Problem-Based Learning Integrated With Augmented Reality: Development and Teacher Perspective

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Abstract
The study aimed to develop a Problem-Based Learning (PBL) model integrated with augmented reality (AR) and to analyze teachers' perceptions of using the AR application for teaching mathematics. This research followed a Research and Development (R&D) design to develop and validate the PBL model using an AR application. Five experts evaluated the model, and fifty secondary school teachers tested the GLARE (Geometry Learning using Augmented Reality Experience) application. Data was collected using a 5-point Likert scale for expert evaluation and teacher perception scales. Experts reported the model, learning content, and AR application were implementable, with a mean score of 4.28 (SD=0.55). They reported that the PBL-based lesson plan provided a comprehensive overview of the learning process and clearly outlined the steps for using the model. They also found that the learning content was consistent with the learning objectives, and the PBL activities were clearly explained and relevant to the material. The illustrations in the learning materials were relatable to everyday life. Additionally, based on teacher perceptions, the total mean score was 4.43 (SD=0.59), indicating teachers provided positive feedback on using the GLARE for teaching. Most teachers agreed it would create a joyful, fun, and interesting learning environment and help teach geometry topics. However, some teachers were unsure if GLARE would simplify teaching, enhance effectiveness, or promote student self-learning. They were also uncertain about using GLARE regularly in their teaching or recommending it to colleagues.

Keywords: Problem-Based Learning, Augmented Reality, Learning Media, Teacher Perception

1 Introduction

Mathematics is one of the most useful cognitive tools, which is crucial because it serves as the foundation for many fields and is crucial for the advancement of modern society (Poçan et al., 2023). However, many students mistakenly believe that success in mathematics requires memorizing countless unrelated facts, so they disengage, give up, and adopt a fixed mindset in mathematics (Hudson, 2021). The complex ideas in mathematics classes can frequently only be presented in a very abstract way because traditional teaching methods like blackboard lectures or remote classrooms due to the COVID-19 epidemic have limited visualization capabilities (Schutera et al., 2021). For these reasons, it is necessary to develop learning applications that offer an immersive and interactive environment because traditional books are insufficient for some topics that demand a high level of visualization in the 3D world (Gargrish et al., 2021). In this regard, Augmented Reality (AR) has been demonstrated to be a very effective method that not only captivates students but educates them on the importance of technology while improving their academic performance (Ab Halim et al., 2020). AR is a term that describes technologies that dynamically integrate real-world settings with context-based digital information (Ibáñez & Delgado-Kloos, 2018; Sommerauer & Müller, 2014). AR technology provides a better learning environment and experience and enables teachers to help students understand complex ideas and procedures more efficiently and effectively (Gargrish et al., 2021; Singh et al., 2019).

Problem-based Learning (PBL) refers to a learning environment in which problems become the main stimulation for learning (Roh, 2003). PBL is well suited to assisting students in becoming active learners because it grounds learning in real-world problems and ensures students are responsible for their learning (Hmelo-Silver, 2004). This approach enables students to actively engage with real-world situations while learning critical information and concepts from the lecture material to help students develop their critical thinking and problem-solving skills (Darhim et al., 2020). Although there are studies that integrate emerging technologies into PBL, there is currently not sufficient empirical research that provides adequate evidence for the integration of AR to support PBL at the middle or junior high school level (Fidan & Tuncel, 2019). Therefore, this study could be a beneficial resource for educators and educational technologists interested in integrating immersive technologies on PBL, specifically through realistic AR designs, to enhance students' comprehension of complex or abstract geometric concepts in mathematics. Because it was well-known that geometry required students to employ visualization skills.

2 Research Question

The purpose of the current study was to develop a PBL model integrated with AR and to analyze teachers' perceptions of using the AR application for teaching mathematics. The study's research questions are as follows:

1. How to develop the model of PBL integrated with AR for teaching mathematics?
2. What are teachers' perceptions of using the AR application for teaching mathematics?

3 Research Method

This study applied Research and Development (R&D) to develop and validate the PBL model using an AR mathematics learning instrument. The PBL model integrated AR and followed the six stages outlined by Fidan and Tuncel (2019): presentation of problem, definition of problem, determining the (un)known, data gathering and sharing, generating solution, and

reflection and evaluation. Additionally, it involves AR applications created to illustrate the learning content and support the stages of PBL related to identifying the (un)knowns, collecting data, reflecting, and evaluating within the PBL process.

Furthermore, the AR application was designed to introduce students to 3D geometry concepts covering several 3D objects, including the cube, cuboid, prism, pyramid, cone, cylinder, and sphere. Unity software had been selected as the tool for creating content within the AR environment. To ensure that users could easily access AR content in real-world scenarios, the Vuforia plugin served as the server for detecting target images through markers in the real-world environment. Android was selected as the operating system for the application because it is a preferred smartphone OS among Indonesian students.

The PBL model and AR application, including lesson plan, learning content, and activities, were evaluated by five experts who were all mathematics education lecturers. A group of fifty secondary school mathematics teachers then tested the AR application. They filled out a perception questionnaire to evaluate the AR learning materials, adapted from Faqih (2022); Pasalidou and Fachantidis (2021); Mutambara and Bayaga (2021); Cabero-Almenara et al. (2019); Su (2019); Weng et al. (2018); Rese et al. (2017) that consists of 21 items. A 5-point Likert scale rating system was used to anchor statements (1=Strongly disagree, 2=Disagree, 3=Neutral; 4=Agree, 5=Strongly agree). This study used quantitative data collection methods, such as expert reviews and percentages collected through the teacher perception scale.

4 Results and Discussion

RQ 1: How to develop the model of PBL integrated with AR for teaching mathematics?

This study aimed to develop a PBL model integrated with AR for teaching geometry topics. The model's feasibility was evaluated by five experts, who provided a total mean score of 4.28 with a standard deviation of 0.55, as shown in Table 1. Additionally, the PBL-based lesson plan received a mean score of 4.33 with a standard deviation of 0.62. The experts noted that the lesson plan offered a clear and comprehensive overview of the learning process, detailing the steps required to implement the model effectively. Regarding the learning content and activities in the PBL lesson plan, a mean score of 4.29 with a standard deviation of 0.46 was recorded. Experts highlighted that the learning assessments were well-aligned with the objectives, and the PBL activities were clearly described and appropriately linked to the learning content. They also commended the use of familiar illustrations that were relevant to real-life contexts. Based on this evaluation, the study implemented the PBL model proposed by Fidan and Tuncel (2019), which comprises six stages: (1) presentation of the problem, (2) definition of the problem, (3) determining the (un)knowns, (4) data gathering and sharing, (5) generating solutions, and (6) reflection and evaluation, as illustrated in Figure 1.

The AR application GLARE (Geometry Learning using Augmented Reality Experience) covered several topics related to 3D geometry, including surface area, volume, and the properties of 3D objects. It featured a variety of three-dimensional shapes such as the cube, cuboid, prism, pyramid, cone, cylinder, and sphere. As shown in Table 1, the application received a mean value of 4.20 and a standard deviation of 0.55, with experts agreeing that the learning objectives and GLARE content were well-aligned. They also rated the application as both useful and easy to use. This finding aligns with the study by Koparan et al. (2023), which demonstrated that AR-based materials are effective for teaching the surface area of a

cube. Furthermore, integrating AR into the teaching and learning process with a contextualized approach significantly enhances students' academic performance and attitudes.

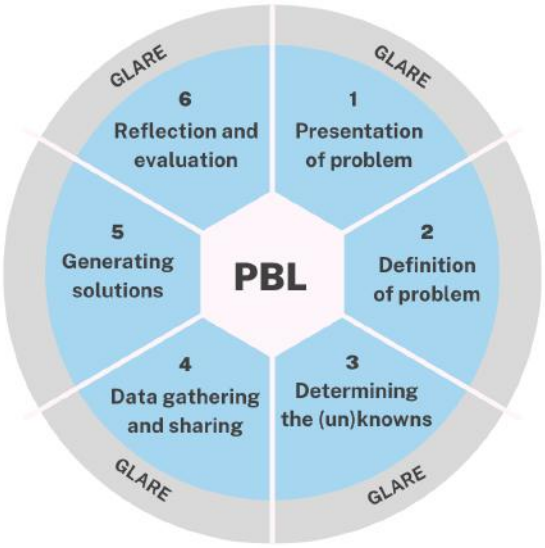

Figure 1: PBL Integrated With AR

Table 1: The Mean Scores of the Experts' Reviews

	Mean	SD
Lesson plan	4.33	0.62
Learning content and activities	4.29	0.46
AR application	4.20	0.55
Total	4.28	0.55

(Source: Authors)

RQ 2: What are teachers' perceptions of using the AR application for teaching mathematics?

The study also aimed to explore the perspectives of secondary school mathematics teachers on using GLARE for learning 3D geometry. Teachers participated by completing a questionnaire with a 5-point Likert scale, and their responses were used to construct a perception of the GLARE application for teaching mathematics.

According to teachers' perceptions, the total mean score was 4.43 (SD=0.59), revealed that most teachers gave good feedback regarding using GLARE in the mathematics class. Most of them believed that the GLARE application would positively affect the learning process, as proven by the mean scores above 4 for each item, which indicated that the GLARE application had significant potential for both effective teaching and enhancing academic achievement. They agreed that GLARE would create a joyful, engaging, and stimulating learning environment and believed it would be beneficial for teaching geometry concepts. Most teachers reported that the application had the potential to improve student performance and effectiveness. Additionally, they would frequently use GLARE and incorporate it into their lesson plans to foster students' interest in learning. Consistent with the findings of Cao and Yu (2023), integrating AR technologies in education could potentially engage and excite learners, fostering positive attitudes toward AR-supported learning.

On the other hand, some teachers were uncertain whether GLARE would foster independent learning in students and effectively simplify and enhance instruction. Compared to traditional

learning methods, some respondents questioned the application's flexibility and ease of use. Additionally, they were hesitant about recommending GLARE to their colleagues or using it regularly in their classrooms.

5 Conclusion

This study focused on developing a PBL model integrated with AR and analyzing teachers' perceptions of using the AR application for teaching mathematics. The findings indicated that experts observed that the lesson plan based on the PBL model provided a comprehensive overview of the learning process and clearly outlined the steps for using the model. It was well-organized, easy to follow, and facilitated active learning. Additionally, they found that the learning assessment material was consistent with the learning objectives, and the PBL activities were clearly explained and relevant to the material. The learning materials' illustrations were realistic and applicable to daily life. Moreover, most teachers expressed approval of GLARE's use in the classroom, affirming that it will improve geometry teaching and foster a fun, interesting, and engaging learning environment. However, some teachers were unclear if GLARE would make instruction easier, increase efficiency, or encourage students to self-learn. Also, they were unsure about GLARE's regular classroom implementation and whether to suggest it to their colleagues.

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Data Availability

The datasets generated or/and analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

None.

Statement of Ethics

This study protocol was reviewed and approved by The Research Ethic Committee Institute for Research and Community Service University of Bengkulu, approval number 21/KER-LPPM/EC/2023.

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