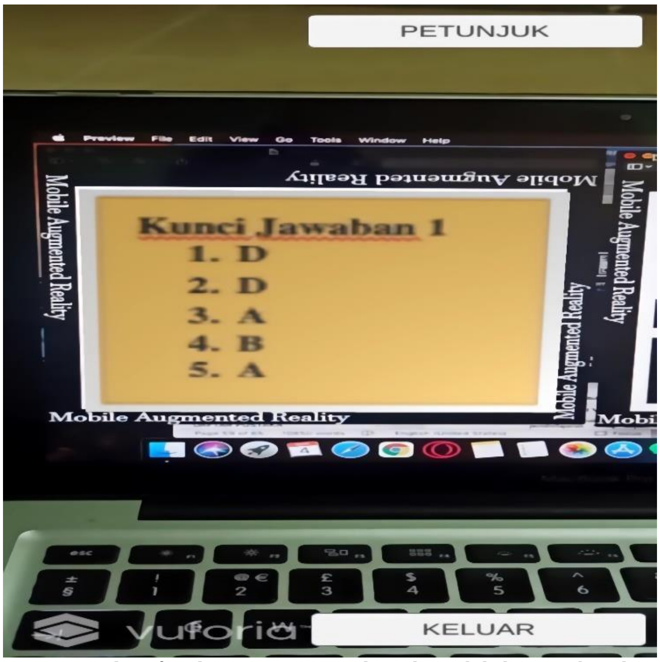

Fig. 11. Display of evaluation menu in multimedia mobile learning based on augmented reality application (APK).

The validation results on the design aspect were calculated using Aiken's V formula presented in Tables VII–X.

TABLE VII: THE VALIDATION RESULTS ON THE DESIGN ASPECT WERE CALCULATED USING AIKEN'S V FORMULA

No	Indicator	$\sum s$	V	Criteria
1	The design of the learning media screen is attractive or appropriate	11	0.92	Valid
2	The letters used are appropriate or easy to read	10	0.83	Valid
3	Images in the media according to the content	10	0.83	Valid
4	The images used help students' to understanding	12	1	Valid
5	The images used help with learning	12	1	Valid
6	The colours used are suitable for reading	9	0.75	Valid
7	The sound used is appropriate or not disturbing	11	0.92	Valid
8	The buttons or signs used are easily recognizable	10	0.83	Valid
9	The positioning of text, graphics, video and markers is Consistent	10	0.83	Valid
10	Software instructions and user guide is Complete	11	0.92	Valid

TABLEVIII: THE VALIDATION RESULTS ON THE PEDAGOGICAL ASPECT WERE CALCULATED USING AIKEN'S V FORMULA

No	Indicator	$\sum s$	V	Criteria
11	Teaching competencies are clearly written	12	1	Valid
12	Teaching competencies can be achieved	11	0.92	Valid
13	Competency formulation becomes a guideline for media users	11	0.92	Valid
14	Topics according to competencies	10	0.83	Valid
15	Presentation of topics attracts students' attention	10	0.83	Valid
16	The information conveyed is easy to understand	10	0.83	Valid
17	This media encourages students to think creatively	10	0.83	Valid
18	Presentation the material is organized and easy to follow	11	0.92	Valid
19	Examples and exercises given are in accordance with the material	11	0.92	Valid
20	Learning methods are suitable for multimedia learning	12	1	Valid

TABLE IX: THE VALIDATION RESULTS ON THE CONTENT ASPECT WERE CALCULATED USING AIKEN'S V FORMULA

No	Indicator	$\sum s$	V	Criteria
21	Learning materials are in accordance with the Curriculum K-13	10	0.83	Valid
22	Learning materials are in accordance with the competence	10	0.83	Valid
23	Learning materials are appropriate to the level of students' abilities	11	0.92	Valid
24	Learning materials are appropriate de for students' basic knowledge	11	0.92	Valid
25	Lesson materials contain an educative value	11	0.92	Valid
26	Lesson materials are accompanied by exercises	11	0.92	Valid
27	Exercises according to the topic of the lesson	12	1	Valid
28	Lesson materials are accompanied by formative tests	12	1	Valid
29	Lesson materials are accompanied by summative tests	11	0.92	Valid
30	Formative tests and summative tests according to lesson materials	9	0.75	Valid

TABLE X: THE VALIDATION RESULTS ON THE TECHNICAL ASPECT WERE CALCULATED USING THE AIKEN'S V FORMULA

No	Indicator	$\sum s$	V	Criteria
31	Users can control the learning process	11	0.92	Valid
32	Media has many branches to other parts	10	0.83	Valid
33	Users do not get stuck while browsing the media	10	0.83	Valid
34	The journey of presenting media content is easy to follow	11	0.92	Valid
35	There is more than one acquisition of information	11	0.92	Valid
36	Users can easily find the information they need	10	0.83	Valid
37	Users can exit the media whenever they want	11	0.92	Valid
38	Software easy to use (operate)	9	0.75	Valid

Data from Tables VII–X showed that all indicators are valid with a validity index ranging from 0.75 to 1, 0.83 to 1, 0.75 to 1 and 0.75 to 1 with an average Aiken validity index of 0.88, 0.89, 0.90, 0.86 respectively.

The reliability of mobile learning multimedia based on augmented reality test was conducted using SPSS program. From the validity of the user, the value of Cronbach's Alpha (α) is shown in Table XI as follows:

TABLE XI: USER DATA RELIABILITY TEST RESULTS (STUDENTS)

Cronbach's Alpha	N of Items
0.908	20

Cronbach's Alpha value is reliable when greater than 0.7 (> 0.7) [58, 59], and the value based on Table IV with the total number of 20 items is = 0.908, greater than 0.7. Therefore, the media is stated to be reliable following the results of media assessment analysis through questionnaire items [56, 60].

B. Results of the Experimental Stage

Data on learning outcomes in the experiment and control classes were collected from 34 experimental class students by administering a pre- and post-test consisting of 25 questions. The results of the experimental class is showed in Table XII

TABLE XII: DIFFERENCES IN LEARNING OUTCOMES BEFORE AND AFTER EXPERIMENTAL

Class	Mean of Pre-test	Mean of Post-test	Differences
Control	66.00	75.32	9.32
Experiments	67.29	87.18	19.87

Table XI shows that both the experimental and control class learning outcomes have improved, by 19.87 and 9.32 respectively. Although both classes have seen significant improvements, a paired sample t-test should be conducted for further analysis. The results of the paired sample t-test on learning outcomes show at Table XIII.

TABLE XIII: RESULT PAIRED SAMPLE T-TEST CONTROL AND EXPERIMENTAL CLASSES

Class	N	Mean differences	Sig. (2 tailed)
Pre-test Experiment	34	19.87	0.000
Post-test Experiment	34		
Pre-test Control	34	9.32	0.000
Post-test Control	34		

The paired sample t-test analysis reveals that the improvement in learning outcomes in the experimental class is significantly different from that of the control (sig. < 0.05). It can therefore be concluded that the use of AR-based learning media can enhance students' understanding of mechanical wave content, as supported by previous researches [3, 21–32].

V. CONCLUSION

Based on the results of the research and discussion that has been carried out, it was found that interactive multimedia mobile learning based on augmented reality (AR) was developed using the ADDIE Instructional Design Model (ADDIE ID Model's) learning which includes four aspects, namely aspects of design, pedagogy, content and techniques. The results of the expert validity analysis show that the interactive multimedia Mobile Learning based on AR is valid in terms of design, pedagogy, content and techniques. While the results of empirical analysis show that interactive multimedia mobile learning based on AR is valid and reliable in terms of design, pedagogy, content and techniques. The results of experiments on learning in class show that interactive multimedia mobile learning based on AR can improve students' physics learning outcomes. This interactive multimedia Mobile Learning based on AR is effective in improving student physics learning outcomes.

CONFLICT OF INTEREST

The authors declare no conflict of interest in this Research.

AUTHOR CONTRIBUTIONS

Muhammad Nasir: Design of the Research, Development of AR Program, Data Collected, Empirical Analysis, Write the paper

Fakhruddin. Z: Data Collected, Validation Processing of multimedia, Data Analysis, Write The Paper

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