

PROBLEM-BASED LEARNING ASSISTED BY AUGMENTED REALITY ON THE RESPIRATORY SYSTEM TOPIC: A STUDY STUDENTS' CRITICAL THINKING SKILLS AND LEARNING MOTIVATION

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ABSTRACT

This study aims to examine the effectiveness of the Problem-Based Learning (PBL) model assisted by Augmented Reality (AR) technology regarding the respiratory system in improving students' critical thinking skills and learning motivation. The research method used was a quasi-experimental design with a one-group pretest-posttest model. The subjects were 30 eleventh-grade students from a public high school in Garut City. Research instruments included a critical thinking test and a learning motivation questionnaire. The results showed a significant improvement in students' critical thinking scores after the implementation of PBL with AR support. Additionally, learning motivation data analyzed from 16 statement items revealed an average score of 76.36%, which falls into the high category. Each indicator of learning motivation also showed positive outcomes, with the highest score on the meaningfulness indicator at 81% and the lowest on the attention indicator at 70%. These findings indicate that the implementation of PBL assisted by AR enhances students' critical thinking and promotes overall learning motivation. Therefore, innovative instruction that integrates AR technology can serve as an effective alternative in biology education, particularly for abstract topics such as the respiratory system.

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INTRODUCTION

Biology learning at the high school level is often faced with the challenge of material complexity and low student interest in learning (Christopoulos et al., 2023; Suwono et al., 2023). One topic that is considered difficult for students to understand is the respiratory system, because it contains abstract and microscopic concepts that are not observed directly (Khotimah & Ahmadi, 2024; Handayani & Rohani, 2025). This phenomenon causes biology learning to often only be oriented towards memorization, not conceptual understanding or high-level thinking skills (McDaniel et al., 2022).

This condition has an impact on students' low critical thinking skills. In fact, critical thinking is one of the important competencies of the 21st century that students must have to be able to select information, analyze problems, and make decisions rationally (Živković, 2016; Rauscher & Badenhorst, 2021; Plummer et al., 2022). Critical thinking skills in the context of biology help students understand the relationship between the structure and function of body organs, including the respiratory system (Cahyani et al., 2022).

However, conventional learning approaches still dominate in biology classes. Teachers tend to be the only source of information, while students play a passive role in the learning process (Watters & Watters, 2007; Carrió et al., 2011; Cleveland et al., 2017). As a result, student engagement is low and learning motivation decreases (Sadler et al., 2015; Mariati, 2024). This situation is an important concern in efforts to transform learning in the digital era.

One of the innovative solutions offered is the application of the Problem-Based Learning (PBL) model. This model places students as the center of learning and emphasizes solving contextual problems that are relevant to real life (Xu et



al., 2021; Muzaini et al., 2022; Anggraeni et al., 2023). In PBL, students are trained to identify problems, seek information, and formulate solutions, which indirectly encourages increased critical thinking skills (Fitriani et al., 2022; Kusuma, 2023).

In addition to learning models, educational technology also plays an important role in enriching the learning experience (Alam & Mohanty, 2023; Zhao et al., 2024). One of the rapidly developing technologies is Augmented Reality (AR), which can present three-dimensional objects in the real world interactively and in real time (Dargan et al., 2023; Coştu, 2025). AR provides opportunities for students to visualize the respiratory organs in a real and comprehensive manner, making it easier to understand abstract concepts (Ibáñez & Delgado-Kloos, 2018).

The integration of PBL and AR is believed to create a more intriguing, interactive, and meaningful learning environment (Lee, 2022; Arici & Yilmaz, 2023). PBL presents students with challenging problem scenarios, while AR facilitates their visual exploration and hands-on experience with the biological objects under study. The combination of the two creates a learning synergy that improves conceptual understanding and arouses students' learning motivation (Arici & Yilmaz, 2023).

Learning motivation is a key factor in educational success. Motivated students tend to have a greater willingness to engage in learning activities, complete tasks, and achieve learning goals (Zainuddin, 2018). According to the motivation theory of Deci and Ryan (2020), a learning environment that supports autonomy, competence, and relatedness will encourage students' intrinsic motivation. In this case, AR-assisted PBL provides a space for exploration and collaboration that supports these three aspects.

Several previous studies have shown that problem-based learning is effective in improving critical thinking skills (Zubaidah et al., 2017; Dakabesi & Luoise, 2019; Sholihah & Lastariwati, 2020). Similarly, studies have demonstrated that the immersive and interactive visual experience of AR enhances students' learning motivation (Akçayır & Akçayır, 2017; Georgiou & Kyza, 2018; Garzón et al., 2019; Abad-Segura et al., 2020). However, there have been few studies that integrate these two approaches simultaneously on respiratory system material.

Therefore, this study tries to answer the need for innovation in biology learning by implementing an AR-assisted PBL model on respiratory system material. The aim is to examine the effectiveness of this approach in simultaneously improving students' critical thinking skills and motivation to learn.

METHOD

This study uses a quantitative approach with a quasi-experimental type and a one-group pretest-posttest design. This design allows researchers to measure the effect of Problem-Based Learning (PBL) treatment assisted by Augmented Reality (AR) on students' critical thinking skills and learning motivation by comparing scores before and after treatment. This design is considered suitable because it considers the limitations of carrying out full control over external variables in a real classroom environment.

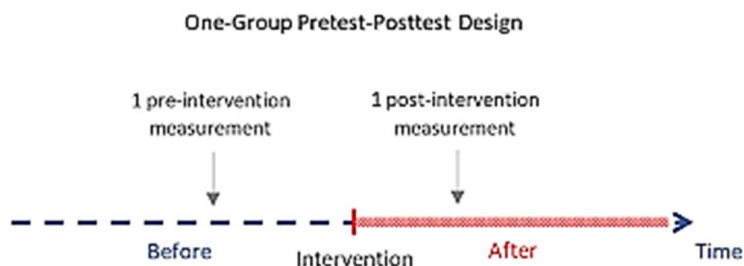


Figure 1. One Group Pretest-Posttest Design

The subjects in this study were 30 grade XI students at a public high school in Garut City who were selected using a purposive sampling technique, considering the school's readiness to use digital devices and the availability of adequate technological infrastructure, such as gadgets and internet connections. This study involved two dependent variables, namely students' critical thinking skills and learning motivation, and one independent variable, namely the problem-based learning model assisted by augmented reality (AR).

The instruments used in this study included a critical thinking test, which was compiled based on indicators from Facione (2011), such as interpretation, analysis, evaluation, inference, explanation, and self-regulation. This test consisted of 15 multiple-choice items that were tested for validity and reliability. Additionally, a learning motivation questionnaire based on the ARCS model from Keller was utilized (Chang, 2021); it included indicators of attention, relevance, confidence,

and satisfaction and comprised 16 items using a 4-point Likert scale that underwent content validity testing and item recapitulation with SPSS.

The research procedure was carried out in three stages, namely preparation (preparation of AR devices and media for the 3D respiratory system), implementation (pretest, application of AR-assisted PBL for 4 meetings, posttest, and motivation questionnaire), and evaluation (analysis of pretest-posttest and questionnaire data). Critical thinking ability data were analyzed using a paired sample t-test after first being tested for normality with Shapiro-Wilk, while learning motivation data were analyzed descriptively and quantitatively in the form of a percentage score for each indicator classified according to the motivation category. The validity of the instrument content was reviewed by three experts consisting of a biology education lecturer, a biology teacher, and an expert in learning technology, while the reliability of the questionnaire was tested using Cronbach's alpha, with results > 0.7 indicating high reliability.

RESULTS AND DISCUSSION

Results

Critical Thinking Skills

The results of the analysis of students' critical thinking skills were obtained from the pretest and posttest tests conducted before and after the implementation of problem-based learning assisted by augmented reality. The following is a recapitulation of students' average scores:

Table 1. Critical Thinking Skills

Test Stage	Mean Score	Standard Deviation
<i>Pretest</i>	52.13	9.84
<i>Posttest</i>	76.27	8.52

The paired sample t-test showed a significant value (Sig. 2-tailed) of $0.000 < 0.05$, which means there is a significant difference between the pretest and posttest scores. This shows that the AR-assisted PBL model significantly improves students' critical thinking skills. This increase is in line with the characteristics of PBL, which encourages students to think reflectively and analytically and provide solutions to real problems.

Learning Motivation

Student learning motivation was analyzed using a questionnaire referring to the ARCS theory by Keller (1987), which includes five indicators: attention, relevance, confidence, satisfaction, and meaningfulness.

Table 2. Learning Motivation

Indicator	Mean Score (%)	Category
Attention	70	High
Relevance	75	High
Confidence	74	High
Satisfaction	78	High
Meaningfulness	81	Very High
Average	76.36	High

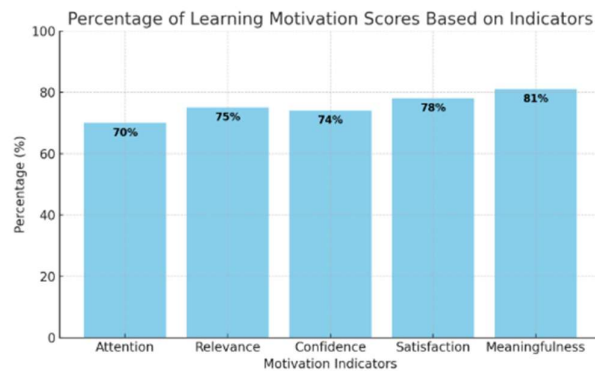


Figure 2. Learning Motivation Graph

The graph above shows that all learning motivation indicators are in the high category, with the meaningfulness indicator having the highest value (81%). This shows that students feel that learning has meaning and relevance in real

life, which is driven by AR visualization that makes abstract material concrete. The indicator with the lowest score is attention (70%), which, although still in the high category, shows that students' attention still needs to be optimized, especially at the beginning of learning.

Discussion

The increase in students' critical thinking skills after the implementation of Problem-Based Learning (PBL) assisted by Augmented Reality (AR) shows a positive impact from the combination of innovative learning models with interactive technology. The average score increased significantly from 52.13 in the pretest to 76.27 in the posttest, which indicates significant development in mastery of high-level thinking skills. In the context of biology learning, especially the abstract and complex respiratory system material, the use of AR allows students to see physiological structures and processes visually. This is very helpful in building deep understanding, which is an important foundation for critical thinking.

PBL encourages students to face real problems, which in this study are associated with phenomena such as air pollution, smoking, and respiratory disorders. The design of these problems encourages students to identify problems, formulate hypotheses, and develop solutions based on relevant scientific information.

The ability to provide reasons, a key indicator of critical thinking, has significantly increased. In the PBL scenario, students must explain the relationship between smoking habits and damage to the respiratory system using data and observation results, which are complemented by AR visualizations of lungs damaged by cigarette smoke. AR visualization prompts students to draw comparisons between the structure of organs in their normal and disturbed states. This technique encourages analytical and evaluative thinking activities, such as concluding the physiological impact of respiratory system dysfunction based on the three-dimensional images they observe. Another indicator that is developing is the ability to construct arguments and make decisions. When students are asked to create a health campaign related to the respiratory system, they refer to their findings from the PBL scenario as well as observations using AR. This process involves assessing evidence, weighing solutions, and choosing the best alternative.

According to Indrašienė et al. (2023), critical thinking includes the ability to think logically, systematically, and reflectively. In this learning, students do not only memorize information but are required to examine data, verify truths, and present solutions that can be scientifically accounted for. In addition to cognitive aspects, student involvement also increases effectively. Group discussions facilitated in the PBL model provide space for students to express opinions, hear friends' perspectives, and revise their understanding collaboratively. This contributes greatly to the development of reflective and argumentative thinking. These results are in line with previous research by Hafizah et al. (2024), which shows that PBL supports the development of critical thinking skills through learning experiences that emphasize exploration, collaboration, and problem solving. When AR elements are added, the experience becomes more immersive and contextual.

Overall, the use of AR-assisted PBL learning has proven effective in improving students' critical thinking skills. The integration of problem-based learning experiences and interactive media provides a stronger stimulus for thinking while enriching students' analytical and evaluation skills in understanding the respiratory system. In addition to critical thinking, learning motivation also increased after the implementation of AR-assisted PBL learning. The results of the questionnaire indicated that the average student motivation score reached 76.36%, which is in the high category. This data shows that students feel interested and involved and enjoy the ongoing learning process.

Building upon the attention indicator, students showed quite high attention (70%), although it was the lowest score among other indicators. This result indicates that although AR-based learning is visually attractive, it still needs to strengthen strategies in the early stages of learning to build students' enthusiasm and curiosity from the start. Strategies that can be used to increase attention are the use of visual triggers or actual phenomena at the beginning of learning, such as video displays about the lungs of active smokers or air pollution simulations. The result can be an initial bridge that connects real life with the topic to be studied.

The relevance indicator has a score of 75%, indicating that students feel that what they are learning is related to their lives. PBL provides a real context that makes students feel that the respiratory system material is not just for exams but is important for their health and daily lives. The confidence indicator scored 74%, reflecting students' confidence in participating in learning. The success of completing tasks and challenges in the PBL scenario, as well as better understanding thanks to AR visualization, provides a positive experience that increases students' confidence in learning biology.

Student satisfaction is also relatively high with a score of 78%. Students feel satisfied because they not only understand the material but also feel successful, appreciated, and supported during the learning process. This reflects the success of the learning design in creating a fun and meaningful atmosphere. The meaningfulness indicator has the

highest score of 81%. This figure shows that students consider their learning to be truly meaningful. By linking respiratory system material to real issues and concrete visualizations, students feel that what they are learning is relevant and important for life.

The PBL model allows students to become active agents in learning. They not only receive information but also explore, discuss, and make decisions. This contributes to increasing intrinsic motivation because students feel they have control over their learning process (Deci & Ryan, 2020). AR visualization also plays an important role in increasing the appeal and meaningfulness of learning. Students can directly see the structure of the respiratory system interactively, which they cannot find in conventional learning based on text or static images. Thus, it can be concluded that problem-based learning assisted by augmented reality is not only effective in improving students' critical thinking skills but also successfully fosters high learning motivation. These two aspects are important foundations in creating an active, enjoyable, and meaningful biology learning experience.

CONCLUSION

Learning using the Problem-Based Learning (PBL) model supported by Augmented Reality (AR) media on the respiratory system material shows positive results in improving the quality of the learning process. The PBL model encourages students to be more active in identifying and solving problems through group work, discussions, and independent information searches. This approach also develops critical, creative, and collaborative thinking skills, which are very important in 21st-century learning. Meanwhile, the use of AR media provides a more captivating and interactive learning experience because it can display three-dimensional visualizations of abstract and complex materials, such as organ systems in the human body. This helps students understand concepts better, increases learning motivation, and strengthens memory. Therefore, the integration between PBL and AR is an effective and innovative learning strategy to improve student learning outcomes, especially in biology learning.

AUTHOR CONTRIBUTIONS

All authors participated in the conceptualization, design, data collection, analysis, interpretation, writing, and revision of the article. All authors approved the finalized manuscript.

CONFLICT OF INTEREST STATEMENT

The author claims there are no conflicts of interest regarding the publishing of this paper. The oversight and assistance provided by supervisors fulfilled their professional responsibilities, and no financial, personal, or other affiliations influenced the research and results presented in this work. We have applied maximum effort to conduct and present the research with the highest standards of integrity and transparency.

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