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Development of a Learning Module for Road and Bridge Design Modeling with Augmented Reality Integration

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Abstract

The average learning outcomes of eleventh-grade students in 2024 indicate a disparity between psychomotor skills (88), which are higher, and cognitive skills (83). Augmented Reality (AR)-based learning is expected to have the potential to enhance the conceptual abilities of vocational high school students, who tend to be less developed than their psychomotor skills. The purpose of this study was to analyze the feasibility of the module, evaluate its effectiveness, and assess the improvement of students' cognitive abilities. This research employed the ADDIE development model (Analysis, Design, Development, Implementation, and Evaluation). The findings revealed that the AR-based module was deemed feasible by both material experts and media experts, with a CVR value of 1. Of the 37 cognitive test items developed, 26 were found to be valid and used in the study, while 11 questions were excluded due to invalidity. The reliability coefficient of 0.854 indicated very high instrument consistency. Based on the N-Gain test, the experimental class recorded an improvement of 0.61 (moderately effective), while the control class achieved only 0.21 (ineffective). These results demonstrate that the AR-based module is more effective in enhancing students' cognitive abilities compared to conventional learning methods.

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INTRODUCTION

Over the last three years in the education sector, particularly in technical education related to building design, has undergone a massive transformation due to the widespread adoption of digital technology. One of the innovation that is applied in learning activities are Augmented Reality (AR). This tool integrates real-world contexts with digital elements to foster interactive and immersive learning experiences. Augmented Reality (AR) technology affords students the ability to engage with 3D objects in real time, thereby facilitating the comprehension of complex concepts through authentic and contextually rich visualizations.

In the subject *Road and Bridge Construction* at SMKN 7 Baleendah, the implementation of Augmented Reality (AR) technology holds significant potential for addressing challenges in the learning process, where students often struggle to visualize complex technical designs. Learning that still relies primarily on textbooks and 2D diagrams has proven ineffective in explaining essential elements such as bridge structures, load analysis, and drainage systems. Therefore, AR can provide a solution through more dynamic and interactive visualizations, thereby enhancing students' comprehension.

Developing an AR-based Learning Module can be an effective solution since it focuses on 3D road and bridge design. Through this technology, students not only see but also interact directly with 3D objects. The students can be facilitated in understanding complex technical concepts. This finding was aligned with Alawyah et al. (2024), who stated that AR has the potential to overcome the limitations of conventional learning media and enhance students' understanding of technical subjects. Therefore, this study aims to explore the implementation of AR technology, specifically through the AUGIN application, in teaching bridge design at SMKN 7 Baleendah and enhancing students' material comprehension.

One of the main challenges in teaching bridge design is the conventional learning media, which fail to provide an interactive learning experience. Students often meet difficulties in visualizing designs and related technical elements. Therefore, this study aimed to develop an augmented reality (AR)-based learning module designed to enhance students' comprehension in constructing 3D models of roads and bridges. By using an AR-based approach, the students are expected to understand technical concepts and improve their learning achievement, especially in the cognitive aspect, which is commonly lower than practical competence. The implementation of AR in this learning context is expected to reduce the gap between students' conceptual and psychomotor abilities, thus improving the quality of education in the field of road and bridge construction.

This study aimed to (1) develop a learning module of Road and Bridge Modeling Design that integrated with AR technology at SMKN 7 Baleendah, Bandung, (2) analyze the feasibility and effectiveness of the module, and (3) examine the improvement of students' cognitive abilities after using the AR-based module at the school.

This research is expected to make a good contribution in theoretical and practical terms. Theoretically, this study contributed to the knowledge development of education technology, particularly regarding the use of Augmented Reality (AR) to enhance students' cognitive skills in road and bridge construction. Furthermore, it can be a reference for future researchers in integrating AR with technical learning at SMK. Practically, this research offers benefits for teachers by introducing an innovative learning medium through an AR-based application. In addition, it assists students in developing critical thinking and spatial visualization skills, while also equipping graduates to address the challenges of the workforce. For schools, this study supports the integration of AR technology into the curriculum, enhances the quality of education in the field of civil engineering, and strengthens its relevance to industry needs. For the industrial sector, the study emphasizes the importance of mastering AR technology to improve work efficiency while preparing graduates to be equipped for employment. In addition, this research provides valuable experience for the researcher and opens opportunities for further studies on the application of AR in technical and engineering education.

METHODOLOGY

This research applied a research and development (R&D) approach with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation) to develop and evaluate an AR-based learning module. The research design used a pre-test and post-test with two groups: the experimental group, which adopted the AR module, and the control group, which applied a conventional method. A pre-test was administered to evaluate students' initial cognitive abilities, whereas a post-test was conducted to assess the improvement in their cognitive skills following the intervention. The following illustrates the research design employed in this study.

Group	**Pre-test (O_1)**	**Treatment (X)**	**Post-test (O_2)**
Experiment	O_1	X	O_2
Control	O_1	-	O_2

Description:
O_1: Pretest (measurement of cognitive abilities before the intervention).
X: Treatment (experimental group using the AR-based learning module).
O_2: Posttest (measurement of cognitive abilities after the intervention)

The research subject comprised 11 grade students majoring in Design and Building Information Modeling (DPIB) at SMK Negeri 7 Baleendah, Bandung. With a total of 69 students, the research subject was divided into two classes. DPIB 1, comprising 36 students, was designated as the experimental group, while DPIB 2, with 33 students, was the control group.

To evaluate the effectiveness of the module, a questionnaire and multiple-choice test were administered to students at the Design and Building Information Modelling (DPIB) program at SMK Negeri 5 Bandung. This trial aimed to ensure that the instrument was valid and objectively capable of reflecting the impact on improving students' cognitive abilities. Once the trial results were obtained, the validity of the instrument was analyzed using the biserial point correlation method, while instrument reliability was tested using the KR-20 coefficient.

Furthermore, the effectiveness of the module was evaluated using a questionnaire and a multiple-choice test administered to students of the Design and Building Information Modelling (DPIB) program at SMK Negeri 5 Semarang. The collection technique involved a material expert, media expert, and instrument expert, using a rubric score to assess product feasibility. The product effectiveness was then tested through a pre-test and a post-test, which were analysed using the t-test and N-gain test.

RESEARCH RESULT AND DISCUSSION

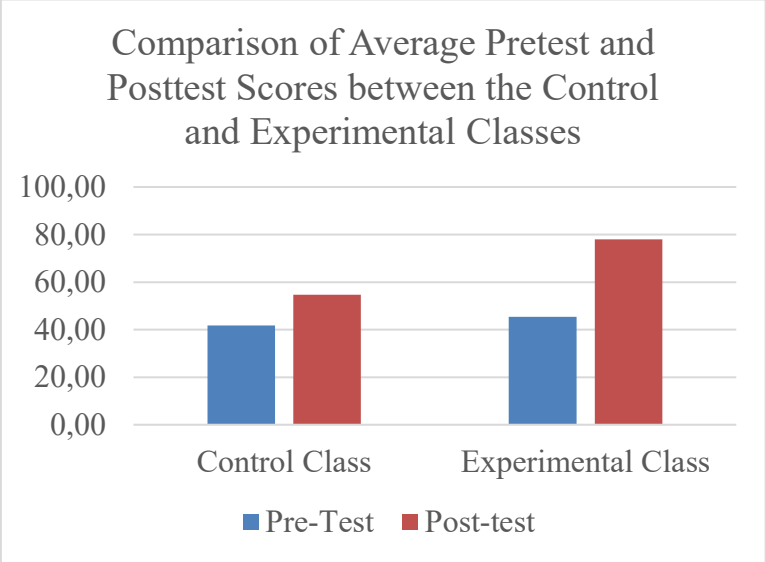
Result

Based on the data analysis, this research adapted a development and evaluation of an integrated learning module on road and bridge 3D with Augmented Reality (AR), which was designed to improve students' cognitive skills in road and bridge design. The content validity was according to a material expert, yielding a Content Validity Ratio (CVR) of 0.96, and reliability was measured using Percentage of Agreement (PA), which was achieved at 98%, or declared "highly feasible". The validation conducted by a media expert, *Content Validity Ratio (CVR)*, gained 0.97 from eight experts, and the reliability of Percentage of Agreement (PA) was 98% or categorized "highly feasible". These results demonstrate that both material experts and media experts agreed that the *3D Road and Bridge Integration Learning Module with Augmented Reality (AR)* is valid and reliable, and therefore suitable for use in the learning process.

The pre-test and post-test were administered to 69 11th-grade students in the Design and Building Information Modeling (DPIB) program at SMK Negeri 7 Baleendah, Bandung. The participants consisted of two classes: DPIB 1 and DPIB 2 as research subjects. The pre-test results from both groups were analyzed using an Independent Sample T-Test to compare differences between the experimental and control groups and to determine whether these differences were statistically significant. Furthermore, the t-test result of the pre-test showed a t-score of 0.259 with a significance level

(Sig. 2-tailed) of 0.259 > 0.05. This result indicated that there was no significant difference in the initial abilities between the two groups.

The post-test result was analysed using descriptive analysis, normality test, homogeneity test, one-way t-test, and N-gain test. The descriptive analysis revealed that the average score of the post-test for the experimental group was 77.97, and the control group gained an average score of 54.70. A normality test using the *Kolmogorov-Smirnov* showed that the control group achieved 0.140 with Sig. 0.138>0.05, while the experimental class gained 0.124 with Sig 0.200 > 0.05, and the results indicated that the data were normally distributed in both groups. The homogeneity test gave a significance value of 0.587 > 0.05, confirming that the data from both groups were homogeneous. The right-tailed (t-test independent sample) showed a t-score of 9.700, which exceeded the t-table of 1.670, with a significance level (Sig. 2-tailed) of 0.000 < 0.05. These results indicate a significant difference between the experimental and control groups in the post-test outcomes.



The data showed there was a big difference in results between the control and experimental group. The research found that the control group achieved a pre-test average score of 41.47, while the experimental group achieved 45.34. This result indicated that there was no significant difference between the two groups before the treatment. Furthermore, after giving the AR-based module, the data showed that the average score of the control group was 54.70, while the experimental group achieved 77.97. The cognitive improvement of the control group was 21.04%, reflecting progress in mastering 3D Road and Bridge material through conventional learning methods. In contrast, the experimental group demonstrated an improvement of 60.97%, indicating a significant enhancement in understanding the material after using the *3D Road and Bridge Integration Learning Module with Augmented Reality (AR).*

The result showed that students' cognitive skills in the experimental group are higher than those in the control group. The cognitive improvement of the experimental group was 60.97%, while the control group gained 21.04%. The N-Gain test results showed that the experimental group achieved an average N-Gain of 0.61, which falls into the "moderately effective" category. On the otherhand, the control group obtained only 0.21, categorized as "ineffective."

Discussion

The development of an Augmented Reality (AR) based learning module in Road and Bridge Modelling Design showed significant results in improving students' cognitive skills. Based on the validation result of materials and media experts, the developed module was feasible to use in the vocational high school (SMK) learning process, especially in the major of Design and Building

Information Modeling (DPIB). The AR-based approach in this module also enhances the appeal of learning by presenting interactive and contextual 3D objects. These findings are consistent with the study by Sahin and Yılmaz (2020), which emphasized that AR technology in education can help students gain a deeper understanding, particularly of complex subject matter. Furthermore, AR presents material with supporting pictures and real animation, making the participant more attracted and making it easier to master the topic given. This finding also supported Sahin and Yilmaz (2020), who stated that the group of students who were given AR had higher learning achievement and positive behavior toward the subject than the control group.

A persistent challenge in vocational education, particularly in the field of Building Information Modeling and Design, is students' limited readiness in navigating career pathways and their insufficient strategies for entering the workforce. This finding is in line with Zulaikhak et al (2024), who stated that the persistently high unemployment rate among vocational high school graduates (approximately 9.60%) highlights the urgent need to strengthen students' career readiness and to align vocational education more closely with industry requirements. In these cases, the vocational education needs to emphasize relevant technical skills that integrate with industrial needs, including technology expertise that supports the job. Therefore, the use of AR-based learning modules can serve as an effective solution to bridge this gap. By providing a more immersive and interactive learning experience, AR can better equip students with the practical skills required in the workplace and prepare them for clearer and more structured career pathways.

Komariah and Setiyadi (2024) emphasized that education at vocational high school must focus on developing practical skills that are relevant to industrial needs. In addition, learning modules are provided to equip students with the necessary competencies to perform the technical tasks required in the workplace. Therefore, the use of AR-based modules can serve as an effective solution for improving student learning outcomes. Nidhom et al. (2022) support this finding by stating that the application of Augmented Reality (AR)-based modules in vocational education has been proven to significantly enhance students' learning outcomes, particularly in mastering more practical technical skills. Trinoviorar (2024) further notes that learning that integrates interactive technologies such as AR can improve students' comprehension, as it directly engages both visual and auditory senses in the learning process. Research by Hendriyani et al. (2019) also revealed that AR can increase students' motivation and engagement, while making complex material easier to understand. In addition, Khan et al. (2022) emphasized that AR greatly assists students in bridging theoretical and practical, especially in technical fields such as road and bridge design. Through AR, students can visualize and directly interact with 3D objects, enabling them to gain a deeper understanding of concepts and their real-world applications.

According to Kartikasari et al. (2024), one effective approach to promoting vocational values is to integrate lessons using a STEAM-based method through the development of self-directed learning modules. The finding is relevant to the development of AR-based learning modules in the present study, which aim to enhance students' technical understanding in the field of Road and Bridge Design Modeling. Furthermore, printed modules remain an efficient choice for vocational school learning, as they are easily accessible and can be used at any time without reliance on internet connectivity or digital devices. Namiroh (2018) highlighted that the strength of printed modules lies in their flexibility in supporting independent learning. Furthermore, Rahayu (2023) emphasized that modules with engaging illustrations and clear instructions can facilitate students' gradual understanding of technical materials. In this study, the advantages of printed modules are combined with Augmented Reality (AR) technology, enabling specific images within the module to trigger 3D objects, such as road or bridge designs that can be viewed through a mobile device. This integration adds an interactive dimension to the learning process, making it more engaging and concrete.

Furthermore, the findings of Ahmed et al. (2024), who affirmed that the use of AR in technical education, particularly in the fields of manufacturing and construction, can enhance student performance by reducing confusion in understanding complex material, support this finding. Printed modules integrated with AR not only facilitate learning but also bridge traditional and modern approaches, making them highly suitable for vocational schools that continue to adopt conventional learning methods while incorporating relevant technology.

The assessment instruments used in this study also met the criteria of validity and reliability, which are essential for accurately measuring students' abilities. Pandian et al. (2023) emphasized that valid and reliable instruments can assess students' understanding with precision. The instruments employed in this study proved effective in evaluating students' cognitive abilities regarding road and bridge design modeling using the AR-based module. This finding is supported by Larasati et al. (2020), who highlighted the importance of testing the validity and reliability of instruments across different student groups to ensure their relevance. Moreover, Ulfah et al. (2025) noted that although an instrument may demonstrate validity and reliability in one group, it is crucial to re-examine its applicability when used with different groups or topics to guarantee consistency and accuracy of the results.

The analysis of pre-test and post-test data indicated a significant improvement in students' cognitive abilities after using the AR-based printed module. The average post-test score for the experimental group was 77.97, whereas the control group achieved 54.70. The cognitive improvement in the experimental group reached 60.97%, compared to 21.04% in the control group. Similarly, Prasetya et al. (2020) demonstrated that AR-based modules can enhance the effectiveness of learning in vocational education, particularly in developing technical skills and conceptual understanding. This finding is consistent with intrinsic motivation theory, which emphasizes the importance of active student engagement in the learning process to improve material comprehension (Hsieh, 2021).

The significant improvement in cognitive abilities observed in the experimental group demonstrates that the use of AR-based modules is more effective than conventional learning methods. Cheng et al. (2025) found that AR enables students to directly interact with 3D objects, thereby reinforcing their understanding of complex concepts. Moreover, AR-based media provide a more immersive learning experience, allowing students to absorb and retain information more effectively.

CONCLUSION

Based on the research and development of the 3D Road and Bridge Integration Learning Module using Augmented Reality (AR) at SMKN 7 Baleendah, it can be concluded that the implementation of this module, developed through the ADDIE model, has been completed and tested. The developed module has been proven to be highly feasible for use in the learning process, particularly in the subject of Road and Bridge Construction. The integration of AR technology within the module has enhanced learning effectiveness, providing students with a more interactive and immersive learning experience. Furthermore, the use of the AR-based module significantly improved students' cognitive abilities, yielding better outcomes compared to conventional teaching methods applied by teachers.

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