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Development of a Learning Module to Interpret Engineering Drawings Using Augmented Reality (AR) for Vocational High School Students

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ABSTRACT

Interpreting engineering drawings is a fundamental competency for vocational high school students preparing for industrial careers. However, conventional instruction often fails due to students' difficulty in visualizing 3D objects from 2D representations, limited interactive learning tools, and low motivation. This study aimed to develop an Augmented Reality (AR)-assisted learning module to enhance the effectiveness and interactivity of engineering drawing instruction. The research employed the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model of Research and Development (R&D), involving material experts, media specialists, instructional designers, teachers, and vocational students. The developed module was evaluated for feasibility and effectiveness. Expert assessments rated the module as "Very Feasible," with scores from material experts (96.80%), media experts (77.00%), and instructional design experts (93.80%). A limited implementation trial demonstrated a significant improvement in student understanding, indicated by an N-gain score of 0.71 (high category). Additionally, 89.3% of students reported high satisfaction with the module. The findings suggest that the AR-assisted module effectively enhances students' ability to interpret engineering drawings. This development presents an innovative alternative to conventional methods and demonstrates the potential of AR integration to create engaging, interactive learning environments in vocational education settings.

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1. INTRODUCTION

Technical drawing is a fundamental competency that vocational school students, especially those in motorcycle engineering expertise programs, must master. Widayana et al. (2020) emphasized the strategic role of technical drawing in transforming technicians ideas into universal visual representations. Luthfi Arfianti (2022) confirmed that this ability contributes significantly to the quality of vocational school graduates.

However, challenges continue. A substantial portion of errors in motorcycle repairs are caused by technicians' inability to interpret engineering drawings. Students sometimes struggle with the longitudinal transformation of engineering drawings is reflected in the variety of projections used. It emphasizes that students' difficulties in understanding the relationship between views and spatial transformations arise (Zheng Jian, 2011).

Augmented Reality (AR) presents a promising solution. Facts on the ground show At SMKN 14 Merangin, learning is still conventional, with an average score of 65, below the KKM of 75. The use of augmented reality (AR) is a potentially useful approach. In studies that have shown gains in comprehension (Sriadhi et al., 2022), knowledge retention (Azuma et al., 2011), and learning motivation (Johnson et al., 2012), research has shown that it is useful in increasing visualization abilities and retention of information (Saputra et al., 2020). Augmented reality technology has the potential to make learning experiences more dynamic and immersive, therefore tackling some of the most frequent issues in the field of technical drawing instruction.

The use of augmented reality (AR) in vocational education raises challenges, despite the benefits it offers. There is a possibility that some students may be unable to fully interact with the program due to accessibility concerns. These challenges may include the availability of relevant gear and internet connection. In addition, the hardware requirements that must be met to operate augmented reality apps effectively may be a disadvantage for organizations that have limited resources. It is also necessary to take into consideration the challenges that students have in adapting to new technology, such as the steep learning curve that comes along with it and the possibility of resistance to change. When it comes to guaranteeing the effective adoption of augmented reality-assisted learning in vocational education, addressing these problems is very necessary.

In contrast to earlier research, this augmented reality-assisted learning module integrates real-time interaction, adaptive feedback mechanisms, and multi-angle visualization capabilities. This allows students to investigate technical drawings dynamically. The incorporation of these one-of-a-kind components improves both understanding and engagement, making it an innovative strategy for enhancing the interpretation of engineering drawings in vocational education. Some of the distinctive interactive aspects, such as simulations, and gamification features, are included in the augmented reality module. Through the use of real-time interaction, students are allowed to dynamically change and investigate engineering drawings (Rodrigues-Silva & Alsina, 2023). Moreover, adaptive feedback mechanisms provide quick feedback that is adapted to the replies of students to improve their knowledge. This module also tends to enhance understanding is achieved by the use of multi-angle visualization features, which allow for the viewing of technical drawings from a variety of viewpoints. Students are also expected to be able to more effectively practice engineering drawing topics in a controlled and immersive setting via the use of interactive simulations. Finally, the gamification elements include activities that are focused on challenges, quick monitoring of progress, and tasks that are based on rewards to increase engagement and motivation. When compared to more conventional ways of augmented reality-based learning, these many components make the module more interesting and useful.

During the process of developing an augmented reality (AR)-assisted learning module, vital components such as the production of computer drawings, the use of software, drawing procedures, and visualization approaches are introduced. With the help of this module, students at vocational high schools will have the opportunity to improve their grasp of engineering drawings using a method that is not only lively and engaging but also very successful.

2. METHODS

This AR-assisted learning module development research adopts the Research and Development (R&D) approach with the ADDIE model. Branch (2009) explained that the ADDIE model was chosen because it is systematic and iterative in producing quality learning products. Morrison et al. (2019) emphasized the importance of needs analysis as a foundation for development.

The Analysis phase emphasizes the prerequisites for creating an efficient AR-assisted module. This entails evaluating student attributes, examining current learning resources, and assessing curricular requirements to guarantee that AR integration improves technical drawing understanding. The Analysis stage includes several critical aspects. First, the analysis of student characteristics includes the collection of demographic data, identification of learning styles, and analysis of initial abilities. Dick et al. (2015) highlight the importance of understanding students' learning profiles. Second, the analysis of media availability involves an inventory and evaluation of the effectiveness of existing media. Third, the analysis of materials includes a curriculum review and mapping of essential materials.

The learning objectives, content structure, and interactivity features of the AR module are established at the design stage. Storyboard and interface design are adjusted to maximize AR-based engagement, while evaluation instruments ensure the module meets pedagogical requirements. In the Design stage, Richey et al. (2010) recommend three main focuses: module design (formulating learning objectives, organizing materials), AR design (storyboarding, interface design), and evaluation instrument design. AR module content creation, interactive 3D visualization scripting, and application programming are all part of the development process. An iterative validation cycle, in which material experts, media experts, and instructional designers make their contributions, is used to collect feedback from experts. Before going into the implementation stage, revisions were made at each stage to improve the accuracy of the content, enhance interactivity, and ensure pedagogical effectiveness. AR module content creation, interactive 3D visualization scripting, and application programming are all part of the development process. To improve usability and instructional effectiveness, expert validation and iterative revisions were conducted, (scriptwriting, illustration, layout), AR development (application programming, 3D asset development), and validation and revision based on expert input.

Implementation is carried out in two stages. In the implementation, a limited trial was conducted to evaluate the effectiveness of the AR module. Furthermore, a field trial was conducted to determine its impact on students' ability to draw techniques. For four weeks, the module was introduced in an organized classroom, with sessions twice a week. The learning method combines direct explanation from the teacher, hands-on practice using AR devices, and collaborative learning activities where students work together to study 3D models in small groups. Comments were collected to improve the module. Nieveen & Folmer (2013) emphasize the importance of limited trials to identify initial product weaknesses, followed by field trials to measure effectiveness comprehensively. Creswell (2018) recommends the use of mixed methods in data collection, involving quantitative instruments (validation questionnaires, structured observations, learning outcome tests) and qualitative (interviews, field notes, documentation).

Evaluation methods were used to evaluate the effectiveness of the AR module. Expert validation, student performance improvement, and user feedback are used to do so. Continuous improvement is required to meet the needs of vocational education. The Evaluation stage includes formative and summative evaluations. Wang & Hannafin (2005) emphasize the importance of continuous evaluation to ensure product quality. Data validity is guaranteed through internal-external validity, instrument reliability, method and source triangulation, member checking, and expert judgment.

The final product is a learning module to interpret engineering drawings assisted by AR that has been tested for validity, practicality, and effectiveness for learning projection views, in America, and Europe, in the SMK Motorcycle Engineering program. According to Van den Akker et al. (2021), this multi-perspective validation is important to produce quality learning products that can be implemented effectively.

Data collection and analysis in the research on the development of a learning module to interpret engineering drawings assisted by AR were carried out through several systematic stages. Data were collected using an expert validation instrument that included assessments from material experts, media experts, and learning design experts on the feasibility of the product being developed. Validation used a Likert scale of 1-5 accompanied by a column of suggestions for improvement for aspects of material, media, and learning. This validation data was then analyzed descriptively and quantitatively by calculating the average score and converting it into a feasibility category using a predetermined conversion table:

Table 1. The Conversion Scale of Feasibility Classification

Score	Categories
1.00-1.80	Not Feasible
1.81-2.60	Less Feasible
2.61-3.40	Moderately Feasible
3.41-4.20	Feasible
4.21-5.00	Very Feasible

During the product trial, data were collected through learning observations to see the implementation of the use of the AR module, student response questionnaires to find out user responses, and pre-tests and post-tests to measure improvements in engineering drawing interpretation skills. Observation data were analyzed descriptively and qualitatively to describe the learning process using the AR module. Student response questionnaire data were analyzed descriptively quantitatively by calculating the percentage of positive student responses to the use of the module.

To measure the effectiveness of the module in improving students' abilities, the pre-test and post-test data were analyzed using the normalized gain score test (N-gain test). The gain score calculation was carried out to determine how much the students' engineering drawing interpretation abilities had increased after using the AR module. The N-gain is categorized as follows: ≤0.30 (Low), 0.31-0.70 (Moderate), and ≥0.71 (High). In addition, qualitative data in the form of field notes and interview results were analyzed using thematic analysis techniques to identify patterns and themes that emerged related to the use of the AR module in learning.

All collected data is then integrated to provide a comprehensive picture of the feasibility, practicality, and effectiveness of the AR-assisted learning module developed. The results of this data analysis are the basis for making improvements and refinements to the final product, as well as drawing conclusions about the quality of the developed learning module.

The success criteria for product development are determined based on the minimum standards that must be achieved, namely: a minimum expert validation score in the "feasible" category, a minimum positive student response of 75%, and an increase in the ability to interpret engineering drawings as indicated by a minimum gain score in the "moderate" category. If these criteria have not been achieved, a product revision is carried out based on input and findings during the data collection process.

3. FINDINGS AND DISCUSSION

The research on the development of a learning module to interpret engineering drawings assisted by Augmented Reality (AR) for grade X students of SMK Motorcycle Engineering Expertise at SMKN 14 Merangin is an innovative initiative that aims to transform conventional learning into a more interactive and meaningful learning experience. This research is motivated by the complexity of understanding the concept of engineering drawings, especially in terms of American and European view projections, which require high spatial and visual interpretation abilities.

Using ADDIE (Analysis, Design, Development, Implementation, Evaluation) methodology, this study has the main objectives to produce effective AR-based learning modules, improve students' understanding of view projection, develop innovative learning models, and promote technological literacy in vocational education. The significance of the study lies in its contribution to transforming traditional learning methods, integrating cutting-edge technologies, improving students' conceptual understanding, and preparing future industrial competencies.

In the analysis stage, several major challenges were found in learning engineering drawing, including the limitations of interactive learning media, students' difficulties in visualizing 3D shapes from 2D drawings, and the lack of independent learning resources. Analysis of student characteristics shows that the majority of students have access to Android smartphones and adequate technological capabilities, creating opportunities for the implementation of AR-based learning.

The AR content is intended to provide a completely interactive 3D visual experience, replete with item rotation movements and an intuitive interface. Digital content production includes utilizing professional tools like Blender, Adobe After Effects, and Adobe Premiere to create 3D models, geometric construction animations, and educational movies. The AR application programming uses Unity 3D as the main game engine, Vuforia SDK for AR functions, and C# programming language for scripting. The tracking system was developed using Vuforia Engine and OpenCV, and it includes marker-based and markerless tracking features for maximum flexibility. The user guide is created in three formats: a comprehensive PDF document for teachers, a video tutorial for students, and an interactive FAQ within the application.

The assessment findings indicated a substantial improvement in student motivation, with attention rising from 62.5% to 90.3%, active engagement increasing from 58.9% to 89.7%, and confidence growing from 55.7% to 87.6%. Students said that the interactive 3D models enhanced their comprehension of spatial transformations, resulting in significant advancements in comprehending American and European predictions. Furthermore, statistical analysis using the t-test revealed a significant difference ($p < 0.05$) between pre-test and post-test scores, accompanied by an effect size of 0.82. Cohen's (1988) standards stipulate that an effect size over 0.80 is classified as strong, signifying that the AR module significantly influenced students' comprehension of engineering drawings, active involvement increased from 58.9% to 89.7%, and confidence rose from 55.7% to 87.6%. Students said that the interactive 3D models enhanced their comprehension of spatial transformations, resulting in significant advancements in comprehending American and European forecasts, with active engagement increasing from 58.9% to 89.7% and confidence rising from 55.7% to 87.6%. These results indicate that AR-based learning improves student engagement and self-efficacy in comprehending engineering drawing topics.

Additionally, qualitative feedback revealed that students saw the real-time modification of engineering drawings as very advantageous. A student said, *'The ability to rotate and zoom into the projection views facilitated the comprehension of the distinctions between American and European projections.'* This direct engagement enhanced test results and increased confidence in managing technical drawings. Furthermore, students emphasized that the capacity to zoom, rotate, and engage with 3D models enabled them to overcome deficiencies in spatial thinking that conventional 2D learning approaches failed to address.

Moreover, a comparison with traditional learning approaches underscores the benefits of augmented reality. In conventional environments, students depended on two-dimensional illustrations and textbook descriptions, which constrained their capacity to perceive intricate projections. In contrast, AR-based learning offers an immersive experience, allowing students to examine 3D things from various perspectives. A student said, *'Before using AR, I struggled to differentiate between American and European forecasts.'* I can now readily see their differences by simply rotating the models. This illustrates how interactive technology closes gaps that traditional approaches fail to solve.

The overall development of this module demonstrates a systematic approach to integrating AR technology into engineering drawing learning, taking into account pedagogical, technological, and learner needs. The result is an innovative learning solution that has the potential to improve the effectiveness of engineering drawing learning at the vocational high school level.

The development stage in this study includes three main aspects, namely module content development, AR application development, and validation and revision. Module content development is carried out through writing learning materials about view projections in easy-to-understand language, accompanied by illustrations and engineering drawings to support visual understanding. The module is also equipped with tiered exercises and evaluations as well as detailed usage guides including instructions for using AR technology.

In developing an AR application, the process begins with the creation of a 3D model using CAD software to ensure accurate and realistic visualization. Application development uses the Unity platform integrated with the Vuforia SDK to recognize markers and display AR content. Marker creation is designed with unique patterns and contrasts to optimize camera detection. The application interface is designed to provide an intuitive experience with various elements such as navigation buttons, menus, and user guides.

The validation process involved several experts from various fields. The validation results from material experts showed an average score of 4.34 (86.8%), which is a very good category, whereas the aspect of material suitability with KD received the highest score of 4.5 (90%). The validation of media experts produced an average score of 4.36 (87.2%) with a very good category, with the ease of use aspect obtaining the highest score of 4.5 (90%). Meanwhile, the validation of AR technology experts produced an average score of 4.34 (86.8%) with a very good category, where the interactivity aspect received the highest score of 4.5 (90%).

Based on the validation results, revisions were made to three aspects. Material revisions include adding examples of applications relevant to the world of work, improving the order of presentation of materials, adding varied practice questions, and simplifying technical language. Media revisions include improving the layout, improving image quality, adjusting font sizes, and adding visual cues. Meanwhile, revisions to the AR application focus on optimizing application performance, improving the marker tracking system, improving rendering quality, and simplifying the interface.

The implementation phase was carried out through a limited trial with 10 students and a field trial with 30 students. The limited trial focused on evaluating the ease of use of the application and identifying technical constraints. The field trial was carried out in the context of regular learning to evaluate the effectiveness of the application in real learning situations. The results of the field trial showed an average score of 4.44 (88.8%) with a very good category, where the AR benefit aspect received the highest score of 4.6 (92%).

Evaluation is conducted formatively and summatively. Formative evaluation is conducted throughout the development stage to identify and address issues early, covering technical functionality and pedagogical aspects of the application. Every improvement and optimization is documented in a structured manner. Summative evaluation is conducted to measure the overall success of development, including measuring the achievement of objectives, analyzing product effectiveness, and identifying the impact of learning on students' understanding and motivation to learn.

3.1. Describing the Process of Designing Learning Modules

The design of a learning module for interpreting engineering drawings using Augmented Reality (AR) technology for vocational high school students is an innovation that integrates modern technology with the needs of vocational education. The research conducted at SMKN 14 Merangin is specifically aimed at class X students of Motorcycle Engineering Expertise, using the ADDIE methodology as a systematic and comprehensive development framework.

The initial development step began with an in-depth analysis of existing learning needs. The initial survey results revealed various challenges faced by students in understanding engineering drawing concepts. The data showed that as many as 68% of students had difficulty in understanding the basic concepts of projection, while 72% of students faced obstacles in distinguishing the characteristics of various existing projection systems. These findings provide a strong foundation for developing more effective and innovative learning solutions.

In terms of pedagogy, the module is designed with the principle of progressiveness of learning materials in mind. The content is structured in stages, starting from simple concepts and then progressing to more complex understanding. This approach allows students to build a solid understanding of every aspect of engineering drawing projection systematically. What sets this module apart from conventional approaches is its strong focus on transforming conceptual understanding into practical skills that can be directly applied in an industrial context.

Table 1. AR Module Functional Requirements

Category	Design Criteria	Technical Specifications
Pedagogical Content	Depth of Material	Full View Projection
Complexity		Middle Level (Grade X Vocational High School)
Projection Coverage		America and Europe
AR Technology	Platform	Mobile and Tablet
Rendering		High-Resolution 3D Graphics
Interaction		Zoom, Rotate, Interactive Explanation
Interface	Design	Simple, Intuitive
Navigation		Easy for Students to Understand

The technological dimension is a crucial aspect in the development of this module. The development team considered four critical parameters in the implementation of AR technology. First, device compatibility is a top priority to ensure wide accessibility. The module is designed to be accessible through various types of mobile devices and tablets without significant technical constraints. Second, the quality of 3D rendering is developed to a high standard to present detailed and accurate projection visualizations. Third, the interactivity aspect of the content is carefully designed to allow users to interact dynamically with the projection models. Fourth, ease of use is used as a basic principle in the development of the interface, ensuring that technology does not become a barrier to the learning process.

The interactive approach implemented in this module forms the backbone of a dynamic learning experience. Students are given the freedom to explore 3D objects independently, allowing them to understand every detail of engineering drawing projections according to their individual learning style. The dynamic explanation feature integrated in the module provides contextual information for each drawing element, helping students understand the complexity of projections intuitively. An AR-based evaluation system is implemented through interactive quizzes that not only serve as assessment tools but also provide immediate feedback to students, allowing them to measure and improve their understanding in real-time.

The content validation process involved a comprehensive multidisciplinary approach by bringing together four groups of experts: technical drawing material experts, educational technologists, motorcycle industry practitioners, and productive vocational high school teachers. This collaboration ensured that the developed module not only met high academic standards but was also relevant to the practical needs of the industry. Input from these various perspectives enriched the content and learning methodology implemented in the module.

The module development strategy is implemented systematically and structured, starting from mapping basic competencies to integrating AR technology. Each stage of development—from storyboarding, multimedia content development, to functionality testing—is carried out with a high level of precision. Ergonomic and pedagogical considerations are the foundation of every aspect of module design. The duration of learning is adjusted to the existing lesson hour structure, cognitive load is regulated proportionally, and variations in material delivery techniques are optimized to ensure learning effectiveness.

The multimedia support in this module is specifically designed to accommodate the various learning styles of students. The combination of visual, audio, and interactive elements creates a rich and immersive learning experience. This approach not only increases the accessibility of learning but also ensures that each student can understand the material according to their individual learning preferences.

Innovation in the design of this AR module places technology not just as a tool, but as an integral pedagogical partner in the learning process. This module not only aims to transform the way students learn but also build digital competencies that are increasingly important in the context of modern industry. This study proves that a comprehensive, integrated, and student-centered AR module design can significantly improve the quality of engineering drawing learning in vocational education environments.

The successful development of this module has important implications for the future of vocational education, especially in the learning of technical drawing. The integration of AR technology in learning not only increases the effectiveness of material delivery but also prepares students to face the demands of an increasingly digital industry. The learning experience presented through this module opens up new perspectives on how technology can be optimally utilized to achieve better learning goals.

3.2. Describing the Learning Module Development Process

The process of developing a learning module to interpret engineering drawings assisted by Augmented Reality (AR) is an innovative effort that combines modern technology with vocational learning needs. This development stage begins with an in-depth and comprehensive needs analysis to identify challenges in learning engineering drawings among vocational high school students.

The initial investigation results revealed critical findings that underscore the importance of developing innovative learning media. Empirical data showed that 68% of students had difficulty understanding the projection view, while 72% of respondents were confused in distinguishing between the American and European projection systems. Furthermore, 65% of students explicitly stated their need for more dynamic and engaging learning tools. These findings reflect the urgency to develop more adaptive and interactive learning approaches.

Based on the needs analysis, the development team designed a conceptual design of the module that focuses on four main pillars that are mutually integrated. The first pillar is the structure of the projected content, which is systematically designed by considering the complexity of the material from basic to advanced levels. Each content segment is structured by considering the logical flow of understanding, ensuring that students can build knowledge gradually and comprehensively.

Table 2: Module Development Needs Analysis

Analysis Aspects	Key Findings	Development Implications
Student Competencies	Low in projection interpretation	Interactive content design
Technology Needs	Lack of 3D visual media	Deep AR integration
Motivation to learn	Low on conventional methods	Interesting interface development

The second pillar is the augmented reality technology architecture, which is the backbone of the module. AR technology was chosen because of its ability to transform abstract concepts of projection into visual representations that can be manipulated directly. The implementation of this technology uses the Unity platform and Vuforia AR SDK, with rendering optimizations that ensure high visual quality and multi-device compatibility.

The interactivity of learning content is the third pillar in module development. Through interactive features, students are no longer passive recipients of information but can experiment, explore, and build understanding through direct experience. Ease of use as the fourth pillar is a key design principle, ensuring that the module is accessible to students with various technological ability backgrounds.

The multimedia content development stage is carried out through a systematic and comprehensive process. Starting with mapping the basic competencies of engineering drawing, the development team focuses on compiling materials that include American and European view projections, accompanied by a comparison of projection systems and examples of practical applications. Content visualization is developed by creating a precise 3D model of engineering drawings, equipped with interactive animations and detailed explanations of each element.

The validation and testing process involved four key groups of experts: technical drawing subject matter experts, educational technologists, industry practitioners, and productive vocational high school teachers. This multidisciplinary approach ensures that the module meets academic standards while being relevant to the practical needs of the industry. Validation covers aspects of pedagogical content, AR technology, user interface, and interaction quality.

The continued development strategy is set with a focus on four key aspects. First, continuous improvement is implemented through periodic evaluation and integration of user feedback. Second, adaptation of the latest technology with a commitment to adopting the latest AR innovations and digital education technologies. Third, the development of additional features such as practice modes, industrial simulations, and automatic assessment mechanisms. Fourth, the scope of materials should be expanded to accommodate broader engineering competencies.

The development of this module is designed in three phases: short-term which focuses on module refinement through continuous validation, medium-term, which emphasizes feature expansion through integration of new technologies, and long-term which aims to achieve module standardization in the national curriculum.

The overall approach to developing this AR module proves the transformative potential of technology in vocational education. The module does not merely function as a visual aid but becomes a pedagogical partner that encourages students' exploration, understanding, and motivation to learn. Through the integration of innovative AR technology, this module provides an effective solution to overcome traditional challenges in learning engineering drawing, while preparing vocational high school students to face the digital era with relevant and modern competencies.

3.3. Analysing the Validity of Learning Modules

The validation process of the Augmented Reality (AR) Assisted Engineering Drawing Interpretation Learning Module for Vocational High School Students is a crucial stage involving three main aspects of validation: learning design, learning materials, and learning media. Each aspect of validation is carried out by competent experts in their respective fields, providing a comprehensive evaluation of the quality and effectiveness of the developed module.

The first validation was conducted by an instructional design expert, Prof. Dr. H. Martinis Yamin, M.Pd, who evaluated the module from four main aspects: material, presentation, language, and AR technology. The validation results showed very satisfactory achievement with a feasibility percentage reaching 93.75%, indicating that the module is in the "Very Valid" category. This evaluation includes aspects of the suitability of the material to basic competencies, accuracy of the material, up-to-dateness of the content, and relevance to the needs of vocational high school students. The presentation and language aspects also received high ratings, indicating that the module has met the required pedagogical standards.

The second validation was conducted by a material and learning expert, Dr. Juni Adri, S.Pd., M.Pd.T from Padang State University. This evaluation resulted in a very high feasibility percentage of 96.8%, confirming the superior quality of the module from the perspective of content and learning methodology. The validator provided a number of constructive suggestions for improving the quality of the module, including the importance of aligning the material with the latest industry standards, optimizing the use of AR technology for 3D visualization, and improving the motivational aspects of learning.

Responding to the feedback, the development team committed to making a series of improvements. This includes additional field studies into related industries, improving the quality of AR content by adding more interactive 3D objects, developing animations for complex concepts, and implementing a gamification system to increase learning motivation. The motivational aspect is strengthened by adding infographics about career prospects and contextualizing the material within the Industry 4.0 framework.

The third validation was conducted by an expert in learning media, Prof. Dr. Refdinal, MT, who provided an in-depth evaluation of the technical aspects and implementation of AR. The validation results showed a feasibility percentage of 77%, which is included in the "Valid" category. The validator provided specific technical suggestions related to device compatibility, suitability of the 3D model with papercraft projection, AR object rotation system, and audio quality.

The development team responded with a comprehensive improvement plan, including expanding compatibility testing to a wider range of devices, improving the quality of 3D models through recalibration and optimization, implementing a more intuitive gesture control system, and improving audio quality using professional equipment. Development will also include the possible implementation of markerless AR technology and a web-based version to improve accessibility.

The technical aspects of AR received special attention in the evaluation, with a focus on marker tracking quality, 3D object stability, loading speed, and interaction responsiveness. Although some aspects still need improvement, such as object stability and interaction control responsiveness which received a score of 3, overall the technical implementation was deemed adequate for learning purposes.

The visual aspect evaluation showed satisfactory results, with high marks for the quality of the 3D models, texture clarity, color and lighting suitability, and text readability. The audio aspect also received positive marks, especially in the clarity of the narrative and the quality of the recording, although there is still room for improvement in terms of sound effects and audio balance.

Overall, the validation process involving three experts from various fields of expertise has provided a comprehensive perspective on the quality of the module. With a high average percentage of eligibility and constructive input from the validators, this module has been proven to meet the quality standards required for implementation in engineering drawing learning at the vocational high school level. Continuous improvement based on validator input will further enhance the effectiveness of the module as an innovative learning tool that is relevant to the needs of modern industry.

3.4. Analysing the Validity of Learning Modules

The research on the practicality test of the learning module to interpret engineering drawings assisted by Augmented Reality (AR) at SMKN 14 Merangin was carried out to measure the effectiveness and ease of use of the product in real learning in the Motorcycle Engineering Expertise Competency for class X. The research methodology was designed comprehensively by integrating quantitative and qualitative approaches, focusing on four key aspects of testing, namely ease of use, technology accessibility, learning motivation, and effectiveness of concept understanding.

In terms of ease of use, researchers evaluated the user interface, navigation flow, and students' ability to access content independently. The results showed a very high level of practicality, with interface navigation reaching 92.4%, clarity of instructions at 90.7%, and AR interaction at 91.5%. For the aspect of technological accessibility, testing was conducted on various devices with very satisfactory results. Android smartphones showed a compatibility level of 95.3%, tablets 93.6%, and laptops 88.9%.

Analysis of students' learning motivation showed a significant increase after using the AR module. Interest in learning increased from 62.3% to 89.7% (an increase of 44.3%), active involvement from 58.6% to 87.4% (an increase of 49.1%), and self-confidence from 55.9% to 86.2% (an increase of 54.2%). The effectiveness of conceptual understanding also showed positive results with an increase in average scores on various aspects of competence. The view projection increased from 65.3 to 85.7 (31.2%), the American projection from 62.1 to 88.4 (42.4%), and the European projection from 60.5 to 90.2 (49.1%).

Table 3. Practical Aspects of AR Module

Dimension of Practicality	Key Indicators	Measurement Method
Ease of Use	Interface Navigation	Student Response Questionnaire
Accessibility	Device Compatibility	Technical Trial
Motivation to learn	Interest and Engagement	Direct Observation
Concept Understanding	Competency Enhancement	Formative Test

3.4.1 Practicality Test Results

Ease of Use

Table 4. Ease of Use Analysis

Criteria	Percentage of Practicality	Category
Interface Navigation	92.4%	Very Practical
Clarity of Instructions	90.7%	Very Practical
AR Interaction	91.5%	Very Practical

Technology Accessibility

Table 5. Device Compatibility

Device Type	Compatibility Level	Information
Android Smartphones	95.3%	Highly Compatible
Tablet	93.6%	Highly Compatible
Laptop	88.9%	Compatible

Student Learning Motivation

Table 6. Motivation Boost

Motivational Aspects	Before AR	After AR	Improvement
Interest in Learning	62.3%	89.7%	44.3%
Active Involvement	58.6%	87.4%	49.1%
Confidence	55.9%	86.2%	54.2%

Effectiveness of Concept Understanding

Table 7. Competency Achievement

Competence	Average Value Before	Average Value After	Improvement
View Projection	65.3	85.7	31.2%
American Projection	62.1	88.4	42.4%
European Projections	60.5	90.2	49.1%

Data collection was conducted through various methods, including direct observation, student response questionnaires, cognitive ability tests, in-depth interviews, and documentation of the interaction process. Data analysis used descriptive and inferential statistical techniques for comprehensive interpretation. The results of the qualitative analysis revealed the students' extraordinary enthusiasm for the AR module, with this technology successfully transforming the abstract concept of engineering drawing projection into a concrete and easy-to-understand learning experience.

Supporting factors for the module's practicality include intuitive interface design, comprehensive user guides, high flexibility, and multi-device compatibility. However, the study also identified several challenges such as device limitations and variations in students' digital capabilities. Solutions offered include providing alternative access, step-by-step guidance, and offline content download options to overcome connectivity constraints.

The practical implications of the study show that the AR module is not only practical in learning but also effective in increasing learning motivation and understanding of engineering projection concepts. This module has proven to be a transformative pedagogical partner that opens up a new paradigm in vocational education, preparing students to face the challenges of modern industry. Recommendations for development are focused on continuous improvement, including increasing interactive features, expanding the scope of materials, optimizing technology performance, and developing a multilevel version that can be tailored to the needs of various learning groups.

3.5. Describing The Interest of The Learning Module

The research on the attractiveness of Augmented Reality (AR)-assisted learning modules at SMKN 14 Merangin was conducted to measure the attractiveness and effectiveness of the product in motivating class X Motorcycle Engineering Expertise Competency students. The research methodology was designed systematically by integrating quantitative and qualitative methods, focusing on four main dimensions: students' affective responses, visual appeal, measurement of learning interest, and assessment of user experience.

In the analysis of students' affective responses, the study explored the emotional and psychological dimensions of students' interactions with learning technology. The results showed a very positive response with initial interest reaching 94.6%, learning joy 92.3%, and curiosity 93.8%. The evaluation of visual appeal was carried out through an in-depth analysis of interface aesthetics, rendering quality, and design composition. The assessment showed very satisfactory results with an average score of 4.7 for design 4.7, color composition 4.6, and rendering quality 4.8, all in the very attractive category.

Table 8. AR Module Attraction Dimensions

Dimensions	Key Indicators	Measurement Method
Affective Response	Emotions and Perception	Attitude Questionnaire
Visual Appeal	Interface Aesthetics	Design Observation
Interest in Learning	Motivation and Engagement	Likert Scale
User Experience	Interaction Satisfaction	In-depth Interview

3.5.1 Attractiveness Measurement Results

Students Affective Response

Table 9. Emotional Response Analysis

Emotional Aspect	Percentage of Positive Responses	Category
Initial Interest	94.6%	94.6%
The Joy of Learning	92.3%	Very interesting
Curiosity	93.8%	Very interesting

Visual Appeal

Table 10. Interface Evaluation

Visual Criteria	Average Score	Category
Graphic design	4.7	Very interesting
Color Composition	4.6	Very interesting
Rendering Quality	4.8	Very interesting

Interest in Learning

Table 11. Increased Motivation

Motivational Aspects	Before AR	After AR	Improvement
Focus on studying	62.5%	90.3%	44.5%
Active Participation	58.9%	89.7%	52.4%
Learning Independence	55.7%	87.6%	57.3%

User Experience

Table 12. User Satisfaction Analysis

Experience Criteria	Satisfaction Level	Category
Ease of Navigation	93.2%	Very satisfied
Clarity of Instructions	91.5%	Very satisfied
Interactivity	94.7%	Very satisfied

Learning interest measurements showed a significant increase after using the AR module. Learning focus increased from 62.5% to 90.3% (44.5% increase), active participation from 58.9% to 89.7% (52.4% increase), and learning independence from 55.7% to 87.6% (57.3% increase). User experience analysis also showed very positive results with high levels of satisfaction in the aspects of ease of navigation (93.2%), clarity of instructions (91.5%), and interactivity (94.7%).

Data collection was conducted through various methods, including structured questionnaires, participant observation, in-depth interviews, documentation of interaction processes, and visual recordings of module use. Data analysis used descriptive statistical techniques and qualitative interpretation to produce a comprehensive picture of the module's appeal.

Qualitative analysis revealed transformative dimensions in students' learning experiences. The AR module successfully created a unique and different learning experience from conventional methods, increased students' intrinsic motivation, and changed their perceptions of the engineering drawing learning process. 3D visualization became a major catalyst in arousing students' curiosity, especially in exploring the American and European view projections interactively.

Supporting factors for module attractiveness include modern visual design that aligns with the aesthetics of the digital generation, cutting-edge technology that showcases the potential of augmented reality, an interactive approach that actively engages students, and relevance to the interests of the technology generation. However, the study also identified several challenges, such as variations in aesthetic perception, differences in technology preferences, and diversity of learning styles.

Development recommendations focus on personalizing the interface, adding gamification elements, diversifying visual styles, and developing advanced interaction features. Pedagogical implications show that AR modules are not only visually appealing, but also increase learning motivation, create meaningful experiences, and support active learning paradigms that are in line with the demands of 21st-century education.

In conclusion, the AR-assisted engineering drawing interpretation learning module has high appeal and has the potential to transform the paradigm of vocational learning through an innovative technological approach. Augmented reality technology has proven to be an effective pedagogical partner in generating students' enthusiasm, motivation, and engagement in the learning process.

3.6. Analyzing The Effectiveness of Learning Modules

This research was conducted at SMKN 14 Merangin to measure the effectiveness and attractiveness of Augmented Reality (AR)-assisted learning modules for class X Motorcycle Engineering Expertise Competency students. The research methodology was designed systematically by integrating quantitative and qualitative methods, focusing on four main interrelated dimensions: students' affective responses, visual appeal, learning interest, and user experience.

In data collection, researchers used various instruments, including structured questionnaires, participant observation, in-depth interviews, documentation of interaction processes, and visual recordings of module use. Data analysis was conducted using a combination of descriptive statistical techniques and qualitative interpretation to gain a comprehensive understanding of the effectiveness of the AR module.

The results of the analysis of students' affective responses showed a very high level of interest, with initial interest reaching 94.6%, learning joy at 92.3%, and curiosity at 93.8%. The evaluation of the module's visual appeal also showed very satisfying results with high average scores in the aspects of graphic design (4.7), color composition (4.6), and rendering quality (4.8).

Table 13. Research Instruments

Instrument Type	Assessment Components	Assessment Weight
Written test	Concept Understanding	40%
Practice Test	Interpretation Ability	35%
Performance Observation	Application Skills	25%

3.6.1 Interpretation Ability

Table 14. Interpretation Ability Analysis

Criteria	Experimental Class
Accuracy of Interpretation	92.3%
Depth of Analysis	89.6%
Complexity of Understanding	91.5%

3.6.2 Application Skills

Table 15. Application Skills

Skill Aspect	Experimental Class
Projection Practice	87.9%
Implementation of the Concept	90.2%
Design Creativity	88.6%

Statistical Analysis:

a. Independent t-test
b. Significance of difference $p < 0.05$
c. Large effect size

Statistical Analysis Table:

Table 16. Application Skills

Variables	t value	Significance	Size Effect
Cognitive	7.42	0.000	0.82
Interpretation	6.95	0.000	0.79
Application	7.13	0.000	0.76

Learning interest measurements revealed a significant increase after the implementation of the AR module. Students' learning focus increased from 62.5% to 90.3%, indicating an increase of 44.5%. Active participation increased from 58.9% to 89.7% (an increase of 52.4%), while learning independence increased from 55.7% to 87.6% (an increase of 57.3%). In terms of user experience, the AR module received very positive responses with high levels of satisfaction in the aspects of ease of navigation (93.2%), clarity of instructions (91.5%), and interactivity (94.7%).

Qualitative analysis revealed that the AR module successfully created a transformative learning experience that was different from conventional methods. AR technology proved effective in increasing students’ intrinsic motivation and changing their perception of learning engineering drawing from a mere task to an interesting and challenging activity. 3D visualization became a major catalyst in arousing students’ curiosity, especially in exploring the American and European view projections interactively.

Factors that support the effectiveness of the module include a modern visual design that aligns with the aesthetics of the digital generation, cutting-edge AR technology, an interactive approach that actively engages students, and relevance to the interests of the tech generation. However, the study also identified several challenges, such as variations in aesthetic perception, differences in technology preferences, and diversity of learning styles that need to be addressed through a flexible and adaptive approach to module design.

Development recommendations focus on personalizing the interface, adding gamification elements, diversifying visual styles, and developing advanced interaction features. Pedagogical implications show that the AR module is not only effective in increasing student motivation and understanding but also supports an active learning paradigm that is in line with the demands of 21st-century education.

4. CONCLUSION

This research sought to create an efficient AR-based educational module using the ADDIE paradigm to tackle significant concerns in engineering drawing instruction, such as understanding obstacles, engagement deficits, and a scarcity of interactive materials. The development of Augmented Reality (AR)-based engineering drawing learning modules for vocational high school students using the ADDIE method is motivated by various learning challenges. The results of the needs analysis show that 68% of students have difficulty understanding the concept of projection, 72% have difficulty distinguishing between American and European projections, and 65% need more dynamic learning media.

In responding to these needs, the module was designed with attention to pedagogical and technological aspects. Development was carried out with four main pillars using Unity and Vuforia AR SDK, which are equipped with interactive features for 3D object exploration and quizzes. Validation involved various stakeholders including material experts, educational technologists, industry practitioners, and vocational high school teachers.

The validation results show that the module is declared suitable for use with a valid to a very valid category, although there are some notes on improvements to the technical aspects of the learning media. In its implementation, the AR module has proven to be very practical and effective in improving learning, with a significant increase in students' learning motivation and understanding of concepts.

This module also sparked a lot of interest, particularly because of its interactive 3D visualization features, contemporary design, and digital-generation-appropriate teaching methods. Future studies should look into the integration of AI-driven adaptive learning features, the scalability of AR learning modules across various vocational disciplines, and the effects of long-term retention. Teachers and legislators should also think about creating affordable augmented reality implementations to enhance accessibility in schools with limited resources, as well as contemporary design and learning strategies that align with the digital generation. Notwithstanding certain obstacles, such as differences in technological preferences and technical limitations, the AR module effectively made learning engineering drawings more tangible and engaging. AR technology is a successful teaching tool for improving students' technical knowledge, motivation, excitement, and active participation in the learning process.

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