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Development of Augmented Reality-Based Digital Teaching Materials on Optical Instruments to Enhance Conceptual Understanding and Project Skills

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ABSTRACT

Students often struggle with conceptual understanding and project-based skills in physics, particularly in abstract topics such as optical instruments. Traditional teaching methods and limited visualization tools contribute to these difficulties. This study addresses the need for innovative instructional resources by developing digital teaching materials integrated with Augmented Reality (AR) to enhance learning outcomes. This research employed a Research and Development (R&D) approach following the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation). Instruments included a needs analysis questionnaire, expert validation sheets, and student practicality questionnaires. Descriptive statistics were used to analyze the data, with validation assessed using Aiken's V and practicality evaluated using a Likert scale. The developed digital teaching materials underwent expert validation across five components: material substance, visual communication, learning design, software utilization, and AR integration. The average Aiken's V score was 0.94, indicating high validity. Practicality testing with 35 grade XI students yielded an average score of 96, categorized as "very practical," showing the teaching materials were easy to use, engaging, and beneficial for learning. The findings support the potential of AR-based teaching materials to address conceptual gaps and foster student engagement. While validity and practicality were confirmed, further research is needed to measure effectiveness in improving learning outcomes. The AR-integrated digital teaching materials are valid and practical for supporting students' conceptual understanding and project skills in optical physics. These materials represent a promising tool for modernizing physics instruction in secondary education.

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1. INTRODUCTION

Education in the 21st century has undergone a significant paradigm shift. Today, the main emphasis is no longer on simply conveying information, but on fostering deep conceptual understanding in learners. Students are required to go beyond memorization, with the ability to decipher, apply, and analyze subject matter. Solid mastery of concepts is a crucial prerequisite for students to be actively involved in solving complex problems, an ability that is highly relevant to the demands of the ever-changing and uncertain modern world. Therefore, quality education must facilitate students in building links between concepts and integrating them with the context of everyday life. Within this framework, the role of the teacher becomes vital in creating meaningful and challenging learning experiences. The effectiveness of learning is not only measured by how much information students can gather, but mainly by their ability to develop a deep understanding of the material. Deep understanding allows students to connect concepts, think critically, and apply knowledge in a variety of situations, so that learning outcomes become more meaningful and long-lasting. (Brainard & Britten, 2023; Hidayat & Haryati, 2025).

In addition to concept mastery, 21st-century students are also required to have skills in carrying out real projects or tasks collaboratively. The importance of project skills in project-based learning cannot be underestimated, especially in the context of 21st century education. Project skills cover several important aspects in preparing students to meet the demands of a dynamic modern world (Fikri, 2020). Project-based learning provides students with contextualized learning experiences that relate directly to the real world. Through projects, students not only understand concepts theoretically but also apply them in real-world situations, enhancing their understanding and the relevance of the subject matter. This approach is in line with the shift towards practical and experiential learning that better equips students for the challenges they will face outside the classroom.

One of the subjects suitable for implementing project-based learning is physics. Project-based learning in physics not only helps students understand physics concepts more deeply but also develops important practical skills and problem-solving skills (Katolik & Mandira, n.d.). Physics plays an important role in human life and can be applied in everyday situations, making it a basic science that supports more focused education. Therefore, it is important for students to master the concepts in physics learning. Physics learning, especially in optics, often faces challenges due to its abstract nature. Optical concepts are difficult to understand without adequate visualization, resulting in low student achievement. This is in line with the opinion of (Amrullah, 2015), physics courses are abstract so that it is difficult for students to understand because of its relationship with physical events. To make it easier for students to understand the material presented by the teacher, a theoretical proof is needed. In the process of proving and understanding a theory, a clear illustration of the case under study is needed. Concept mastery in physics is very important to improve student understanding.

However, the actual situation in the field is different from the expected conditions. The main problem comes from students' inadequate understanding of physics education. This is consistent with several studies that show the difficulties students face in understanding physics learning. Data shows that students' physics learning outcomes on the topic of optical instruments tend to be low and the average national exam score for this material continues to decline below the passing standard. One of the studies conducted by (Hafi & Supardiyono, 2018), revealed that many students find it difficult to understand physics subjects. The teaching and learning process mainly relies on textbooks, and students are then assigned to solve various problems, mainly focusing on formulas. This approach makes it difficult for students to understand the material presented to them. This is evidenced by the student difficulty level of 78.2% in understanding physics concepts.

Based on these problems, a solution that can be provided is through the development of digital teaching materials with Augmented Reality (AR) to improve students' concept understanding and project skills. On the topic of optical devices that tend to be abstract, teaching materials that utilize AR technology are needed to support more effective and efficient learning. AR is able to display interactive 3D visualizations, thus helping students understand abstract concepts more concretely and attracting their interest in learning. This is one way AR overcomes the challenge of explaining physics concepts that are difficult to convey directly and makes abstract concepts such as the optical system of the eye, refraction of light, and color mixing more concrete and easier to understand (Liu et al., 2024). AR technology can enhance realistic physics learning, and the use of ICT can facilitate students in developing their thinking skills (Asrizal et al., 2022). The use of AR in learning optics is proven to improve student understanding and provide a more effective and enjoyable learning experience (Saputri & Asrizal, 2023).

There are two theories connected to the improvement of digital learning materials. The primary hypothetical viewpoint of this arrangement is related to digital learning materials. Digital learning materials are an innovation that contributes significantly to changing the learning process, where learning is no longer just listening to the teacher's explanations but also involves students in various activities such as observing, doing, demonstrating, and more (Ratiyani et al., 2014). Systematic digital learning materials contain several elements such as exercises, work instructions or worksheets, competencies to be attained, supporting information, and assessments (Prastowo, 2015). Digital learning materials have several advantages compared to print materials. Digital learning materials make it easy for educators to explain abstract concepts, transform the role of learners from passive to active, and make it possible for teachers and students to converse without being constrained by time, place, or distance (Sanaky, 2013).

The second theoretical perspective of this solution is related to AR technology. With augmented reality (AR) technology, virtual things can be superimposed simultaneously on the physical world (Meilani, 2018). The use of AR is intended to construct a new environment, either directly or through the use of a medium, ultimately causing users to perceive the environment they create as reality (Indrawaty et al., 2014). AR technology serves in the process of delivering a message to its users. AR has several development methods (Martono, 2011). There are two types of methods developed, namely Marker-Based Tracking and Markerless AR. A technique called "marker-based tracking" needs markers, which are often images in black and white. With markerless AR, users can immediately display virtual objects without the use of markers or photos. (Lazuardy, 2012). With the use of devices like webcams, PCs, Android smartphones, or special glasses, augmented reality technology can add certain information to the virtual environment and display that information in the actual world (Mauludin et al., 2017). In the field of education, AR is widely utilized as a research tool in laboratories and can also serve as a learning medium in classrooms (Lazoudis et al., 2011).

Previous studies have proposed various approaches to the development of digital teaching materials. For example, Wulandari et al. (2020) explored the use of augmented reality (AR) applications to enhance students' conceptual understanding and creative thinking skills. Similarly, Sugiarto (2022) investigated the effectiveness of AR-based Assembler Edu Media in improving comprehension of the circulatory system. Aryanta (2021) focused on the development of Physics BUGAR to support students' conceptual understanding in physics. While these studies contributed valuable insights, they also exhibit certain limitations. Importantly, they serve as foundational references for the present research due to their shared emphasis on digital teaching materials and the improvement of conceptual understanding.

The current study seeks to address gaps in previous research by introducing several key innovations. First, the digital teaching materials developed in this study are enhanced with AR technology and specifically designed for use on smartphones. Second, unlike prior work, the instructional content focuses on optical physics. Third, the materials are designed not only to strengthen conceptual understanding but also to foster students' project-based learning skills. Additional innovations include the integration of interactive features such as animations, which aim to enhance student engagement and promote active learning.

The development of digital teaching materials on optical media with Augmented Reality (AR) is an important part of improving learning effectiveness, helping students understand complex concepts in a more visual and practical way. Interest in utilizing AR technology for digital teaching materials on optical media is in line with the opening of new opportunities to create innovative and effective learning experiences. AR technology in digital teaching materials on optical media can present information visually and interactively, create interesting teaching materials, motivate students, and support deeper understanding. Therefore, this study aims to develop and assess the validity and practicality of AR-based digital teaching materials for optical instrument topics."

2. METHODS

The type of research employed is Research and Development (R&D). The research and development method is a scientific approach to investigate, plan, produce, and test the validity of the resulting product (Sugiyono, 2019). This study utilizes the ADDIE development model, with development stages including analysis, design, development, implementation, and evaluation (Branch, 2010). The outcome of this development is a digital teaching material for optical material with AR, designed to enhance students' conceptual understanding and practical skills. The stages of the ADDIE development include:

2.1 Analysis

Needs analysis is conducted by identifying requirements in the development of digital teaching materials. Activities undertaken in this stage include analyzing issues in physics learning, examining student characteristics, and analyzing problems related to the topic of optical instruments. The analysis of learning issues is associated with constraints in utilizing Information and Communication Technology (ICT) in teaching materials. The analysis of student characteristics involves considering background, learning interests, motivation, and learning styles. The analysis of problems related to optical instruments is based on the students' annual national exam scores. The results of this analysis form the basis for designing appropriate learning solutions (Cahyadi, 2019).

2.2 Design

The second stage is the design phase. This stage aims to facilitate the process of developing a product. There are several stages of the process carried out in product design. These stages include designing digital teaching material components, designing digital teaching material content, designing digital teaching material interfaces, the design of AR objects, and the design of instruments. The components within the teaching material include a cover, profile, main menu, instructions, competencies, content, student worksheets, exercises, evaluations, bibliography, and AR camera. The content of the digital teaching material covers optical instruments in competency standards 3.11 and 4.11. Canva is the program used to develop the digital instructional material's interface. All of the instructional material designs will be brought together using Unity into a single application format after a good interface design has been achieved. A mature design will facilitate the process of developing learning products (Sugihartini & Yudiana, 2018).

2.3 Development

The activity carried out is the validation test to ensure the perfection of the developed digital teaching material. The product validation test aims to determine whether the developed product has been declared valid by experts, making it suitable for students to use in learning. This verification is called rational verification, as it is an evaluation based on rational thinking rather than facts in the field. The digital teaching material developed is validated by three experts. The selection of experts in the validation process aims to ensure that the products developed have adequate content, construct, and display quality. Experts were selected from physics lecturers for material, media, and language validation. After initial validation, revalidation is carried out if there are suggestions or criticisms from experts to assess the quality of digital teaching materials. Products that have been validated by experts will then provide results that show weaknesses and deficiencies in the digital teaching materials.

2.4 Implementation

This stage is carried out if the results of the expert test meet the criteria for acceptability. The implementation stage involves testing the practicality with users, namely physics teachers as learning practitioners and 11th-grade science students at MAN 1 Kota Padang in a small-scale trial, comprising 35 individuals. The trial with 35 students is included in the one-group trial or pilot testing, which aims to see: whether the media can be used properly by students, whether there are technical or pedagogical obstacles when used, and how students' initial responses to the use of AR media.

2.5 Evaluation

Evaluation is conducted to assess the effectiveness and quality of the product. Evaluation can be formative (during the process) or summative (after implementation). Evaluation results are used for further improvement and development (Adriani et al., 2020). The evaluation stage in ADDIE ensures that any weaknesses or shortcomings of the product can be identified and corrected, so that the final product is truly effective in improving students' concept understanding and project skills (Samsudin et al., 2021).

The ADDIE model was chosen in this study because it provides a systematic and structured framework for producing valid, practical, and effective learning products. ADDIE guides researchers through clear stages, starting from analyzing student needs and materials, media design, product development, classroom implementation, and evaluating product effectiveness (Kencana et al., 2021) (Nusroh et al., 2022). Each stage ensures that the resulting product is truly in line with learning needs and can be tested for feasibility in stages. This research is limited only to the implementation stage, due to limited time and energy. There were five instruments used to collect data in this study, which can be seen in Table 1.

Table 1. Research Instruments

Stages	Instrument Type
Needs Analysis	• ICT Constraints Questionnaire • Questionnaire of Student Characteristics • Literature Study Analysis related to the student national exam results on the topic of optical devices
Validity Analysis	• Digital Teaching Materials Validity Sheet
Practicality Analysis	• Practicality Sheet of Digital Teaching Materials (by teacher) • Practicality Sheet of Digital Teaching Materials (by students)

The data analysis technique used is descriptive statistics. The needs analysis, validity test analysis, and practicality test analysis results were processed using descriptive statistical analysis so that tables or graphs could be displayed. A tabular study of the barriers that instructors face when integrating information and communication technology (ICT) into their lesson plans is provided. Graphics are used to analyze student characteristics, difficulties with optical instrument material, validity tests, and practicality tests. A Likert scale with scores 1 to 5 is used in the assessment of this study. The five scores represent each category defined as follows: 5 means Strongly Agree (SA), 4 means Agree (A), 3 means Neutral (N), 2 means Disagree (D), and 1 means Strongly Disagree (SD). The validity test results obtained were analyzed using the Aiken's V equation, where a value ≥ 0.6 is included in the valid category and a value <0.6 is included in the invalid category (Azwar, 2015). The results of the practicality test obtained were analyzed descriptively quantitatively with a value of 0-20 indicating the category of less, a value of 21-40 indicating the category of less than satisfactory, a value of 41-60 indicating the category of satisfactory, a value of 61-80 indicating the category of good, and a value of 81-100 indicating the category of very good (Riduwan, 2010).

3. FINDINGS AND DISCUSSION

3.1 Findings

3.1.1 Needs Analysis Results

The analysis of learning issues describes the problems encountered during the learning process. Learning issues at MAN 1 Kota Padang are related to constraints in utilizing Information and Communication Technology (ICT) in teaching materials. This instrument was completed by two Physics teachers at MAN 1 Kota Padang. The indicators used include constraints in creating digital teaching materials, difficulties in mastering digital teaching materials, challenges in using software, difficulties in creating digital teaching materials using software, and challenges in using digital teaching materials for learning. The results of the analysis can be seen in Table 2.

Table 2. Results of Analysis of Constraints in the Use of Digital Teaching Materials

Indicator	Value
Difficulty in Creating Digital Teaching Materials	84
Difficulty in Mastering Digital Teaching Materials	78
Difficulty in Using Software	88
Difficulty in Creating Digital Teaching Materials Using Software	88
Difficulty in Using Digital Teaching Materials for Learning	75

Table 2 presents the analysis of teachers' difficulties in utilizing ICT for developing and implementing digital teaching materials, with data ranging from scores of 75 to 88. The findings indicate five key areas of challenge.

First, teachers struggle with the creation of digital teaching materials, including difficulties in converting content into digital formats, documenting administrative tasks digitally, developing tutorial-based learning content, and presenting materials in electronic form. Second, teachers face challenges in mastering digital teaching materials. These include difficulties in engaging with digital modules, worksheets, and discussion forums, as well as implementing exercises in digital formats.

Third, significant obstacles are evident in the use of software, particularly in terms of internet access, understanding and operating new software, and utilizing available digital tools effectively. Fourth, teachers encounter challenges in using software to create digital teaching materials. Many have limited experience with such tools, lack awareness of the latest software options, struggle to identify appropriate tools, and face difficulties using advanced features to produce interactive content.

Finally, teachers experience challenges in applying digital teaching materials in instructional settings. These include difficulties in integrating them into the learning process, presenting content effectively, facilitating student understanding, and conducting assessments.

Overall, the data suggest that teachers experience considerable constraints in utilizing ICT effectively for teaching material development and instructional use.

The results of the second needs analysis are the analysis of student characteristics. The analysis of student characteristics includes four indicators. The four indicators include background (BG), learning interest (LI), learning motivation (LM), and student learning style (LS). Student characteristics data were obtained from the characteristic questionnaire instrument given to 35 grade XI students. The results of the analysis of student characteristics can be seen in Figure 1.

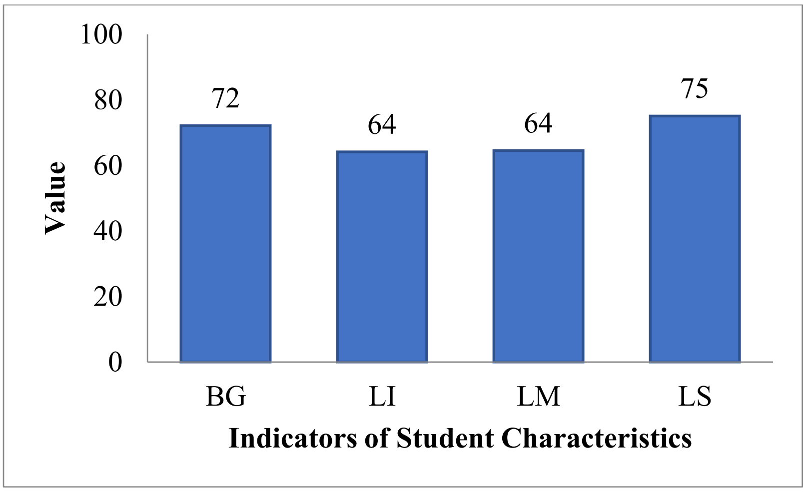

Figure 1. Results of Student Characteristics Analysis

Based on Figure 1, the characteristics of 35 students in physics learning can be seen. The results of the analysis show that student characteristics are in the range of values between 64 and 75. Indicators of students' backgrounds and learning styles were categorized as good. Meanwhile, the indicators of students' interest and motivation to learn were categorized as moderate. These data show that internal factors have not fully supported students in the physics learning process. Student learning motivation is closely related to student learning interest. The higher the student's learning motivation, the higher the learning interest. The student's background influences the student's learning style. Learning style is related to how students understand the learning process. Overall, student characteristics in learning influence students' understanding and conceptual skills.

The third result of the needs analysis is a problem related to the optical instrument material. The results of the optical instrument material problem were obtained from a literature review. The literature review focused on the National Examination (UN) physics scores at MAN 1 Padang, especially on the optical physics material. The UN scores collected are the average percentage at each level, starting from the educational unit, district/city, province, to national. The time span of the UN score data analyzed covers 2015-2019. The percentage of correct answers on the UN physics optics material among students at MAN 1 Padang can be seen in Figure 2.

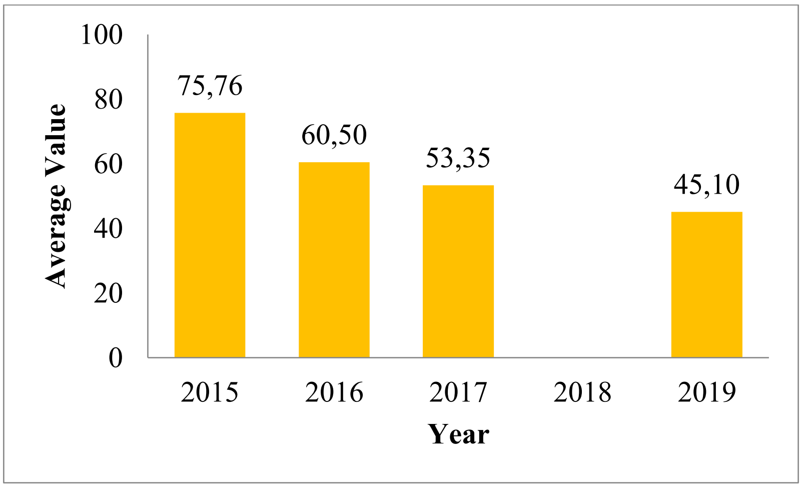

Figure 2. Physics National Examination Scores for Optics Content

The data in Figure 2 shows that the average value of the National Exam (UN) in physics on optical material continued to decline from 2015 to 2017, so that it no longer met the standard of graduation achievement. In the 2018 UN, optical material was not tested in the questions so there was no average value that year. Optics was again included in the UN questions in 2019. The scores in this year continued to decline from previous years and did not meet the graduation achievement standards. This indicates a problem in students' understanding of optical materials.

3.1.2 Validity Test Results

The next research result is the result of the product validity test. The digital teaching materials that have been developed are validated by experts to test their level of validity. The digital teaching material validation instrument is a questionnaire consisting of five components. The five components include material substance (MS), visual communication (VC), learning design (LD), software utilization (SU), and AR utilization (AU). Validation data were obtained from the validity test by experts on digital teaching materials on optical material with Augmented Reality (AR). The product validation results are shown in Figure 3.

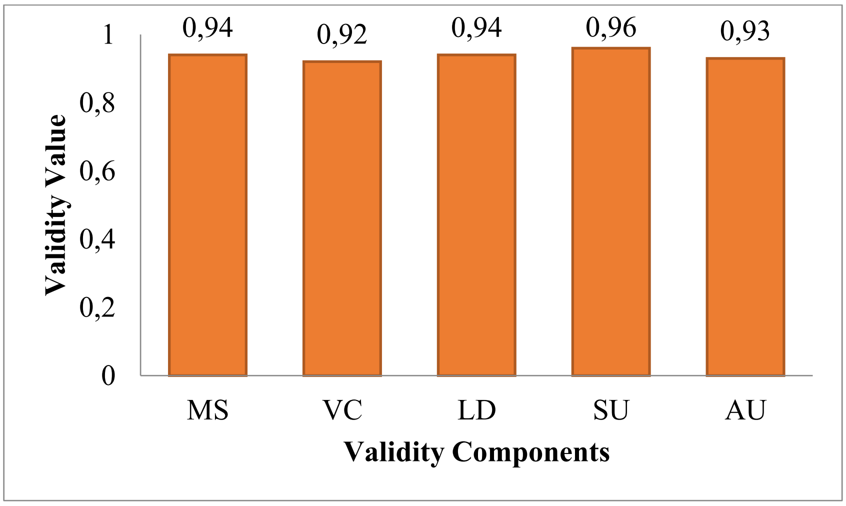

Figure 3. Product Validity Results

Based on the data analysis in Figure 3, it can be explained that the results of the validity of digital teaching materials are obtained from the five validity components. Aiken's V values for the five components, which include material substance, visual communication, learning design, software utilization, and AR utilization, range from 0.92 to 0.66 which are included in the valid category. Indicators of the material substance components include 1) accuracy, 2) material coverage, 3) relevance, and 4) readability. Indicators of the visual communication components include 1) navigation, 2) typography, 3) media, 4) color, 5) animation, and 6) layout. Indicators of the learning design components include 1) title, 2) basic competencies, 3) learning objectives, 4) material, 5) sample questions, 6) exercises, 7) worksheets, 8) authorship, and 9) bibliography. Indicators of the software utilization components include 1) interactivity, 2) supporting software, and 3) originality. Indicators for AR utilization components include 1) AR characteristics and 2) AR advantages. Based on the results of data analysis of the five components, an average Aiken V value of 0.94 was obtained, with a valid category. This indicates that the validity of the digital teaching material on optical instruments with AR is in the valid category and suitable for use in learning.

The next research result is the design of digital teaching material products on optical instrument material with AR to improve students' understanding of concepts and project skills. This digital teaching material is designed using Unity and Blender software. In addition, the development of digital teaching materials also utilizes Vuforia in creating AR technology. The design of digital teaching materials on optical instrument material with AR is based on the structure of written teaching materials. The digital teaching materials developed can be illustrated in Figure 4.

(a) (b)

Figure 4. (a) Cover Design, (b) Main Menu Design

Based on Figure 4, the design of this digital teaching material consists of a cover and a main menu. The cover of the digital teaching material includes the title, content, and the class to be studied, which is the 11th grade of high school. The cover also features play, exit, and audio buttons. The main menu includes options for instructions, competencies, material, worksheets, exercises, evaluations, references, and animations in the form of an AR camera. The instructions section contains learning and AR camera usage instructions. The competencies section includes core competencies, basic competencies, achievement indicators, learning objectives, and concept maps. In the material section, there are several subtopics on optical instruments and example questions for each subtopic. The worksheets section contains four steps for creating a project on simple optical instruments. The exercises section includes essay questions for students to work on. The evaluation section contains 20 multiple-choice questions to be tested on students. The reference section contains sources relevant to the development of digital teaching materials. The AR camera is interactive so that students can interact directly through 3D animations produced by AR technology through the AR camera.

To produce high-quality digital teaching materials, validators provided several suggestions and inputs for the improvement of the digital teaching material. There were several suggestions from validators used as an initial step in refining the digital teaching material for learning. First, the AR objects were deemed insufficient, prompting the addition of more AR objects to make the digital teaching material more comprehensive. Before the improvement of the product, the digital teaching material on optical instruments had only two AR objects, namely the process of image formation in the eye and the process of image formation in a microscope. Based on the validator's feedback, two additional AR objects were developed for the digital teaching material, depicting the process of image formation in individuals with hypermetropia and myopia. As a result, the AR objects in the digital teaching material on optical instruments were expanded to include four AR objects. Second, the navigation within the digital teaching material was considered lacking, necessitating the addition of navigation in several sections, particularly in the evaluation section. Before the product improvement, the evaluation component was designed without previous or next buttons because, when an evaluation question was answered, it automatically progressed to the next question. This was implemented to ensure that students completed the entire evaluation. In this improvement, navigation added was specifically to return to the main menu. The refinement of the digital teaching material on optical instruments, in line with the feedback and suggestions from validators, will result in a better teaching material.

3.1.3 Practicality Test Results

The validated digital teaching material then underwent a practicality assessment, which was filled out by 35 students from XI IPA 2 MAN 1 Kota Padang. The instrument used in this stage was a practicality instrument in the form of a questionnaire comprising six indicators. These indicators include benefit (BN), easy to use (EU), attraction (AT), clarity (KR), and cost efficiency (CE). The results of the practicality test by students can be illustrated in Figure 5.

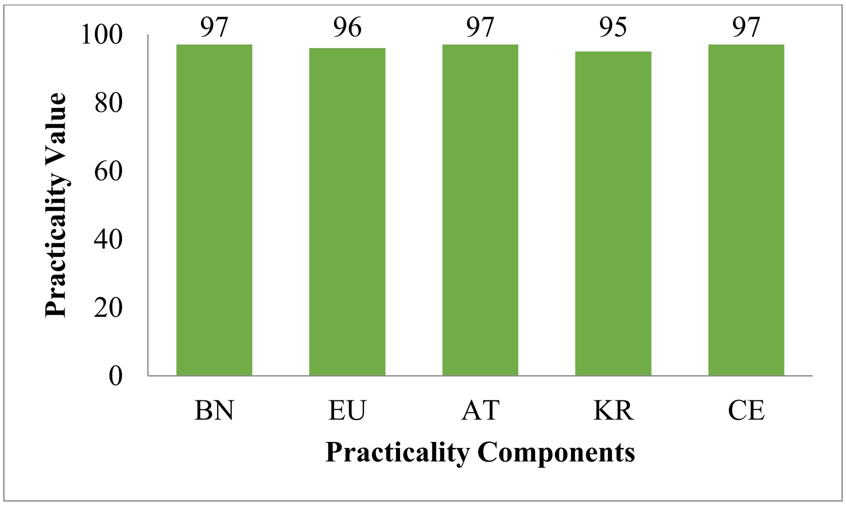

Figure 5. Results of Product Practicality

Figure 5 shows that the scores for each component of practicality, as assessed by 35 grade XI students of MAN 1 Padang City, fall into the 'very good' category, ranging from 95 to 97. Thus, the digital teaching materials developed proved to be useful, easy to use, interesting, clear, and cost-effective in the learning process.

3.2 Discussion

The first achievement in this research pertains to the needs analysis. The initial needs analysis involves examining issues in learning related to teachers' challenges in utilizing Information and Communication Technology (ICT). The integration of technology in education is crucial as it offers positive impacts. Students and teachers can save time in the learning process through the use of digital teaching materials, cut expenses, minimize paper usage, and help individuals acquire technological proficiency as demanded by 21st-century education (Rindaryati, 2021). Additionally, digital teaching materials enhance the learning experience by improving student engagement and making learning interactive through the inclusion of images, videos, audio, and hyperlinks (Sriwahyuni et al., 2019). The second needs analysis involves examining student characteristics. The lower knowledge scores of students are influenced by their lack of interest and motivation in studying Physics. Physics is perceived as less appealing, leading to reduced interest among students. However, considering students' learning styles, especially those who enjoy experiments and discussions, provides an opportunity to explore alternative solutions. Understanding students' characteristics allows teachers to select appropriate learning resources and create engaging classroom environments tailored to students' learning styles. By involving students directly in discussions and experiments, teachers can make learning more interactive. Thus, a viable solution is needed to enhance students' interest and motivation in learning, ultimately improving their knowledge scores. The development of digital teaching materials on optical instruments with Augmented Reality (AR) in the form of a smartphone-accessible application presents a solution to address these challenges.

The second outcome achieved in this study concerns the validity of the developed digital teaching materials on optical instruments with Augmented Reality (AR). Validity, derived from the word 'validitas' in Indonesian, refers to authenticity. Product validity is a process to test the authenticity of the developed product through assessments provided by several experts (Sudjana, 2002). The components of the validity assessment instrument must be relevant and consistent with the theories used in developing digital teaching materials. The validity of the digital teaching materials on optical instruments with AR was assessed by three experts, considering four components: material substance, learning design, visual communication display, and software utilization (Direktorat Pembinaan SMA, 2010). Another added component in the validity assessment is the utilization of AR. The validity of material substance includes accuracy and symbols, completeness of material presentation, information up-to-dateness, and adherence to the rules of proper Indonesian writing. The validity of visual communication display entails having clear navigation buttons and engaging animations to create an interactive and attractive learning atmosphere. The validity of learning design involves a design that incorporates components of digital teaching materials. The validity of software utilization ensures that the materials are developed using supporting software that enhances student interactivity and includes evidence as proof of the originality of the teaching materials (Pratiwi & Jasril, 2020). The validity of AR utilization assessment involves characteristics and advantages of AR. The developed digital teaching materials were deemed valid and suitable as they met the criteria of the five indicators for digital teaching materials' validity.

The third outcome achieved in this research is the practicality of the digital teaching materials on optical instruments with Augmented Reality (AR) in enhancing students' conceptual understanding and project skills. Practicality testing was conducted on 35 students from class XI IPA 2 at MAN 1 Kota Padang. The practicality assessment aimed to determine students' responses to the feasibility and practicality of using digital teaching materials on optical instruments with AR. The practicality of the teaching materials was measured based on several indicators, including benefits, ease of use, attractiveness, clarity, and cost efficiency. The practicality of teaching materials needs to be assessed to determine their usefulness. Practicality refers to the attractiveness of digital teaching materials due to their engaging appearance, complemented by animations and videos (Fajriati & Putra, 2023). The efficiency of electronic teaching materials is evaluated based on the flexibility to be used anytime and anywhere, as well as the effective and efficient use of time during learning (Sari & Atmojo, 2021). Electronic teaching materials provide students with the opportunity to learn independently (Asrizal et al., 2020). The digital teaching materials on optical instruments with AR were rated as very practical in the excellent category. This indicates that in general students find this teaching material easy to use, interesting, and useful in assisting the understanding of optical devices material. However, despite the high practicality score, it should be noted that students may still face challenges in accessing AR content, especially in environments with low internet connectivity or limited compatible devices. This is an important note for further development so that teaching materials can still be used in various infrastructure conditions.

In addition, the results of this study are in line with previous findings by (Wulandari et al., 2020), which showed that the use of AR media can increase student motivation and interest in learning. However, the development in this study has a further contribution, namely by integrating the project component into digital teaching materials. This provides a more active and contextualized learning experience, thus not only improving conceptual understanding, but also developing students' project skills in accordance with the demands of 21st century learning.

The limitations of this study need to be considered. First, the number of samples used in the pilot test was limited to 35 students, so the results cannot be widely generalized. Second, this study has not directly measured student learning outcomes such as increased concept understanding and project skills, but only focuses on validity and practicality.

Based on the obtained results, the developed product can be utilized in the physics learning process, specifically in the topic of optical instruments. The advantages of the digital teaching material on optical instruments with Augmented Reality (AR) include enabling students to be more active in learning, facilitating the learning process, making the taught material more engaging, aiding students in retaining the learning content, and assisting teachers in teaching while optimizing time in the learning process. The digital teaching material on optical instruments with AR can serve as a primary learning resource in physics education. This aligns with the research findings, demonstrating that the digital teaching material on optical instruments has been validated and proven practical for implementation.

4. CONCLUSION

This research revealed three main significant findings. First, the results of the needs analysis showed the existence of real challenges in physics learning, namely the low integration of technology by teachers, the lack of student motivation and interest, and the achievement of student learning outcomes on the topic of optical devices that are still below standard. This finding reinforces the urgency of developing innovative and relevant digital teaching materials. Second, the development of Augmented Reality (AR)-based digital teaching materials is declared valid in content and design, as indicated by the results of expert validation. This validity confirms that the developed media has met the pedagogical, visual, and technological standards required for use in the learning process. Third, from the results of the limited trial, this digital teaching material proved to be very practical to use by students. This shows that the product is not only theoretically feasible, but also functional and well received by direct users, namely students. This finding has important implications: AR-based digital teaching materials can be an effective tool to increase students' learning motivation and conceptual understanding, as well as encourage project skills as part of 21st-century competencies. Future research is recommended to develop similar teaching materials in various physics topics and conduct effectiveness tests on a wider scale in order to strengthen their impact in a more general educational context.

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