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ORIGINAL

Project-based Augmented Reality (PjBAR): Evaluation for Vocational Education Effectiveness

Realidad Aumentada Basada en Proyectos (PjBAR): Evaluación de la Eficacia en la Educación Vocacional

Muslim[1], Ambiyar[1], Arwizet Karudin[1], Muhammad Syafiq Hazwan Ruslan[2], Hsu-Chan Kuo[3], Doni Tri Putra Yanto[1]

[1]Universitas Negeri Padang, Faculty of Engineering. Padang, Indonesia.
[2]Universiti Teknologi MARA, School of Chemical Engineering. Selangor, Malaysia.
[3]National Cheng Kung University, Center for Teacher Education. Tainan, Taiwan.

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Corresponding Author: Muslim

ABSTRACT

Introduction: the Industrial Revolution 4.0 requires vocational education to adopt innovative learning approaches that integrate advanced technology with real work practices. This study aims to analyze the effectiveness of the Project-based Augmented Reality (PjBAR) model in improving the quality of learning in vocational education.
Method: data were collected through a trial implementation of the PjBAR model compared to direct instruction. The effectiveness of the model was analyzed using effect size to determine how much influence the PjBAR model had on learning outcomes.
Results: this study revealed a significant difference between the PjBAR model class and the direct instruction method. The average learning outcomes of the PjBAR class were superior to those of the direct instruction class. Effect size analysis indicated that the PjBAR model had a strong impact on improving student learning outcomes.
Conclusions: this model not only improves learning outcomes and the quality of education but is also able to provide a more interesting learning experience through the integration of augmented reality technology, making it relevant to meet the needs of 21st-century learning.

Keywords: Effect Size; Learning Effectiveness; Project-Based Augmented Reality; Vocational Education; Quality Education.

RESUMEN

Introducción: la Revolución Industrial 4.0 requiere que la educación vocacional adopte enfoques de aprendizaje innovadores que integren tecnología avanzada con prácticas laborales reales. Esta investigación tiene como objetivo analizar la efectividad del modelo de Realidad Aumentada basado en Proyectos (PjBAR) para mejorar la calidad del aprendizaje en la educación vocacional.
Método: los datos se recopilaron probando la implementación del modelo PjBAR en el grupo experimental y el grupo de control mediante instrucción directa. La efectividad del modelo se analiza utilizando el tamaño del efecto para determinar cuánta influencia tiene el modelo PjBAR en los resultados del aprendizaje.
Resultados: este estudio reveló diferencias significativas entre las clases del modelo PjBAR y el método de instrucción directa. Los resultados de aprendizaje promedio de la clase PjBAR fueron superiores a los de la clase de instrucción directa. El análisis del tamaño del efecto indica que el modelo PjBAR tiene un fuerte impacto en la mejora de los resultados de aprendizaje de los estudiantes.

Conclusiones: este modelo no solo mejora los resultados del aprendizaje, sino que también puede proporcionar una experiencia de aprendizaje más interesante mediante la integración de tecnología de realidad aumentada, lo que lo hace relevante para satisfacer las necesidades de aprendizaje del siglo XXI.

Palabras clave: Tamaño del Efecto; Eficacia del Aprendizaje; Realidad Aumentada Basada en Proyectos; Educación Vocacional; Educación de Calidad.

INTRODUCTION

The Industrial Revolution 4.0 has brought major changes to life, with the dominance of technologies such as artificial intelligence, the Internet of Things (IoT), and automation in various industries.[1,2] In facing this challenge, vocational education is required to produce graduates who not only have technical skills but can also adapt to the latest technology.[3,4,5] Vocational education can integrate theory, practice, and technology, which is important to prepare graduates to face the dynamics of the world of work.[6,7,8] In addition to technical skills, digital skills, critical thinking, collaboration, and creativity are also increasingly valued.[9,10]

The Powertrain course is required to adapt concepts and skills to the needs of the automotive industry.[11] However, vocational education faces obstacles, such as minimal integration of technology in the curriculum due to a lack of long-term investment[12,13] and adequate lecturer training.[14] Pedagogical approaches are also often not to the needs of the dynamic industry.[15] Augmented Reality (AR) technology can be an effective solution to bridge this gap by providing an immersive and interactive learning experience.[16] Real-world simulation through AR, such as disassembly and assembly of powertrain components, can reduce costs, improve safety, and accelerate the acquisition of technical skills.[17]

Vocational education needs to integrate technology with the development of cognitive and practical skills to meet the needs of the world of work that continues to develop dynamically. According to the World Economic Forum report,[18] cognitive skills remain a priority even though many companies are investing in practical skills. Unfortunately, vocational education still faces significant gaps in effective technology integration.[19] UNESCO[14] also emphasizes the importance of relevant vocational education to advance access to decent work, entrepreneurship, and lifelong learning. In this regard, the AR-based learning model offers an integration of theory and practice to prepare students to face the challenges of the Industrial Revolution 4.0. With AR, students not only learn theory but also directly master relevant technical skills, giving them a competitive advantage in the world of work based on technology and sustainability.

Software simulations, as mentioned by Mustapha et al.[20] are effective in honing technical skills with minimal risk, although they lack support for collaboration skills. The Project-based Learning (PBL) approach, according to Aldabbus,[21] can increase student engagement and problem-solving skills through projects that are relevant to the world of work. In addition, AR technology has been shown to enhance the learning experience through interactive and immersive visualizations, such as mechanical system simulations in engineering education.[22] However, AR is often only used as a visual aid without integration with collaborative approaches such as PBL.

This study proposes a Project-based Augmented Reality (PjBAR) model that combines the advantages of PBL and AR to create holistic learning. PjBAR combines theory and practice, improves collaboration skills, and problem-solving, and provides technical visualizations that are relevant to industry needs.[23] This model is expected to be an effective solution for vocational education in the Industrial Revolution 4.0 era.

In response to this problem, this study aims to evaluate the effectiveness of the PjBAR model in improving students' conceptual understanding and skills in vocational education which is tested at the Department of Automotive Engineering, Padang State University, Indonesia. In addition to aiming to evaluate the effectiveness of the PjBAR model, this study also aims to provide empirical evidence of the contribution of this model in improving learning outcomes in powertrain courses. This model is designed to integrate the strengths of the developed PBL and AR technology so that students not only get an interactive learning experience but also relevant to the needs of modern industry.

METHOD

Research Design and Participants

This study used a pretest-posttest control group experimental design[24] with cluster random sampling. Two classes out of 10 classes of Automotive Engineering vocational students in the Powertrain course were randomly selected and then drawn for assignment to the experimental group (PjBAR) and control (direct instruction). The dependent variables were cognitive learning outcomes and practical skills. The number of students was 30 per group (beginning and end of the study). Inclusion criteria: 1) active students; 2) taking Powertrain, 3) willing to participate in the study. Exclusion criteria: not taking full learning or not completing the posttest. This study has complied with applicable ethical standards, including obtaining written consent from participants through a consent form explaining the purpose of the study, procedures, and participant rights. The researcher

ensured the confidentiality of the data and gave participants the freedom to withdraw at any time without consequences.

Project-based Augmented Reality (PjBAR) Model

The PjBAR model that has been developed has 5 learning syntaxes that are integrated with interactive AR media. Students use additional devices such as smartphones to use the AR application that has been developed. The syntax of this PjBAR model is 1) exploration; 2) scenario design; 3) AR-enhanced execution; 4) interactive demonstration; and 5) evaluation and reflection.[23]

Data Collection and Analysis

The research instrument used was a test item to see the learning outcomes of both classes in the cognitive aspect. Observation sheets were used to obtain the learning outcomes of both classes in the skills aspect. Normality and homogeneity tests were used as initial prerequisites before conducting a hypothesis test.[25] The hypothesis test used to determine the differences in learning outcomes in the two classes in the cognitive aspect is the independent sample test, while to see the increase in scores in the two classes the N-Gain test is used. The effect size was conducted to see how effective the learning model was between the two classes using Cohen's d test.[24] Based on the results of observations using the Likert scale in the skills aspect, the percentage of classical completeness was used to see the effectiveness of the learning model implemented in both classes. Skill learning outcomes are said to be better if more than 80 % of students complete the total number of students in 1 class.[26,27]

RESULTS

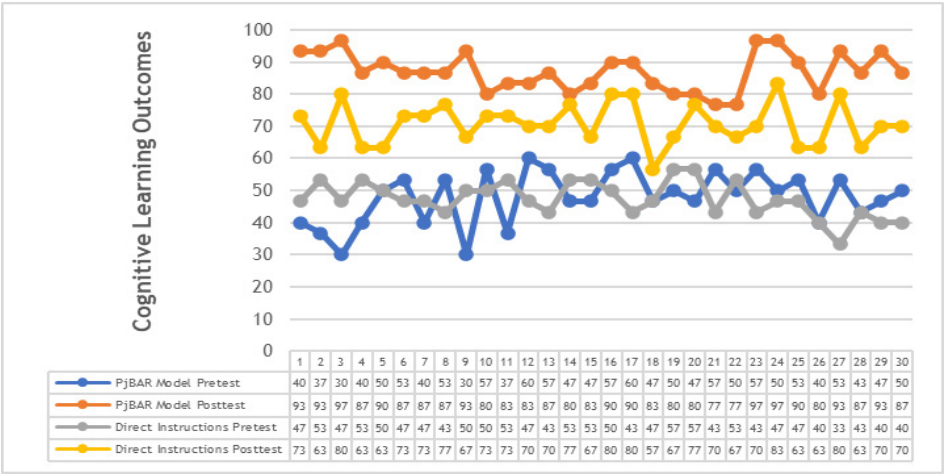
Data Distribution of Experimental and Control Classes

The average pretest of the PjBAR class was 47,89 and the direct instruction class was 47,33, indicating equivalent initial abilities. After the treatment, a posttest was given so that the PjBAR class experienced a significant increase with an average value of 87, much higher than the control class which only reached 70,78 (table 1). The smaller standard deviation in the PjBAR class (5,96) compared to the direct instruction class (6,53) indicates more consistent results in the PjBAR class.

Table 1. Number of Research Samples

Information	Experimental Class		Control Class	
	Pretest	Posttest	Pretest	Posttest
N	30	30	30	30
Mean	47,89	87	47,33	70,78
Median	50	86,67	46,67	70
Mode	46,67[a]	86,67	46,67	63,33[a]
Std. Deviation	8,28	5,96	5,49	6,53228
Minimum	30	76,67	33,33	56,67
Maximum	60	96,67	56,67	83,33
Sum	1436,69	2610,01	1419,99	2123,32

Source: Muslim et al.[23]



Source: Muslim et al.[23]

Figure 1. Distribution of Pretest-Posttests in Experimental and Control Classes

The distribution of pretest and posttest scores in the PjBAR class and direct instruction class is presented in figure 1. The figure illustrates a significant increase in the PjBAR class posttest scores, with a more even distribution of scores in the high range (above 80). In contrast, the direct instruction class showed a more limited increase, with some students still in the low range.

Cognitive Test Analysis

Prerequisite Test and Difference Test

Normality analysis showed that the p-value for the pretest and post-test data in the PjBAR and direct instruction classes was greater than 0,05, meaning that the distribution of the pretest post-test data was normally distributed. Homogeneity analysis also produced a p-value greater than 0,05, indicating that the data had the same variance. For the analysis of differences, the independent sample t-test was used, as shown in table 2.

The difference test showed that there was no significant difference in the pretest between the PjBAR class and the direct instruction class, with a p-value of 0,76 (> 0,05). These results indicate that the initial abilities of the two groups were at an equivalent level. In contrast, the test results on the final learning outcomes showed a very significant difference, with a p-value of 0,00 (< 0,05). This finding confirms that the application of the PjBAR learning model has a significant effect on improving learning outcomes in the experimental group compared to the control group.

Table 2. Independent Sample Test Output

Description	t	df	Sig. (2-tailed)
Initial Learning Outcomes	0,31	58	0,76
	0,31	50,39	0,76
Final Learning Outcomes	10,05	58	0,00
	10,05	57,52	0,00

Source: Muslim et al.[23]

N-Gain

The average N-Gain of the PjBAR class and the direct instruction class can be seen in table 3. The average N-Gain of the PjBAR class is 0,74 with a standard deviation of 0,02, while the group using the direct instruction method has an average N-Gain of 0,44 with a standard deviation of 0,03. This difference shows that the PjBAR model provides a higher increase in learning outcomes than direct instruction. The small standard deviation value indicates the consistency of the increase in scores in each group.

Table 3. Group Statistic Average N-Gain

	Learning Model	N	Mean	Std. Deviation
Score Improvement	PjBAR	30	0,74	0,02
	Direct Instruction	30	0,44	0,03

Source: Muslim et al.[23]

Effect Size

The statistical results show that the average posttest score of the class using the PjBAR model is 87 with a standard deviation of 5,96, while the Direct Instruction class has an average of 70,78 with a standard deviation of 6,53 (table 4). Cohen's d calculation produces a value of 2,59, which indicates a very large effect size. This indicates that the PjBAR model provides a much more significant increase in learning outcomes compared to the Direct Instruction method. Based on the effect size value, the PjBAR model has proven to be very effective in improving student learning outcomes, with a significantly large effect compared to the Direct Instruction learning method.

Table 4. Group Statistic Average Posttest of Experimental and Control Classes

Learning Model	N	Mean	Std. Deviation	Std. Error Mean
PjBAR	30	87	5,96	1,09
Direct Instruction	30	70,78	6,53	1,19

Source: Muslim et al.[23]

Skill Test Analysis

Based on the analysis, the average skill in the PjBAR class reached a value of 84,18 % with the category "Skilled," while the direct instruction class recorded an average of 78,74 % with the same category (table 5). Referring to the classical completion threshold of 80 %, the PjBAR class managed to achieve classical completion, while the direct instruction class had not achieved it. The results of this skill test analysis indicate that the PjBAR model is effective in improving student skills, as evidenced by the better classical completion achievement in the PjBAR class compared to the direct instruction class.

Table 5. Group Statistic Average N-Gain

Aspect	Kelas Eksperimen		Kelas Kontrol	
	Average (%)	Criteria	Average (%)	Criteria
Preparation	87,08	Highly Skilled	85,00	Skilled
Work Process	82,50	Skilled	78,33	Skilled
Work Results	81,04	Skilled	76,46	Skilled
Attitude	86,94	Highly Skilled	78,06	Skilled
Time	83,33	Skilled	75,83	Skilled
Average	84,18	Skilled	78,74	Skilled

Source: Muslim et al.[23]

DISCUSSION

The results of the study indicate that the PjBAR model has a significant impact on improving student learning outcomes, including cognitive and skill aspects. This model creates an interactive, immersive, and real-world relevant learning environment. The high and consistent posttest scores in the PjBAR class, as well as the achievement of the "skilled" category classically in the skill aspect, are evidence that this approach is effective in improving the quality of learning. Compared to direct instruction methods, the PjBAR model plays a role not only as a learning aid but also as a medium that motivates students to participate actively and independently in the learning process.

These findings confirm that PjBAR can answer the challenges of 21st-century learning, especially in vocational education which demands a balance between conceptual understanding and mastery of practical skills. The application of augmented reality (AR) technology in learning is one of the key factors in the success of this model. AR technology provides a more interactive and contextual learning experience, as supported by research by Kuanbayeva et al.[28] and Lin et al.[29], which states that AR can make learning more interesting and immersive. However, the contribution of this study lies in the integration of AR technology into the PBL approach, which has been proven to significantly improve student learning outcomes, as confirmed by research by Ismael et al.[30] and Anwar et al.[31]

The PjBAR approach also has a positive impact on student learning motivation, critical thinking skills, and cognitive skills, as supported by previous studies.[32,33,34] In terms of skills, students in the PjBAR class showed a clear advantage compared to the direct instruction class. The "skilled" category achieved classically shows the success of this approach in building essential process skills. Students in the PjBAR class showed more thorough preparation, a more positive attitude, and better time efficiency in completing tasks, supporting the findings of Abdullah et al.[35] and Kalkabayeva et al.[36] who stated that AR technology can improve process skills. In addition to these successes, the study makes a unique contribution by showing that the PjBAR model can significantly improve practical skills, in addition to strengthening cognitive outcomes. This combination makes PjBAR a holistic and applicable learning model, suitable for application in vocational education.

However, this study has several limitations that need to be considered. The scope of the sample is limited to two classes in one vocational education institution, limiting the generalization of the findings, so that the results of the study cannot fully represent the wider population. In addition, the AR technology used in this study is still marker-based, which limits the flexibility of its use. Further research is recommended to include larger and more diverse samples and develop markerless-based AR technology to increase flexibility and functionality, thereby expanding the potential application of this model. In addition, further research can also consider the analysis of external factors that influence the effectiveness of the PjBAR model, such as the readiness of teaching staff, support for technological infrastructure, and student engagement during the learning process.

Overall, the PjBAR model offers a relevant and promising innovation in vocational education in the modern era. By integrating AR technology into PBL, this model is not only able to improve students' conceptual understanding but also prepare them with skills that are relevant to the real world. This approach has proven its potential to bridge the needs of technology-based learning with the demands of practical skills, making PjBAR a strategic solution to improve the quality of holistic vocational education.

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CONCLUSIONS

This study shows that the implementation of the Project-Based Augmented Reality (PjBAR) model effectively improves students' cognitive learning outcomes and skills in vocational education. The findings confirm that the PjBAR model provides an interactive, contextual, and relevant learning experience to the needs of modern industry. The results of the analysis show that the PjBAR model not only improves students' conceptual understanding but also their skills significantly compared to direct instruction methods. Students in the PjBAR class achieved more consistent learning outcomes with a more even distribution of grades at a high level. In addition, the project-based approach that integrates AR technology has proven effective in supporting students' skill achievement, including aspects of preparation, work processes, and time efficiency. This study reinforces the importance of adopting innovative technology-based learning approaches, especially PjBAR, in vocational education to prepare graduates to face the challenges of the Industrial Revolution 4.0.

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AUTHORSHIP CONTRIBUTION

Conceptualization: Muslim, Ambiyar, Arwizet Karudin.
Data curation: Muslim, Ambiyar, Muhammad Syafiq Hazwan Ruslan.
Formal analysis: Muslim, Ambiyar, Doni Tri Putra Yanto.
Research: Muslim, Ambiyar, Arwizet Karudin, Muhammad Syafiq Hazwan Ruslan, Hsu-Chan Kuo, Doni Tri Putra Yanto.
Methodology: Ambiyar, Muhammad Syafiq Hazwan Ruslan, Hsu-Chan Kuo.
Project management: Muslim, Ambiyar, Arwizet Karudin, Muhammad Syafiq Hazwan Ruslan.
Resources: Muslim, Ambiyar, Muhammad Syafiq Hazwan Ruslan.
Software: Muslim, Doni Tri Putra Yanto.
Supervision: Ambiyar, Arwizet Karudin, Muhammad Syafiq Hazwan Ruslan, Hsu-Chan Kuo.
Validation: Ambiyar, Arwizet Karudin, Hsu-Chan Kuo.
Display: Muslim, Doni Tri Putra Yanto.
Drafting - original draft: Muslim, Doni Tri Putra Yanto.
Writing - proofreading and editing: Doni Tri Putra Yanto.