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ORIGINAL

Augmented Reality-Enhanced 5-Step Project-Based Learning Framework for Advancing Technical Education

Marco de Aprendizaje Basado en Proyectos de Cinco Pasos Potenciado con Realidad Aumentada para Avanzar en la Educación Técnica

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ABSTRACT

Introduction: in facing the challenges of the Industrial Revolution 4.0, vocational education requires a learning model that can integrate technology with real work practices. This study aims to develop, test the validity of the construction, and evaluate the practicality of a project-based learning model assisted by augmented reality in engineering education.
Method: the development model used is the ADDIE model. The construction validity test uses Confirmatory Factor Analysis to evaluate the model syntax, while the model's practicality is tested through a survey given to lecturers and students.
Results: the results of the CFA test show that all PjBAR model syntaxes have good construction validity and reliability. In addition, the results of the practicality test show that this model is very practical to use, with an average score of more than 80 % of the responses of lecturers and students.
Conclusion: the PjBAR model developed shows good validity and reliability as well as high practicality, so it is worthy of being applied in engineering education to improve the quality of learning through AR technology.

Keywords: Augmented Reality; Vocational Education; Construct Validity; Model Practicality; Quality Education.

RESUMEN

Introducción: enfrentando los desafíos de la revolución industrial 4.0, la educación vocacional requiere un modelo de aprendizaje que integre tecnología con prácticas laborales reales. Esta investigación tiene como objetivo desarrollar, probar la validez de construcción y evaluar el nivel de practicidad de un modelo de aprendizaje basado en proyectos con apoyo de realidad aumentada en la educación técnica.
Método: el modelo de desarrollo utilizado es el modelo ADDIE. La validación de la construcción se llevó a cabo mediante análisis factorial confirmatorio (CFA) para evaluar la sintaxis del modelo, mientras que la practicidad del modelo se evaluó a través de encuestas aplicadas a profesores y estudiantes.
Resultados: los resultados del CFA demostraron que toda la sintaxis del modelo PjBAR tiene buena validez y fiabilidad de construcción. Además, los resultados de la prueba de practicidad mostraron que este modelo es altamente práctico, con una puntuación promedio superior al 80 % según las respuestas de profesores y estudiantes.

Conclusiones: el modelo PjBAR desarrollado demuestra una buena validez y fiabilidad, así como un alto nivel de practicidad, por lo que es adecuado para ser implementado en la educación técnica para mejorar la calidad del aprendizaje mediante la tecnología de realidad aumentada.

Palabras clave: Realidad Aumentada; Educación Vocacional; Validez del Constructo; Practicidad del Modelo; Educación de Calidad.

INTRODUCTION

The digital era and the Industrial Revolution 4.0 demand the application of technology in various aspects of life, including in vocational education.[1] Vocational education must continue to adapt to these developments to produce graduates who are ready to face the world of work and technology that continues to develop. Innovation in learning, such as the use of technology-based learning media, is very important to prepare students with 21st-century skills and problem-solving abilities according to real conditions.

With the rapid development of technology, the application of innovative active learning approaches is becoming increasingly crucial. Lecturers are now required to integrate learning technology, one of which is interactive media such as Augmented Reality (AR), to create a more interactive and interesting learning experience.[2,3] AR allows lecturers to deliver material in a more varied way, as well as facilitate more effective communication and collaboration, which in turn can increase student engagement and motivation.[4,5,6]

A well-designed learning process by lecturers is very important to produce graduates who are ready to work and skilled, according to the goals of vocational education.[7,8] One effective approach in this case is project-based learning (PBL), which must be integrated with the latest technology. PBL that adopts relevant technology can develop students' skills, attitudes, knowledge, and competencies to be in line with technological developments and advances.[9,10,11]

PBL has long been recognized as an effective pedagogical approach to developing 21st-century skills, such as critical thinking, collaboration, and creativity.[12,13,14] However, the implementation of PBL still faces several significant challenges. One of the main problems is the need for intensive preparation, both in project design and learning planning.[15,16] This process takes longer to ensure that the project is aligned with the curriculum and learning objectives.[17,18] This deficiency is exacerbated by the limitations of lecturers in utilizing technology, which can reduce student motivation during project implementation. This causes the lack of optimal implementation of PBL in many educational institutions, especially in vocational education which relies heavily on the alignment of theory with real practice.

According to the World Economic Forum report,[19] cognitive skills are at the top of the workforce even though 80 % of companies are committed to investing in practical skills. UNESCO,[20] vocational education that focuses on skills plays a vital role in advancing access to decent work, entrepreneurship, and lifelong learning, through education that is relevant to the needs of the labor market and sustainability. Therefore, the urgency to create a learning model that can integrate technology with cognitive and skills development is crucial to preparing a workforce that is adaptive, innovative, and ready to face future demands.

As a solution to this problem, several experts offer an approach that focuses on integrating technology into learning. Efstratia[21] states the importance of utilizing technology in project-based learning to increase student motivation and engagement. Dincă et al.[22] suggest that lecturers be given training in utilizing AR-based learning technology and work-based learning. This aims to make lecturers more capable of facilitating and managing more complex projects, as well as encouraging active student involvement in the learning process.

However, although the solutions proposed by these experts are effective in improving the quality of PBL implementation, there has been no research that proposes the development of a fully AR-assisted PBL model designed to enable students to engage in more immersive and contextual learning. This can help overcome the problem of limited preparation time by providing lecturers with more accessible tools to design and manage projects. Based on the issues that have been identified previously, this study aims to develop, test the construct validity, and evaluate the level of practicality of an augmented reality-assisted project-based learning model in engineering education.

METHOD

Research Design

The development of AR-assisted PBL is a development research program consisting of 5 phases of activities that refer to the ADDIE model of instructional design.[23] The product development steps can be seen in Figure 1 which presents a flow diagram regarding the development of the AR-assisted PBL model.

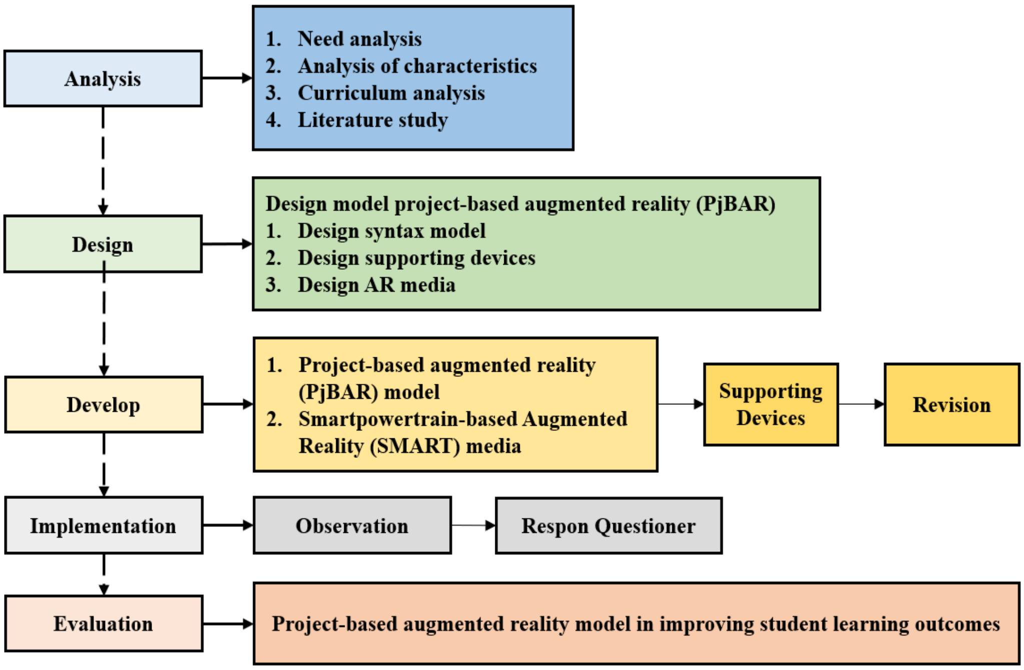
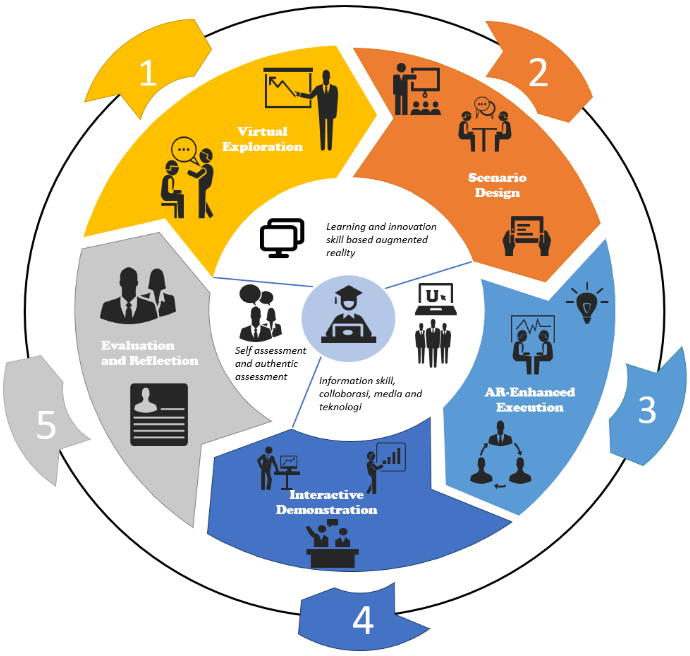


Figure 1. Research Procedure

During the development phase, the developed product (PjBAR) is tested for construct validation against the model syntax using the Confirmatory Factor Analysis (CFA) test.[24] The CFA analysis uses the Covariance-based Structural Equation Modeling (CB-SEM) approach.[25] The results of the CFA test analysis are used to test the validity of the PjBAR model syntax data by ensuring that the model meets academic standards so that it can be applied in the learning process. The PjBAR model has 5 syntaxes consisting of virtual exploration, scenario design, AR-enhanced execution, interactive demonstration evaluation, and reflection which can be seen in figure 2.



Source: Muslim et al.[26]

Figure 2. Project-based Augmented Realilty (PjBAR) Model

The assessment of indicators based on the syntax that has been developed can be seen in table 1. The preparation of these indicators aims to ensure a good model structure in order to achieve learning objectives optimally.

Table 1. PjBAR Model Construct Validation Grid

Assessed Aspects	Indicators
Virtual Exploration (VE)	Preparation of learning, delivery of objectives, and delivery of the Learning Implementation Plan (LIP)
	Providing motivation, conducting apperception, and ensuring student understanding in the use of AR media
	Exploring topics independently with the help of AR media
	Providing essential questions for the basis of problem-solving
Scenario Design (SD)	Providing students with the freedom to investigate problems through research, discussion, interviews, or using AR media
	Collaborating in making project plans and project topics
	Collaborating in compiling project activity schedules
	Lecturers monitor planning and create interactive learning activities
AR-Enhanced Execution (AR-EE)	Conducting discussions with students either face-to-face or online
	Monitoring students during project activities
	Guiding in completing project assignments by utilizing AR media
	Assisting and providing input on problems found in completing projects
Interactive Demonstration (IDE)	Providing opportunities for students to present project results
	Inviting other students to interact through constructive criticism, suggestions, and questions
	Providing assessments of projects that have been demonstrated
	Guiding students who face difficulties during project demonstrations
Evaluation and Reflection (EaR)	Providing feedback on student project work results
	Assessing project assignments based on assessment criteria and rubrics
	Inviting students to reflect process that has been passed
	Providing further guidance on aspects that have not been fully mastered by students

Source: Muslim et al.[26]

Scope of Study

The sample used for construct validation was 56 respondents consisting of 26 experts recommended by educational institutions. The remaining 30 respondents from students who participated in the learning process using the PjBAR model which was tested in the Powertrain course at Universitas Negeri Padang (UNP) as well as respondents for the practicality of the model. The practicality evaluation form was developed with a 5-level assessment scale.

RESULTS

PjBAR Model Construct Validation

CFA analysis was conducted to test the validity of the PjBAR model construct. The results of the analysis used the CB-SEM approach, with the results presented in Table 2. The results of the analysis showed that all syntaxes had Composite Reliability values above 0,7 and AVE above 0,5, which indicated good reliability and convergent validity. VE has Cronbach's alpha 0,824 and AVE 0,542, SD 0,806 and 0,516, AR-EE 0,801 and 0,506, ID 0,837 and 0,576, and EaR 0,823 and 0,536. Correlations between constructs such as VE-SD (0,966) and VE-ID (0,824) show significant relationships. These results confirm that each indicator can reflect its construct well.

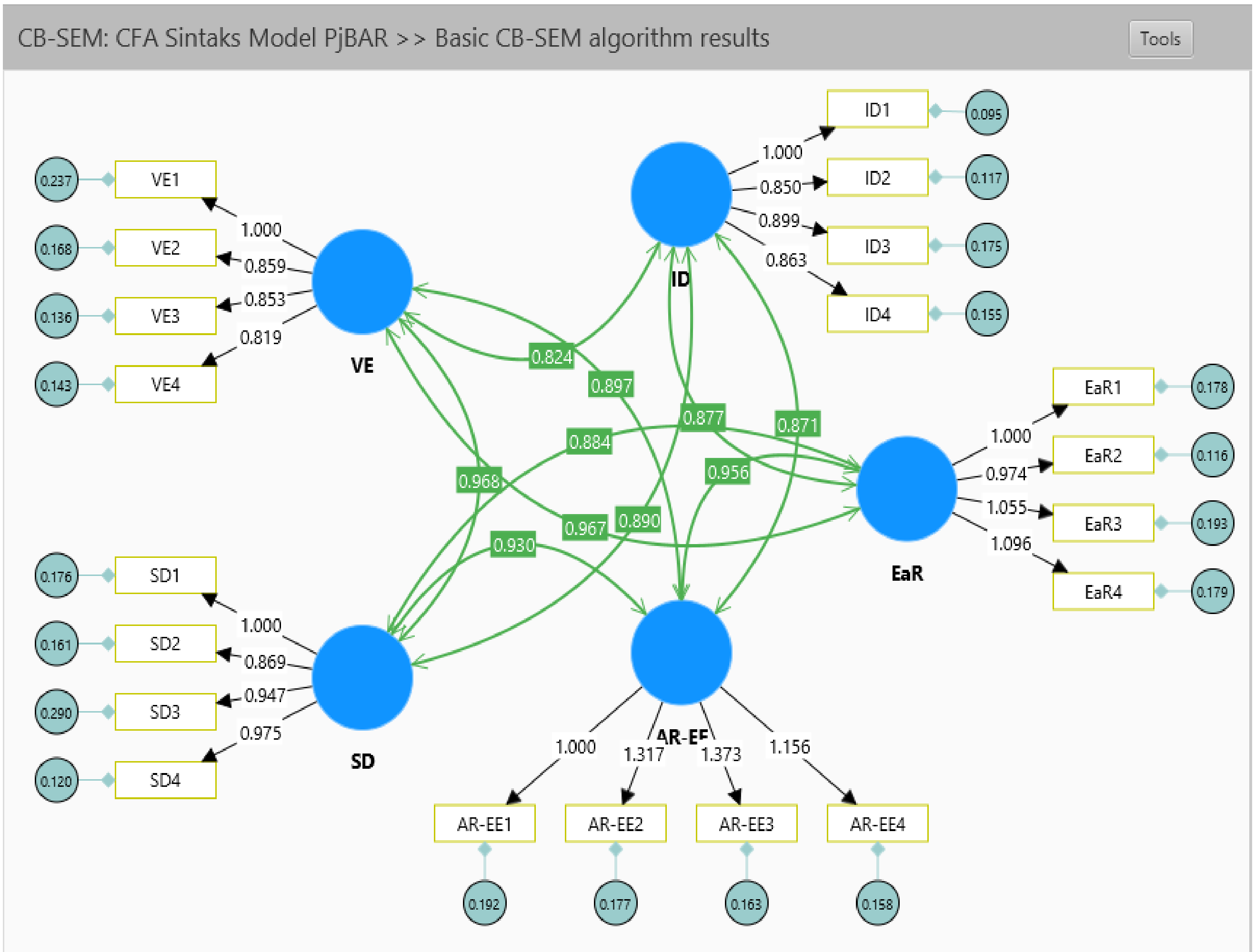
Table 2. CFA Analysis Output of PjbAR Model Syntax

Syntaxis	Indicator	Outer loading	Cronbach's alpha (Std)	Composite reliability (rho_c)	AVE
Virtual Exploration (VE)	VE1	0,720	0,824	0,823	0,542
	VE2	0,727			
	VE3	0,760			
	VE4	0,738			
Scenario Design (SD)	SD1	0,738	0,806	0,802	0,516
	SD2	0,706			
	SD3	0,629			
	SD4	0,791			
AR-Enhanced Execution (AR-EE)	AR-EE1	0,623	0,801	0,806	0,506
	AR-EE2	0,738			
	AR-EE3	0,764			
	AR-EE4	0,713			

Interactive Demonstration (ID)	ID1	0,837	0,837	0,843	0,576
	ID2	0,762			
	ID3	0,712			
	ID4	0,719			
Evaluation and Reflection (EaR)	EaR1	0,708	0,823	0,820	0,536
	EaR2	0,770			
	EaR3	0,712			
	EaR4	0,738			

Source: Muslim et al.[26]

There is a strong correlation between constructs such as VE and SD with a value of 0,966, and VE and ID with a value of 0,824 (figure 3). This indicates that the constructs are significantly related to each other. The results of the CFA test show that each syntax in the PjBAR model has good reliability with a Composite Reliability value above 0,7.



Source: Muslim et al.[26]

Figure 3. Output of the CFA Test of the PjBAR Model Syntax

The practicality of the PjBAR Model

The practicality test of the PjBAR model involved five Powertrain team teaching lecturers and 30 students. Complete results regarding the practicality of this model can be seen in Table 3. Based on the analysis results, the PjBAR model was declared very practical to use. The lecturer's response showed a total average score of 88,86 %, with all indicators above 80 %. The highest indicators were M9 and M14 (96 %), highlighting the ease of implementation and suitability of the model to learning objectives, while the lowest indicator was M8 (80 %), which remained in the Very Practical category. Student responses recorded an average score of 87,67 %, with the highest indicator M3 (92 %), related to the effectiveness and relevance of the model, and the lowest indicator M5 (83,33 %), which although very practical, can still be improved.

Table 3. The practicality of the PjBAR Model Lecturer and Student Responses

Aspect	Indicator	(Lecturer) Average Score (%)	Category	(Students) Average Score (%)	Category
PjBAR Model	M1	88,00	Very Practical	85,33	Very Practical
	M2	84,00	Very Practical	84,00	Very Practical
	M3	92,00	Very Practical	92,00	Very Practical
	M4	88,00	Very Practical	85,33	Very Practical
	M5	84,00	Very Practical	83,33	Very Practical
	M6	88,00	Very Practical	86,67	Very Practical
	M7	92,00	Very Practical	90,67	Very Practical
	M8	80,00	Very Practical	88,00	Very Practical
	M9	96,00	Very Practical	88,67	Very Practical
	M10	88,00	Very Practical	88,67	Very Practical
	M11	92,00	Very Practical	88,00	Very Practical
	M12	88,00	Very Practical	88,67	Very Practical
	M13	88,00	Very Practical	87,33	Very Practical
	M14	96,00	Very Practical	90,67	Very Practical
Total Average (%)		88,86	Very Practical	87,67	Very Practical

Source: Muslim et al.[26]

DISCUSSION

The results of the study indicate that the Project-based Augmented Reality (PjBAR) model has good construct validity and reliability based on the Confirmatory Factor Analysis (CFA) analysis. This model consists of five learning syntaxes, namely virtual exploration, scenario design, AR-enhanced execution, interactive demonstration, and evaluation and reflection. Each syntax shows an outer loading value above 0,6, Composite Reliability above 0,7, and Average Variance Extracted (AVE) above 0,5, indicating the consistency of the indicators in reflecting their constructs.

CFA on the PjBAR model is in line with the research of Andersson et al.[27] on the validation of the hierarchical structure of the learning model, although this model is innovative through the integration of AR technology. The Virtual Exploration syntax is supported by the research of Fokides & Antonopoulos[28] which highlights the relationship between intrinsic motivation and immersion in VR-based learning. The Interactive Demonstration Evaluation and Reflection syntax are relevant to the multidimensional validation described by Makransky et al.[29] while the Scenario Design syntax is by the iterative approach in cross-project learning discussed by Alashwal & Abdul-Rahman.[30] The AR-Enhanced Execution syntax is supported by the findings of Barrett et al.[31], which show the superiority of immersive technology in improving learning outcomes.

The PjBAR model also shows high practicality with an average score of 88,86 % from lecturers and 87,67 % from students, both in the very practical category. These results are relevant to several researches[32,33,34,35,36,37] which emphasize motivation, implementation, and reflection. However, technical challenges and the need for interactivity as expressed in the study of Schott et al.[38] on Virtual Situated Learning Environments (VSLE) need to be considered to improve the implementation of PjBAR. Overall, although this model is effective and practical, optimization of the methodology and solutions to technical constraints remain important concerns.

The PjBAR model presents innovation through the integration of AR technology, which overcomes the challenges of intensive preparation in the design and implementation of learning projects. With syntax such as Scenario Design and AR-Enhanced Execution, this model provides an efficient structure for educators to design projects that are in line with the curriculum and learning objectives while reducing the burden of preparation. The Virtual Exploration and Interactive Demonstration Syntaxes offer solutions to educators' limitations in utilizing technology, by providing an AR-based platform that enhances immersive exploration and interaction. This innovation supports student motivation and the development of 21st-century skills such as critical thinking, collaboration, and creativity.

This study has limitations in the relatively small number of respondents so external validity cannot be generalized. In addition, the AR technology used is still marker-based, limiting the flexibility of its use. AR can also only operate under certain conditions and is not yet compatible with various smartphone devices, especially those based on other than Android. This study also only evaluates the construct validation and practicality of the PjBAR model without measuring its effectiveness in depth. Further research needs to involve more respondents to increase external validity, develop marker-free AR technology to increase efficiency and flexibility and expand AR compatibility with various devices and operating systems. In addition, future research is recommended to evaluate the effectiveness of the PjBAR model, covering various educational contexts and measuring long-term impacts.

CONCLUSION

This study successfully developed and tested the construct validity of the Project-based Augmented Reality (PjBAR) model using CB-SEM-based CFA analysis. This model consists of five main syntaxes: virtual exploration, scenario design, AR-enhanced execution, interactive demonstration, and evaluation and reflection. The results of the analysis show that the model has strong construct validity and reliability. In terms of practicality, the PjBAR model is considered very practical by lecturers and students, making it effective to be applied in learning. With the integration of AR technology, this model offers an interactive, innovative, and relevant learning approach to industry needs, and can improve the learning experience in the digital era.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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