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DEVELOPMENT OF AUGMENTED REALITY-BASED PHYSICS MODULE ON CIRCULAR MOTION

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Abstract :
This study aims to develop a valid and practical augmented reality-based physics module on circular motion material used in learning. The background of this study is the difficulty of students in understanding the concept of circular motion and the minimal use of technology-based teaching materials such as augmented reality in schools. This study uses the Research and Development (R&D) method with the 4-D model (Define, Design, Develop, and Disseminate), but is only carried out up to the Develop stage. The subjects of the study were 2 physics teachers and 15 students of class XI IPA SMA Azharyah Palembang. Data collection techniques include observation, interviews, and questionnaires, while data analysis techniques use a Likert scale to assess the validity and practicality of the product. The validation value was obtained from the validation results by material, media, and language experts with an average percentage value of 81.67% which indicates that the developed module is in the very valid category. The practicality value is obtained from the responses of teachers and students after using the augmented reality-based physics module on the circular motion material in a small-scale trial obtained a percentage of 88.5% with very practical criteria and in the practicality test the teacher obtained a percentage of 88% with very practical criteria. Thus, this augmented reality-based physics module is suitable for use as an interactive learning media to improve students' understanding of the circular motion material.

Keywords: Physics Module, Augmented Reality, Circular Motion

Abstrak:

Penelitian ini bertujuan untuk mengembangkan modul fisika berbasis *augmented reality* pada materi gerak melingkar yang valid dan praktis digunakan dalam pembelajaran. Latar belakang penelitian ini adalah kesulitan siswa dalam memahami konsep gerak melingkar serta minimnya penggunaan bahan ajar berbasis teknologi seperti *augmented reality* di sekolah. Penelitian ini menggunakan metode *Research and Development* (R&D) dengan model 4-D (*Define, Design, Develop, dan Disseminate*), namun hanya dilakukan sampai pada tahap *Develop* saja. Subjek penelitian adalah 2 orang guru fisika dan 15 orang siswa kelas XI IPA SMA Azharyah Palembang. Teknik pengumpulan data meliputi observasi, wawancara, dan angket, sedangkan teknik analisis data menggunakan skala likert untuk menilai kevalidan dan kepraktisan produk. Nilai validasi didapatkan dari hasil validasi oleh ahli materi, media, dan bahasa dengan nilai persentase rata-rata 81,67% yang menunjukkan bahwa modul yang dikembangkan masuk dalam kategori sangat valid. Nilai kepraktisan didapatkan dari respon guru dan siswa setelah menggunakan modul fisika berbasis *augmented reality* pada materi gerak melingkar pada uji coba skala kecil memperoleh persentase sebesar 88,5% dengan kriteria sangat praktis dan pada uji kepraktisan guru memperoleh persentase sebesar 88% dengan kriteria sangat praktis. Dengan demikian, modul fisika berbasis *augmented reality* ini layak digunakan sebagai media pembelajaran interaktif untuk meningkatkan pemahaman siswa terhadap materi gerak melingkar.

Kata Kunci: Modul Fisika, *Augmented Reality*, Gerak Melingkar

INTRODUCTION

Education plays an important role in shaping people's behavior and practices. Differences in the quality of education between generations are an indicator of the progress or decline of a society (Afsari et al., 2021). Human Resources (HR) in the era of society 5.0 are highly dependent on education. One of the efforts needed by education is a change in the educational paradigm. The role of education is not only to present teaching materials, but also to bring out the creativity of students. The level of education of a nation is greatly influenced by the development of educational technology. The development of additional educational technology facilities has the potential to produce modern and up-to-date human resources, thus fostering quality and highly competitive education. Therefore, increasing technological development in accordance with the development and characteristics of educational goals is one strategy to achieve national progress. No exception in physics learning, the use of technology has expanded the efficiency and effectiveness of learning. As a result, the lecture method has been replaced by the use of interactive media in learning (Ardiansyah & Nana, 2020).

One of the technologies that is now widely used in education is augmented reality (AR). This technology allows the presentation of information visually in two or three dimensions that can interact with the real world through smartphone devices. Integrating augmented reality into physics learning can improve students' self-efficiency in physics learning, as shown by better understanding of concepts, practice and communication. In addition, the integration of augmented reality into physics learning can motivate students to learn more deeply (Cai et al., 2021). Combining augmented reality with learning models and teaching materials can support students' learning processes and outcomes, making learning more meaningful (Wulandari et al., 2020). The use of augmented reality in physics learning can improve students' understanding of concepts, increase their interest in the lesson (Socrates & Mufit, 2022). Therefore, AR has great potential as an interactive teaching aid, especially for physics subjects which are known to be abstract and difficult for some students to understand.

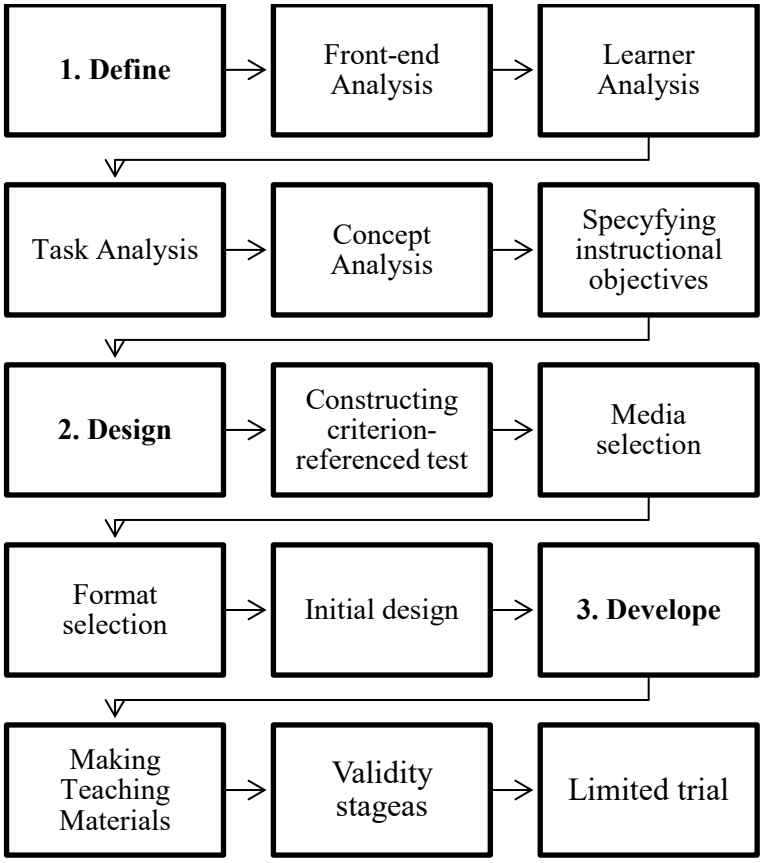
Based on the results of observations and interviews with one of the physics teachers at SMA Azharyah Palembang, information was obtained that there is still a lack of facilities and supporting teaching materials that can help the learning process. The learning resources used only use textbooks as teaching references and provide verbal explanations, so that students are less interested in participating in physics learning. Circular motion material is one of the materials that is quite difficult for students to understand. This difficulty can be seen from the fact that there are still many students who get daily test scores below average. Based on the results of interviews with 6 students, they considered that circular motion material was difficult to understand. Students' failure to understand circular motion material is caused by several factors, including the learning media used by teachers who are less able to explain circular motion material well (Sya'roni et al., 2021). The method used in the learning process can also influence, in reality many learning objectives are not achieved because the learning theory applied so far is still too focused on associative learning or rote learning. Learning like this has no meaning for students (Ria, 2019). Students find it difficult to understand circular motion material if it is only limited to theory and students need to understand the formula for each circular motion material (Sunarti & Rusilowati, 2020). Circular motion is one of the physics materials that often has misconceptions among students. Misconceptions that are often experienced by students include errors in determining the relationship between the radius of two wheels connected by a rope and the angular velocity of each wheel. Students experience misconceptions related to frequency with the assumption that frequency is directly proportional to travel time. Most students have alternative concepts regarding circular motion, especially speed, acceleration, and force (Sya'roni et al., 2021). According to the results of a pre-study conducted by distributing questionnaires to 30 grade XI IPA students, 56.7% stated that they were not interested in physics subjects. In addition, the survey showed that teachers had not used teaching materials in the form of modules in learning or used interactive learning media based on augmented reality in physics learning. In addition, 90% of students support the development of physics teaching materials that combine modules and augmented reality technology to make learning more interesting and easier to understand.

This condition shows that innovation is needed in the development of physics learning media that are not only interactive and interesting, but also innovative that supports the effectiveness of physics learning in the digital era and is relevant to the habits of students who are accustomed to using technological devices such as smartphones. The development of an augmented reality-based physics module can be the right solution to bridge learning needs with the latest technology. This module is

expected to be able to help students visualize abstract concepts, strengthen understanding, and increase student interest in learning. The purpose of this study is to describe the validity and practicality of the augmented reality-based physics module on the circular motion material that was developed.

METHODS

This study uses the research and development (R&D) method. The purpose of this research method is to produce a specific product and test its effectiveness (Sugiyono, 2020). The development model used in this study is the 4-D model developed by Sivasailam, Thiagarajan, Dorothy S. Semmel, and Melya I. Semmel (1974). This model consists of four main stages, namely: define, design, development, and disseminate. However, in this study, the development process was only carried out up to the third stage, namely the develop stage, due to time constraints and the focus of the research on the development and initial validation of the product and the responses of teachers and students. The following is a picture of the research design carried out:



Time and Place of Research

This research was conducted in the even semester of the 2024/2025 academic year in class XI IPA of SMA Azharyah Palembang located at Jl. KH. Azhari, 12 Ulu, Sebrang Ulu II District, Palembang City, South Sumatra.

Research subjects

The subjects in this study were 2 physics teachers and 15 students of class XI IPA at SMA Azharyah Palembang.

Research Procedures

This study began with the define stage which includes initial analysis, analysis of student characteristics, task analysis, concept analysis, and formulation of learning objectives. The next stage is design which includes the preparation of assessment instruments, format selection, and initial design of learning media. This study then focused on the third stage, namely develop which consists of media creation, validity stage, revision of learning media and limited trials, and did not continue to the disseminate stage due to time constraints and research objectives that focus on the validity and practicality of the product. Consequently, the results of this study do not yet include wide distribution or long-term evaluation of media effectiveness.

In the development stage, learning media was created in the form of a physics module based on augmented reality (AR), which is packaged in an application called GEMAR (Gerak Melingkir Augmented Reality). This application was developed to provide a more interactive and contextual learning experience for the material on circular motion. Media validation was carried out by six experts consisting of two media experts, two material experts, and two language experts, to assess the feasibility of the content, appearance, and language of the module. After going through a revision process based on input from experts, a limited trial was conducted on fifteen grade XI IPA students and two physics teachers. This trial aims to assess the practicality of the learning media based on user responses. In its implementation, students and teachers were asked to download the GEMAR application via the QR code listed on the module cover, use the media in learning, and then fill out a response questionnaire to measure the level of ease, attractiveness, and usefulness of the media. The data from this limited trial became the basis for an initial evaluation of the practicality of the media before being tested widely.

Data Collection Techniques

Qualitative Data Analysis Techniques

Qualitative data were obtained from the results of observations, open interviews, comments and suggestions on questionnaires and documentation. Qualitative data analysis techniques were carried out through the stages of data reduction, data presentation, and drawing conclusions (Milles & Huberman, 1994). This observation was carried out to obtain valid evidence by recording and documenting learning facilities and processes. The open interview method was used in this study to collect data and information from research subjects directly. The results of interviews conducted with one physics teacher and six grade XI IPA students were analyzed to reveal perceptions, obstacles, and suggestions related to the use of learning media. The purpose of the questionnaire was to evaluate the requirements for developing teaching materials, expert validation, and student and teacher responses after using the products developed by the researcher. This study used a student questionnaire at the define stage, a validation questionnaire given to media experts, material experts and language experts and a response questionnaire addressed to physics teachers and students. In the validation questionnaire and teacher and student responses there are several indicators, where each indicator has 5 answer choices including very good (5), Good (4), Enough (3), Less (2), and Very Less (1). These findings are used to support quantitative results and provide a more comprehensive picture of the practicality and acceptability aspects of the media developed.

Quantitative Data Analysis Techniques

a. Validity data analysis

To analyze the validity of learning media, a descriptive quantitative approach is used. Data were obtained from the results of questionnaires filled out by experts (validators) covering aspects of material, media, and language. The scores given were calculated using the following formula (Arikunto, 2014):

$$N = \frac{\sum Acquisition\ value}{\sum maximum\ value} \times 100\%$$

Description:

N = Percentage of total achieved

The results of the validity percentage were then interpreted into qualitative categories according to the criteria set by Riduwan (2017) as shown in Table 1:

Table 1. Validity Assessment Category

Criteria (%)	Validation Level
81% - 100%	Very valid
61% - 80%	Valid
41% - 60%	Quite valid
21% - 40%	Less valid
0 - 20%	Not valid

Sumber: (Riduwan & Sunarto, 2017)

b. Practical data analysis

The practicality data analysis was conducted using a similar technique using data from teacher and student response questionnaires to the physics module based on augmented reality that was developed. The formula used to calculate the percentage of practicality is:

$$N = \frac{\sum Acquisition\ value}{\sum maximum\ value} \times 100\%$$

Interpretation of practical results was carried out based on categories adapted from Riduwan (2017), as in Table 2:

Table 2. Practicality Assessment Category

Criteria (%)	Practicality Level
81% - 100%	Very Practical
61% - 80%	Praktical
41% - 60%	Quite Praktis
21% - 40%	Less Praktis
0 - 20%	Not Praktis

Sumber: (Riduwan & Sunarto, 2017)

RESULTS AND DISCUSSION

This study aims to develop a valid and practical augmented reality-based physics module on circular motion material for use in learning in high school. The results of this study were reviewed quantitatively based on expert validation and practicality tests, and analyzed qualitatively based on expert comments and user responses (teachers and students).

1. *Define*

Based on the results of initial observations conducted, it is known that the curriculum used in the school uses the independent curriculum. Information obtained from the results of interviews with one of the physics teachers that students experience difficulties in learning physics, especially in the topic of circular motion, these difficulties can be seen from the number of students who get daily test scores below average. The test results data shows that only 14 out of 30 grade XI IPA students or around 46.66% achieved the Learning Objective Achievement Criteria (KKTP), with a scale or interval of KKTP values for physics subjects ≥66. This shows that student learning scores are still low on circular motion material. This is in accordance with the results of interviews conducted with 6 students that students face various difficulties in understanding circular motion material. The learning media used to assist the physics learning process that are currently available are still relatively minimal, especially media that is integrated with technology that is still limited. Based on the results

of filling out the needs questionnaire by students on the aspect of "needs for developing physics modules based on augmented reality" the percentage was 90%.

Based on the results of the analysis questionnaire, students are less interested in learning physics, as seen in the indicator "student interest in physics lessons" which obtained a low percentage of 43.3%. In addition, the results of observations can be seen because students are less active in asking questions, less enthusiastic in the learning process, and have low interest in reading. The results of interviews with students showed that 4 out of 6 students stated that they rarely read physics textbooks. Furthermore, based on the results of the questionnaire on the indicator "student interest in reading physics textbooks" of 40% which shows that the level of student interest in reading textbooks is low. In terms of the quality of printed books, the percentage obtained is quite low, namely 40% with poor criteria. According to students, printed books are too thick, too much writing and there are few pictures, causing students to feel bored, monotonous, and less interested in reading them and have difficulty in understanding and visualizing abstract material. The teaching materials expected by students are those that contain lots of pictures and not too much writing and explanations that are easy to understand.

Based on the results of interviews with physics teachers, teachers often give assignments in the form of practice questions sourced from printed books or Student Worksheets (LKPD). Based on the assignments given by teachers, it can be seen that the abilities and skills of students that teachers want to develop include cognitive, affective and psychomotor abilities.

Based on several sources of physics textbooks, the researcher determined the subconcepts that will be presented in the module, which consist of three sub-topics which are then compiled into two learning activities. The determination of these subconcepts is guided by the needs of the Learning Objectives (TP) for the circular motion material. These subconcepts include: Uniform Circular Motion (GMB), physical quantities in circular motion, and the relationship between wheels. In addition, in the augmented reality-based module, the researcher also describes various concepts that contain practical activities that can hone students' affective and psychomotor abilities. The indicators for achieving learning objectives and learning goals can be seen in Table 3 below:

Table 3. Learning Objectives in the Module

Learning Activities	Learning Objective Achievement	Indicator Learning Objectives
1	1. Describe the physical quantities in regular circular motion. 2. Analyze the characteristics of regular circular motion, 3. Apply the concept of regular circular motion in solving problems.	1. Students can describe physical quantities in regular circular motion. 2. Students can analyze the characteristics of regular circular motion. 3. Students can apply the concept of circular motion in solving problems.
2	1. Analyze the relationship of wheels on the same axle. 2. Analyze the relationship of wheels that touch. 3. Analyze the relationship of wheels connected by rope/chain.	1. Students can analyze the relationship between coaxial/concentric wheels. 2. Students can analyze the relationship between intersecting wheels. 3. Students can analyze the relationship between

	wheels connected by rope/chain.

2. *Design*

In the design stage, the first step taken is to compile an expert validator assessment instrument and teacher and student responses to the media developed. In addition, a student learning outcome test is also compiled. This test is compiled based on the results of task analysis and learning objectives. Next, select the media to be developed, the media is selected by adjusting the results of student analysis and concept analysis. In this study, the media to be developed is an augmented reality-based physics module on circular motion material which will be presented in the form of a printed module. The module format will be classified into three main parts, namely the opening section, the core section, and the closing section. After compiling the test, selecting the media and format, the next stage is to create a storyboard and prototype of the GEMAR module and application to be developed. The physics module is designed using the Canva application, while the GEMAR application is made using several software such as Blander, Vuforia, and Unity 3D.

3. *Develop*

Validity of Augmented Reality-Based Physics Module on Circular Motion Material

The validity of the physics module based on augmented reality on the circular motion material is obtained through the development stage which is reviewed by expert material validators, media expert validators, and language expert validators. Validation is carried out by providing a validation sheet with the aim that the physics module based on augmented reality on the circular motion material is assessed and given suggestions by the validator.

The learning media that has been created will then go through the development stage to produce the final product of the physics module based on augmented reality on the circular motion material that is suitable for use through the validation, revision, and response trial processes. The validation stage is carried out by 6 expert validators including 2 material experts, 2 media experts, and 2 language experts.

Material validation aims to determine the level of product validity in terms of content feasibility and presentation feasibility. The instrument used is a closed questionnaire consisting of 27 questions. The following is a table of material validation results can be seen in Table 4.

Table 4. Validation Analysis Results by Material Expert

No.	Aspect	Penilaian		Average Expert Percentage Assesment	Criteria
		Expert 1	Expert 2		
1.	Content Suitability	83%	71%	77%	Valid
2.	Presentation Suitability	77%	78%	78%	Valid
Average percentage (%)				77%	Valid

Validation conducted by material experts resulted in an average of 77% with a valid category. However, this feasibility aspect showed the lowest value (77%) compared to the presentation aspect (78%). According to validator comments, the low score was caused by the lack of integration between the explanation of the concept and real applications, the explanation of the concept was too long, and there were still parts of the material that were too theoretical and had minimal contextual illustrations. In response to this, the researcher made revisions by summarizing the material into important points, adding illustrations of circular motion applications in real life, and clarifying the use of technical terms with a glossary.

Media validation aims to determine the level of product feasibility from the graphic aspect, and the use of augmented reality technology. The instrument used was a closed questionnaire consisting of 29 questions. The following is a table of media validation results can be seen in Table 5. below:

Table 5. Results of Validation Analysis by Media Experts

No.	Aspect	Validator		Average percentage of experts (%)	Criteria
		Expert 1	Expert 2		
1.	Graphics	88%	88%	88%	Very valid
2.	Use of AR technology	92%	79%	85%	Very valid
	Average percentage of (%)			87%	Very valid

Validation by media experts obtained an average of 87% (very valid), with a slightly lower value for the AR usage aspect (85%). Input from the validator included the absence of an application usage tutorial, the absence of minimum device specifications, and inconsistencies in margins and color contrast. Improvements were made by adding a QR code on the front cover page of the module, adding a video tutorial and AR display screenshots, and adjusting the layout and color contrast. According to the media expert validator, the validation results of the augmented reality-based physics module on the circular motion material were declared very valid or very feasible to use with an average percentage of 87%. Each aspect of the material validation met the very valid criteria, with the graphic aspect getting the highest percentage of 88%. This shows that the visual elements in the evaluated module can increase the attractiveness, understanding, and readability of the material by students.

Language validation aims to determine the level of product feasibility in terms of straightforwardness, communicativeness, dialogicity, interactiveness, suitability to student development, suitability to language rules, and the use of terms, symbols, and icons. The instrument used was a closed questionnaire consisting of 14 questions. The following is a recapitulation of the assessment results from language experts regarding the development of an augmented reality-based physics module on the circular motion material, which can be seen in Table 6 below..

Table 6. Validation Analysis Results by Language Experts

No.	Aspect	Validator		Average percentage Expert	Criteria
		Expert 1	Expert 2		
1	Straightforward	80%	87%	83%	Very Valid
2	Communicative	80%	80%	80%	Valid
3	Logical and Interactive	80%	80%	80%	Valid
4	Suitability to student development	80%	80%	80%	Valid
5	Suitability to language rules	80%	80%	80%	Valid
6	Use of terms, symbols, and icons	80%	80%	80%	Valid
	Average percentage (%)			81%	Very Valid

Each component of the language validation meets the criteria of very valid, and the validation results of the augmented reality-based physics module on the circular motion material are stated to be very valid or very suitable for use with an average percentage of 81%. Some of the revisions made include writing units and improving sentence structures to make them more communicative. This is important because appropriate language plays an important role in avoiding scientific misconceptions in students (Hasby, 2018; Panjaitan et al., 2021).

Practicality of Augmented Reality-Based Physics Modules on Circular Motion Material

Practicality in the physics module based on augmented reality on the material of circular motion is obtained through the results of filling out the practicality questionnaire by students and physics teachers. After students and physics teachers know and study the module, a practicality test is carried out by distributing a response questionnaire.

In it, students and teachers are asked to assess the product being tested. The researcher conducted a small group trial on 15 grade XI IPA students and 2 physics teachers. The trial was carried out by providing a physics module product based on augmented reality on the material of circular motion and a questionnaire sheet. The purpose of this trial was to determine the practicality of the product developed by the researcher. Based on the questionnaire that had been distributed, the students' responses to the module can be seen in Table 7.

Table 7. Student Practicality Test Results

No.	Aspect	Average percentage of each aspect	Criteria
1.	Tampilan fisik	89%	Sangat Ptaktis
2.	Teknik Penyajian materi	88%	Sangat Praktis
3.	Bahasa	88%	Sangat Praktis
4.	Penggunaan teknologi *augmented reality*	89%	Sangat Praktis
Average percentage (%)		88,5%	Sangat Praktis

The modules and applications that have been developed by researchers fall into the practical category as seen in small group trials. When getting to know and studying the module, many students gave positive responses when using the module. Positive responses in this case can be seen that students are enthusiastic about using the GEMAR module and application. This is because the use of augmented reality in class increases the motivation and involvement of students who are familiar with technology (Ibanez & Delgado-Kloos, 2018). After getting to know and studying the modules and applications developed, researchers distributed student response questionnaires to see the level of practicality of the product.

Based on the results of the trials conducted by students, the five elements are categorized as very practical: physical appearance of 89%, material presentation techniques of 88%, language of 88%, and the use of augmented reality technology of 89%. percentage of practicality value.

From the results of the response test, it can be seen that the highest percentage is in the aspect of physical appearance and the use of augmented reality technology. This shows that the visual elements in the module are considered to be able to increase the attractiveness, understanding, and readability of student materials and can improve the quality of learning. This is in accordance with research conducted that augmented reality-based modules train students' skills, train students to learn independently, make students enthusiastic and more motivated to participate in learning activities (Ilhamsyah et al., 2018). In addition, augmented reality provides an interactive experience for users to interact with 3D virtual objects in the real world (Kruger et al., 2019).

The results of the response test with these students show that the use of augmented reality technology in physics learning is very likely to solve learning problems. This is due to the fact that teachers must more easily provide students with an understanding of abstract physics concepts and make learning easier and more enjoyable. Conventional media is less effective in motivating students, so augmented reality learning offers a better alternative for understanding concepts (Karlina et al., 2021).

Next, the module was introduced to physics teachers. After teachers were familiar with and studied the module from various aspects, teachers were asked to provide an assessment of the module by filling out a questionnaire to determine the practicality of the module developed from the aspects of physical appearance, material presentation techniques, language used, and the use of augmented reality technology. At the educator response stage, it was carried out by two physics subject teachers. The instrument used was a closed questionnaire consisting of 37 questions. The following is a recapitulation of the results of educator responses regarding the development of an augmented reality-based physics module on the material of circular motion which can be seen in Table 8 below:

Table 8. Teacher Practicality Test Results

No.	Aspect	Teacher Response		Average Percentage	Criteria
		Teacher 1	Teacher 2		
1.	Physical appearance	87%	100%	93%	Very practical
2.	Material presentation techniques	81%	87%	84%	Very practical
3.	Language used	93%	87%	90%	Very practical
4.	Use of augmented reality technology	90%	82%	86%	Very practical
	Average percentage			88%	Very practical

Based on the results of the teacher response test, it can be seen that the percentage of the physical appearance aspect gets a percentage of 93%, the material presentation aspect gets a percentage of 84%, the language aspect gets a percentage of 90%, and the aspect of using augmented reality technology gets a percentage of 86%. These four aspects meet the criteria of being very practical, with an average practicality value of 88%. This means that they are very practical to use..

From the results of the teacher response test, it can be seen that the highest percentage is in the physical appearance aspect, so that the module looks attractive to students and teachers, this is also supported because the module is equipped with augmented reality images can increase students' interest in learning circular motion. Visual media makes it easier for students to improve their memory of the material, in addition, visual media is a learning tool that can attract students' interest in learning activities (Yeni et al., 2024). In addition, intermediary media or the use of material and its absorption through hearing and sight allows students to acquire attitudes, knowledge, or skills.

On the other hand, from the results of the teacher and student response tests, the presentation aspect of the material both got the smallest percentage. In the results of the student response test, the percentage was 88.5%, while in the results of the teacher response test, the percentage was 84%. This is because the learning material is not in accordance with the thinking abilities of students, where the explanation of the material is too long. Therefore, a revision of the module was carried out so that the material in the module becomes shorter and easier for students to understand. Based on the questionnaire and interviews, students stated that the module was easy to use even without verbal guidance from the teacher, the AR feature made it easier to understand abstract concepts that were difficult to visualize only through text, the module was interesting because it presented content with lots of pictures and animations. The teacher said that the module was effective for use as an

independent teaching aid, saving time explaining complicated concepts, especially in explaining the direction of motion, centripetal acceleration and angular velocity, but it needed to be adjusted again in terms of the amount of text to suit the level of student literacy. These comments and suggestions were used to make revisions such as simplifying the explanation of the concept and adding 3D motion illustrations in several parts of the module.

From initial observations, interviews and test results, it was found that students had difficulty understanding the velocity and acceleration vectors in circular paths, the relationship between wheel radius and angular velocity, and the differences between frequency, period and angular velocity. The AR feature in the module was specifically developed to visualize rotational dynamics, centripetal force direction and wheel relationship simulation. With AR, students can see the movement of objects in a circular path in real-time, apply the concept of relative motion in the rotation of two wheels, and connect physics concepts with phenomena such as vehicle wheels. This is in line with the findings that AR is very effective in improving students' spatial and conceptual understanding of the concept of rotation (Cheng & Tsai, 2020). Likewise, students find it easier to understand dynamic systems when supported by interactive AR visualizations (Yen et al., 2023).

This study strengthens the findings of developing AR for direct current circuit material and reports an increase in student understanding and interest (Ilhamsyah et al., 2018). AR increases interaction, collaboration, and learning motivation in STEM learning (Ibanez & Delgado-Kloos, 2018). Increasing students' self-efficacy in physics when using AR (Cai et al., 2021). The uniqueness of this study compared to previous studies is that the module combines printed and digital teaching materials, making it flexible for use in limited infrastructure conditions. AR can be accessed without an internet connection, simply by scanning the marker and using the GEMAR offline application. The module was developed based on an analysis of the needs of students and teachers, making it more adaptive to field needs.

CONCLUSION AND SUGGESTION

This study aims to develop and assess the quality of an augmented reality (AR)-based physics learning module on circular motion material for grade XI IPA students. The module development process is carried out through systematic instructional design stages, integrating AR technology to create a more interactive and contextual learning experience. The validation results show that this module has a high level of validity, with an overall average score of 81.67% (very valid category). Validation from material experts shows a level of validity of 77% (valid), media experts 87% (very valid), and language experts 81% (very valid). This indicates that the content, appearance, and language of the module have met the eligibility standards as teaching materials. In terms of practicality, this module is considered very practical to use by students and teachers, with scores of 88.5% and 88% respectively. This shows that the AR module is not only theoretically feasible, but also applicable in the real learning environment. The use of augmented reality technology in this module is an important innovation in 21st century science learning, because it allows students to visualize the concept of circular motion in a more realistic and interesting way, thereby increasing engagement and in-depth understanding of the concept.

For teachers, this module can be used as an alternative interactive teaching material to enrich learning strategies in the classroom. For media developers, the AR approach can be expanded to other physics topics or other subjects that require visualization of abstract concepts. For further researchers, it is recommended to conduct a broad effectiveness test to see its impact on improving students' learning outcomes and critical thinking skills.

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