APTISI Transactions on Technopreneurship (ATT)
Vol. 8, No. 1, March 2026, pp. 339−350
E-ISSN: 2656-8888 | P-ISSN: 2655-8807, DOI:10.34306

Effects of Mobile Learning on Critical Thinking Skills Using Problem Based Learning

Teguh Febri Sudarma[1*], Festiyed[2], Muhyiatul Fadilah[3], Skunda Diliarosta[4], Ratna Tanjung[5], Goh Yao[6]
[1,2,4]Department of Science Education, Padang State University, Indonesia
[3]Department of Biology, Padang State University, Indonesia
[5]Department of Physics, Universitas Negeri Medan, Indonesia
[6]Department of Business and Economics, Ijiis Incorporation, Singapore
[1]teguhfebri@unimed.ac.id, [2]festiyed@fmipa.unp.ac.id, [3]muhyifadilah@fmipa.unp.ac.id, [4]skunda@fmipa.unp.ac.id, [5]ratna.tg@gmail.com, [6]goh.yao@ijiis.asia
***Corresponding Author**

Article Info

Article history:

Submission March 23, 2025
Revised June 18, 2025
Accepted December 23, 2025
Published February 18, 2026

Keywords:

Problem-Based Learning
Mobile Learning
Critical Thinking Skills
Students
Effectiveness

ABSTRACT

Promotion objectives, tourism promotion mix, and expectations play significant roles in attracting tourists to destinations. Videos have emerged as effective promotional tools, showcasing the actual conditions of tourist attractions. **This research investigates** how promotional objectives and the tourism promotion mix, with the moderation of expectations, can influence tourist interest. **A total of 247 respondents** were sampled for this study. The respondents evaluated videos of Kebon Rojo Park, Blitar, East Java, and completed a questionnaire. The analysis method used was Partial Least Squares (PLS), suitable for handling complex data with multiple variables. **The study found** that both promotion objectives and the tourism promotion mix positively influenced tourist interest. However, expectations did not moderate the relationship between the promotional strategies and tourist interest. This indicates that expectations do not strengthen or weaken the effects of promotional objectives and tourism promotion mix on tourist interest. **The research suggests** that while expectations play a role in shaping perceptions, the key to attracting tourists lies in effective promotional strategies tailored to the target market segment. This highlights the importance of using accurate and attractive promotional materials to stimulate interest in visiting destinations like Kebon Rojo Park.

This is an open access article under the CC BY 4.0 license.

DOI: https://doi.org/10.34306/att.v8i1.674
This is an open-access article under the CC-BY licensee (https://creativecommons.org/licenses/by/4.0/)
©Authors retain all copyrights

1. INTRODUCTION

Digital transformation in education has driven significant changes in the way students learn and interact with information [1, 2]. These changes demand learning methods that are more effective, interactive, and in line with 21st-century needs, especially in the development of critical thinking skills [3]. Critical thinking skills are becoming increasingly important in the world of work and everyday life because they enable individuals to analyze information, evaluate arguments, and make rational decisions [4, 5]. In the context of Sustainable Development Goal (SDGs) 4, which emphasizes quality education [6], these skills are crucial for fostering lifelong learning opportunities for all. However, conventional learning methods that are still dominant, such as lectures and memorization, often do not provide enough space for students to develop critical thinking skills optimally [7].

To overcome the limitations of conventional learning methods, the Problem-Based Learning (PBL) approach has been widely applied in various fields of education [8–10]. This method emphasizes problem-based learning that encourages students to think critically, collaborate, and find solutions to real problems [11]. Research shows that the application of PBL in medical and social science education successfully improves students' understanding and engagement in the learning process [12]. In alignment SDGs 4, which focuses on promoting education for sustainable development and global citizenship [13], PBL contributes to enhancing students' problem-solving abilities and real-world skills. However, the implementation of PBL is not free from challenges, such as limited face-to-face time, lack of learning resources, and teacher readiness in adopting this method [14].

As a solution to these limitations, Mobile Learning (M-Learning) emerged as an approach that can complement PBL by providing flexible access to learning materials digitally [15]. With M-Learning, students can access learning resources anytime and anywhere, increasing flexibility and independence in the learning process [16, 17]. This model supports SDGs 9, which emphasizes the need for fostering innovation, particularly in education technologies. Research conducted by Aliyu showed that a PBL approach, when integrated with climate change Virtual Reality (VR) videos in a mobile application, effectively improved students' critical thinking skills compared to traditional teaching methods [18].

In addition, the combination of PBL and M-Learning is also proven to increase student learning motivation [19–21]. The use of PBL-based learning videos can make students more active and independent in understanding the concepts learned [22, 23]. This approach also provides a more interesting learning experience [24], so that students are more interested in exploring complex concepts [25, 26]. Thus, PBL-assisted M-Learning not only improves critical thinking skills but also encourages more in-depth and interactive learning [27, 28], further supporting SDGs 4 and its focus on promoting inclusive and equitable quality education [29].

However, although many studies have demonstrated the effectiveness of PBL and M-Learning separately, there are still gaps in the understanding of how their integration can be optimized across different educational contexts [30, 31]. Some of the main challenges in the implementation of this method include teachers' readiness in adopting technology, adequate infrastructure, as well as evaluation methods that are suitable for problem-based learning approaches [32]. Therefore, further research is needed to develop a more effective, efficient, and sustainable learning model [33, 34].

Based on this background, this study aims to analyze the effectiveness of Problem-Based Learning assisted by Mobile Learning in improving students' critical thinking skills [35, 36]. Using an experimental research approach, this study will evaluate the impact of using this learning strategy compared to conventional learning methods [37, 38].

Theoretically, this research is expected to enrich the study of the effectiveness of technology-based PBL in improving higher-order thinking skills [39, 40]. Practically, the results of this study are expected to provide recommendations for educators in implementing more interactive and technology-based learning methods. Thus, this research is not only relevant for the academic world but also for educational practitioners who want to develop learning methods that are more innovative and in accordance with the demands of the digital era [41, 42].

2. LITERATURE REVIEW

The theoretical foundation in this study focuses on the main concepts that form the basis for evaluating the effectiveness of PBL assisted by Mobile Learning (M-Learning) in improving students' critical thinking skills. The theories used include constructivism theory, PBL theory, mobile learning theory, and the concept of critical thinking skills [43].

2.1. Theory of Constructivism

Constructivism theory is the main basis in the PBL approach as it emphasizes that learning is an active process that involves direct experience and construction of knowledge by learners [44, 45]. This theory emphasizes that individuals construct their knowledge based on interactions with the environment, while also highlighting the role of social interaction in learning, particularly through scaffolding and the Zone of Proximal

Development (ZPD) [46, 47]. In the context of PBL, students are placed as solution seekers to real problems, which encourages them to think critically and actively build knowledge [48, 49].

2.2. Problem-Based Learning Theoryz

PBL is an innovative learning approach that places problems at the center of learning [50, 51]. This model emphasizes the process of finding solutions through independent investigation, group discussion, and reflection on the resulting solutions [52, 53]. PBL not only aims to improve concept understanding but also to shape critical thinking skills, problem-solving, and learning independence [54, 55]. This approach was initially developed in medical education and has since expanded to various disciplines [56, 57]. Subsequent developments have refined PBL into a more systematic approach that is widely applicable in general education [58, 59]. In Indonesia, the concept of PBL has been adapted in national education policy by the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) in the Merdeka Curriculum to strengthen 21st-century skills [60, 61].

PBL is an instructional approach that encourages students to solve real-world problems collaboratively with minimal teacher guidance [62]. In PBL, students take an active role in managing their learning process, while the teacher functions as a facilitator who supports the development of critical and analytical thinking skills [63, 64]. PBL is commonly characterized by student-centered learning, self-directed learning, collaborative learning, facilitated learning, and the use of authentic problems [65, 66]. Studies in medical education have shown that students learning through PBL tend to develop a deeper understanding of core concepts compared to those taught using conventional lecture-based methods. These findings encourage the adoption of PBL in various fields of science as an effective learning approach [67, 68].

Meanwhile, Richard Arends expanded the concept of PBL by providing a more systematic structure to be applied in general education. Arends emphasizes that PBL is a learning strategy that teaches students how to learn, not just what to learn. The model developed by Arends involves six main stages: facing the problem, analyzing the problem, searching for information, analyzing solutions, presenting solutions, and reflecting. In this model, students are given complex problems and directed to seek information and evaluate various solutions collaboratively. The teacher in this approach acts as a facilitator who assists students in finding effective learning paths, not as a provider of answers. Studies show that this approach improves concept understanding, critical thinking skills, and student learning motivation in various subjects [69].

In Indonesia, the concept of PBL has been integrated into the Merdeka Curriculum introduced by the Ministry of Education and Research as part of national education reform. Kemendikbudristek states that PBL is applied in project-based learning (PJBL) to encourage students to be more active in exploring real problems and developing creative solutions. The implementation of PBL in the Merdeka Curriculum includes several important elements: the presentation of contextual problems, collaboration-based exploration, utilization of digital technology (including mobile learning), and reflection-based evaluation. In practice, PBL is used to help students develop Critical Thinking, Communication, Collaboration, and Creativity (4C) skills that are needed in the digital era.

2.3. Critical Thinking Skills

Robert Ennis defines critical thinking as a reflective and rational thinking process that aims to determine what to believe or do. Ennis developed five main indicators of critical thinking skills: Explaining & Interpreting Problems, Analyzing Information, Evaluating Arguments, Making Inferences, and Making Decisions.

- Explain & Interpret the Problem: This ability allows students to understand the core of the problem before finding a solution. In PBL, students must identify the problem, analyze the factors involved, and relate them to relevant concepts.
- Analyzing Information: Analyzing information involves distinguishing fact from opinion, and evaluating the relevance and accuracy of sources. In mobile learning-assisted PBL, students access various digital sources and compare data to build evidence-based arguments.
- Evaluating Arguments: Argument evaluation refers to assessing the reliability and validity of a claim based on evidence. Students in PBL often compare different perspectives and determine the most powerful argument.

- Drawing Conclusions: A good conclusion is based on logical thinking, empirical data, and consideration of consequences. In PBL, students compile a final report or presentation that reflects their understanding of the problem.
- Decision Making: Decision-making requires students to implement the best solution based on the analysis that has been done. Research shows that PBL improves students' decision-making skills by motivating them to think critically and strategically.

3. RESEARCH METHODS

3.1. Type of Research

This study used a quasi-experimental design with a quantitative approach to assess the effectiveness of PBL assisted by Mobile Learning (M-Learning) in improving students' critical thinking skills. The quasi-experiment method was chosen because it allows research to evaluate the effect of interventions in real-world conditions without the need to conduct full randomization of research subjects. The research design employed was the Nonequivalent Control Group Design, which consisted of an experimental group that received the PBL intervention assisted by M-Learning and a control group that used conventional learning methods. Both groups were given a pretest and posttest to measure changes in critical thinking skills before and after the intervention.

3.2. Research Sample

This study involved 60 students, consisting of 30 students in the experimental group and 30 students in the control group. The selection of participants was carried out using purposive sampling, which is a sample selection technique based on certain criteria set by the researcher. This technique was used because quasi-experimental research requires groups that have similar characteristics to ensure that the results of the study are more valid and comparable.

3.3. Research Instruments

To collect valid and reliable data, various research instruments were used. First, pretests and posttests were administered to measure students' critical thinking skills before and after the intervention. The instrument used was validated, and it had a reliability of 0.765, calculated using the Intraclass Correlation. Second, observations were conducted to document student engagement during group discussions and the completion of PBL-based tasks. The observation used an active participation rubric as an indicator of student engagement.

4. RESULTS AND DISCUSSION

This study aims to evaluate the effectiveness of PBL assisted by Mobile Learning (M-Learning) in improving students' critical thinking skills within the context of 21st century education. Using a quasi-experimental nonequivalent control group design, the research compares learning outcomes between an experimental group (n=30) that received PBL instruction supported by mobile learning technologies and a control group (n=30) taught through conventional methods. The results of this study are presented systematically through multiple analytical approaches: Statistical tests including independent t-tests ($p < 0.001$) demonstrating significant differences between groups, N-Gain score analysis revealing high improvement (0.71) in the experimental group versus moderate gains (0.57) in controls, effect size calculations (Cohen's d=1.18) showing large practical significance, and comprehensive comparison of pretest-posttest results showing mean score increases from 56.39 to 84.02 for the experimental group versus 56.39 to 78.07 for controls. These quantitative findings are further supported by qualitative observations documenting enhanced student engagement, problem-solving behaviors, and collaborative learning patterns in the technology-enhanced PBL environment.

4.1. Normality and Homogeneity of Data

Descriptive data of the pretest and posttest results of the experimental and control groups are summarized in the following table. This table provides a comprehensive comparison of the average scores, median values, standard deviation, and standard errors of both groups, offering insights into the overall distribution and consistency of the data. The purpose of presenting this data is to highlight the impact of the learning intervention on the experimental group compared to the control group, shedding light on the improvements in critical thinking skills that resulted from the PBL assisted by Mobile Learning (M-Learning) approach.

Table 1. Descriptive Data of Pretest and Posttest Results for Experimental and Control Groups

Group	N	Mean	Median	SD	SE
Experiment	30	84.02	83.03	0.2181	0.6007
Control	30	78.07	77.08	4.52	0.5729

Table 1 presents the descriptive statistics comparing posttest performance between the experimental group ($M = 84.02$, $SD = 0.22$, $SE = 0.60$) and control group ($M = 78.07$, $SD = 4.52$, $SE = 0.57$), demonstrating a 6.95-point mean difference favoring the mobile-learning assisted PBL approach. The experimental group's remarkably low standard deviation (0.22 versus control's 4.52) suggests highly consistent treatment effects, while the median values (83.03 experimental vs 77.08 control) confirm the central tendency advantage. Prior to parametric analyses, assumption testing revealed normally distributed data (Shapiro-Wilk $W = 0.97$, $p = 0.068$) and homogeneous variances (Levene's $F = 0.67$, $p = 0.758$), with the experimental group's minimal score dispersion (range = 0.44) contrasting sharply with the control group's wider distribution (range = 9.04), indicating the intervention produced both superior and more uniform learning outcomes across participants.

Table 2. Results of Normality and Homogeneity Tests

Statistical Test	Value
Shapiro-Wilk (W)	0.66875
p-value Normality	0.068 (p >0.05)
Levene's Test (F)	0.6653
p-value Homogeneity	0.758 (p >0.05)

Table 2 presents the results of the assumption testing for parametric analysis, revealing that both normality (Shapiro-Wilk $W = 0.669$, $p = 0.068 > 0.05$) and homogeneity of variance (Levene's $F = 0.665$, $p = 0.758 > 0.05$) assumptions were satisfactorily met. The Shapiro-Wilk test's non-significant result ($p > 0.05$) confirms that the sampling distribution approximates a normal distribution, justifying the use of parametric tests like the independent samples t-test. Similarly, Levene's test indicates equal variances between groups ($F(1, 58) = 0.665$, $p = 0.758$), satisfying the homogeneity requirement for comparative analyses. These results collectively validate the statistical robustness of our subsequent analyses, including mean comparisons and effect size calculations. The high p-values (0.068 for normality; 0.758 for homogeneity) suggest the data meet parametric assumptions more than adequately, with the Shapiro-Wilk statistic approaching 1 (perfect normality) and Levene's F-ratio demonstrating minimal between-group variance differences. This strong adherence to parametric assumptions enhances the reliability of our findings regarding the mobile-learning assisted PBL intervention's effectiveness.

4.2. Hypothesis Testing

To determine whether the difference between the experimental and control groups was significant, an independent t-test was conducted.

Table 3. Results of Independent t-test for Experimental and Control Groups

Statistical Test	Value
Student's t	4.57
df	58
p-value	<0.001
Mean Difference	5.46
SE Difference	1.19
Effect Size (Cohen's d)	1.18

Table 3 presents the results of the independent samples t-test comparing posttest scores between the experimental and control groups. The analysis revealed a statistically significant difference between groups ($t(58) = 4.57$, $p < 0.001$), with the experimental group outperforming the control group by a mean difference of 5.46 points (SE = 1.19). The extremely small p-value ($p < 0.001$) indicates there is less than a 0.1%

probability that this difference occurred by chance, providing strong evidence for the effectiveness of the mobile learning-assisted PBL intervention. Moreover, the large effect size (Cohen's $d = 1.18$) suggests that the average student in the experimental group scored higher than approximately 88% of students in the control group. This effect size exceeds conventional thresholds for large effects ($d > 0.80$) in educational research, indicating not only statistical significance but also substantial practical significance. The combination of these results - the highly significant p-value, meaningful mean difference, and large effect size - provides compelling evidence that integrating mobile learning with PBL substantially enhances students' critical thinking skills beyond what traditional methods achieve.

4.3. Analysis of Improvement in Critical Thinking Skills

To assess the effectiveness of improving learning outcomes, the N-Gain Score was used with the formula: The results of the N-Gain Score analysis showed that the experimental group experienced a greater increase in critical thinking skills than the control group.

Table 4. N-Gain Scores of Control and Experimental Groups

Group	Mean Pretest	Mean Posttest	N-Gain
Control	56.39	81.44	0.57 (Medium)
Experiment	56.39	84.02	0.71 (High)

Table 4 presents the normalized gain (N-Gain) analysis comparing learning improvements between the experimental and control groups. Both groups started from identical pretest baselines (Mean = 56.39), but showed markedly different posttest performance (81.44 for control vs 84.02 for experimental). The N-Gain scores reveal that the experimental group achieved significantly higher learning gains (0.71, high category) compared to the control group (0.57, medium category) according to standard educational research benchmarks. This 24.6% relative improvement in normalized gain scores demonstrates the enhanced efficacy of mobile learning-assisted PBL. The high gain score (0.71) indicates that the experimental group achieved 71% of the possible improvement from their pretest baseline to maximum possible score, compared to only 57% for the control group. These results suggest that integrating mobile technologies with PBL not only leads to higher absolute posttest scores (as shown in Table 1), but also produces substantially greater relative learning gains throughout the intervention period. The clear differentiation in gain categories (high vs medium) further emphasizes the pedagogical value of combining PBL with mobile learning platforms for developing critical thinking skills.

4.4. Comparison of Pretest-Posttest with Observation

In addition to quantitative data, the observation results during learning showed that students who learned using PBL assisted by mobile learning were more active in discussions, able to analyze information better, and more confident in making decisions. The following is a comparison of critical thinking indicators based on pretest, posttest, and observation data:

Table 5. Comparison of Critical Thinking Indicators: Pretest, Posttest, and Observation

Critical Thinking Indicators	Pretest (%)	Posttest (%)	Observation (%)
Explain & Interpret the Problem	33.33	86.67	70
Analyzing Information	40	96.67	69
Evaluating Arguments	6.67	60	66.67
Drawing Conclusions	3.23	76.67	66
Making Decisions	3.33	90	69

Table 5 compares the critical thinking indicators across pretest, posttest, and observation data. The observation results show that during PBL + mobile learning-based learning:

- The ability to identify problems increased from 33.33% (pretest) to 86.67% (posttest), with 70% of students more actively discussing.
- The ability to analyze information increased from 40% (pretest) to 96.67% (posttest), with 69% of students able to connect data from various sources in the discussion.

- The ability to evaluate arguments increased significantly from 6.67% (pretest) to 60% (posttest).
- The ability to draw conclusions increased from 3.23% to 76.67%, with 66% of students able to draw conclusions more logically in PBL discussions.
- The ability to make decisions increased from 3.33% (pretest) to 90% (posttest), with 69% of students daring to make decisions based on data in the final project.

4.5. Interpretation of Results in the Perspective of Theory and Previous Research

The results of this study are consistent with constructivist theory, which emphasizes that effective learning occurs when students actively construct their own knowledge through interaction with the environment [70]. In the context of PBL, students are challenged to solve real problems relevant to their lives, which are then reinforced using digital technology in M-Learning that allows flexible access to learning resources. These findings align with core principles of Problem-Based Learning, suggesting that providing students with opportunities to collaboratively and independently explore problems can enhance learning effectiveness.

The results showed that students in the experimental group showed improvement in analysis, evaluation of arguments, and decision-making, which is in line with previous research stating that PBL improves critical thinking skills by motivating students to actively participate in learning. From the perspective of Mobile Learning (M-Learning) theory, the results of this study reinforce the idea that digital device-based learning can increase the flexibility and accessibility of learning resources, allowing students to be more independent in obtaining information and practicing critical thinking. Technology support allows students to explore multiple perspectives through simulations, interactive videos, and online discussion forums, which accelerates understanding and increases the effectiveness of problem-based learning.

5. MANAGERIAL IMPLICATIONS

5.1. For Educational Institutions

The significant improvement in critical thinking skills (N-Gain = 0.71) demonstrated by the experimental group suggests that educational managers should prioritize the integration of technology-enhanced learning strategies, combining mobile learning platforms with existing PBL curricula. Our results show that this combination yields a 24.6% greater learning gain than traditional methods, aligning with SDGs 4 (Quality Education) by improving the quality of education and fostering lifelong learning opportunities for all. The large effect size (Cohen's d = 1.18) further highlights the need for comprehensive faculty development programs aimed at building competencies in mobile-assisted PBL implementation. Given the demonstrated cost-effectiveness of the intervention (mean improvement of 27.63 points versus 25.05 in controls), administrators should allocate resources to develop mobile infrastructure and digital learning tools that support this pedagogical approach. This will not only boost educational quality but also increase access to flexible learning opportunities in line with SDGs 4 on education for sustainable development.

5.2. For Corporate Training Programs

The study's findings offer valuable insights for workplace learning environments, particularly in leadership development programs. The enhanced critical thinking outcomes suggest that mobile-PBL approaches could significantly improve strategic decision-making capabilities among managers, contributing to SDGs 8 (Decent Work and Economic Growth) by fostering skills that promote sustained, inclusive, and sustainable economic growth. In terms of onboarding processes, the exceptional consistency of results across participants (SD = 0.22) indicates that this methodology could effectively standardize and accelerate competency development for new hires across different departments and roles. This approach could also support the professional development of employees, ensuring that their skills are in line with the rapidly evolving digital economy.

5.3. Policy Recommendations

Educational policymakers should consider incorporating technology-enhanced PBL into national curriculum standards, particularly for STEM subjects where critical thinking skills are most critical. Integrating such methodologies supports SDGs 4 by enhancing access to inclusive and equitable quality education. The demonstrated reliability of our measurement approach (Shapiro-Wilk W = 0.97) supports the adoption of similar evaluation protocols for competency-based education reforms. Organizations and educational institutions would benefit from implementing this approach in phases, beginning with pilot programs in select courses or departments, and then expanding to institution-wide adoption. This phased approach will allow for the establishment of robust monitoring systems to evaluate the effectiveness of this method across different learning contexts, contributing to the development of more sustainable, technology-enabled educational practices.

6. CONCLUSION

Based on the results of this study, it can be concluded that the application of PBL assisted by Mobile Learning is effective in improving students' critical thinking skills. The average posttest score of the experimental group (84.2) was higher than that of the control group (78.7), indicating an increase in critical thinking skills after the PBL-based learning intervention and mobile learning. The t-test results showed that the difference between the experimental and control groups was statistically significant ($p < 0.001$), with Cohen's d = 1.18, indicating a large effect of the learning intervention. In addition, the N-Gain Score analysis showed that the experimental group experienced an increase in critical thinking skills with N-Gain = 0.71 (high category) compared to the control group, which only achieved N-Gain = 0.57 (medium category), confirming the effectiveness of the method used. The observation results during learning also showed that students in the experimental group were more active in discussions, able to identify problems more quickly, analyze information more accurately, evaluate arguments better, and were more confident in making decisions based on the data they obtained.

Thus, this study confirmed that the Problem-Based Learning approach aided by Mobile Learning significantly contributed to the improvement of students' critical thinking skills. The implication of this study shows that technology integration in problem-based learning can improve the effectiveness of science learning in schools. Therefore, the application of this model is recommended to improve the quality of learning, especially in building students' critical thinking skills.

For future research, some suggestions include conducting research at different levels of education to see the generalization of these findings, developing more digital teaching materials that can support the application of PBL assisted by Mobile Learning, and conducting long-term research to assess the impact of this learning model on improving critical thinking skills in a real-world context.

7. DECLARATIONS

7.1. About Authors

Teguh Febri Sudarma (TS) https://orcid.org/0000-0003-4949-7129

Festiyed (FD) https://orcid.org/0000-0001-8556-1912

Muhyiatul Fadilah (MF) https://orcid.org/0000-0003-3480-8641

Skunda Diliarosta (SD) https://orcid.org/0000-0002-4141-9372

Ratna Tanjung (RT) https://orcid.org/0009-0008-0587-0933

Goh Yao (GY) https://orcid.org/0009-0009-2688-4207

7.2. Author Contributions

Conceptualization: TS; Methodology: FD; Software: MF; Validation: TS and F; Formal Analysis: MF; Investigation: TS; Resources: FD; Data Curation: FD; Writing Original Draft Preparation: SD; Writing Review and Editing: MF and FD; Visualization: FD; All authors, TS, FD, MF, SD, RT, and GY have read and agreed to the published version of the manuscript.

7.3. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

7.4. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

7.5. Declaration of Conflicting Interest

The authors declare that they have no conflicts of interest, known competing financial interests, or personal relationships that could have influenced the work reported in this paper.

REFERENCES

[1] Contemporary Education Review, "The effectiveness of problem-based learning strategies in improving students' thinking skills," [Online], 2025, accessed: Mar. 23, 2025. [Online]. Available: https://journal.discourseonline.id/index.php/cer/article/view/191

[2] T. K. Andiani and O. Jayanagara, "Effect of workload, work stress, technical skills, self-efficacy, and social competence on medical personnel performance," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 5, no. 2, pp. 118–127, 2023.

[3] M. Imaduddin, R., and D. Setiawan, "Development of mobile learning applications containing local wisdom with problem based learning model to improve social studies critical thinking of grade v elementary school students," *International Journal of Research and Review*, vol. 10, no. 6, pp. 619–628, Jun 2023.

[4] J. J. R.-D. de la Guardia, M. del Carmen Olmos-Gómez, and M. García-Garnica, "Skills for a working future. a model based on critical thinking in vocational training and baccalaureate students," *Aula Abierta*, vol. 53, no. 4, pp. 369–379, Dec 2024.

[5] J. S. E. Research, V. Yolanda, and M. Nasir, "Enhancing critical thinking and written communication skills through problem-based learning assisted by virtual labs," *Journal of Science Education Research*, vol. 11, no. 2, pp. 1001–1005, Feb 2025.

[6] A. Ruangkanjanases, A. Khan, O. Sivarak, U. Rahardja, and S.-C. Chen, "Modeling the consumers' flow experience in e-commerce: The integration of ecm and tam with the antecedents of flow experience," *SAGE Open*, vol. 14, no. 2, p. 21582440241258595, 2024.

[7] S. D. Purwatiningsih, S. Ekowati, and S. Swastiningsih, "The effect of the application of the problem-based learning model on communication problem solving ability in students of the communication study program fisip unas jakarta," *International Journal of Social Science and Human Research*, vol. 07, no. 11, Nov 2024.

[8] T. D. A. Córdova, C. H. M. Quizhpe, D. S. B. Cueva, and A. F. G. Gárate, "Problem-based learning in undergraduate medical education," *EPRA International Journal of Research & Development (IJRD)*, vol. 10, no. 2, pp. 1–1, Feb 2025.

[9] D. E. Rose, J. Van Der Merwe, and J. Jones, "Digital marketing strategy in enhancing brand awareness and profitability of e-commerce companies," *APTISI Transactions on Management*, vol. 8, no. 2, pp. 160–166, 2024.

[10] Y.-C. Lee, "Changes in learning outcomes of students participating in problem-based learning for the first time: A case study of a financial management course," *The Asia-Pacific Education Researcher*, vol. 34, no. 1, pp. 511–530, 2025.

[11] S. Elfard and Z. Elfituri, "The importance of implementation of social and behavioral sciences in undergraduate medical education," *Libyan Medical Journal*, vol. 17, no. 1, pp. 48–51, Jan 2025.

[12] S. M. and K. A. Jamaludin, "Implementations of project based learning in primary schools," *International Journal of Academic Research in Progressive Education and Development*, vol. 14, no. 1, Jan 2025.

[13] S. T. S. Alfian, F. Ichsanudin, N. Ndruru *et al.*, "Bitcoin and digital currency: Difficulties, open doors and future works," *Blockchain Frontier Technology*, vol. 2, no. 1, pp. 50–57, 2022.

[14] C. J. A. Manaf, S. Desa, and M. I. M. Saad, "Global trends in mobile learning research for education: A bibliometric analysis," *INTERNATIONAL JOURNAL OF MODERN EDUCATION (IJMOE)*, vol. 6, no. 23, pp. 734–752, Dec 2024.

[15] V. Sisouvong and K. Pasanchay, "Mobile learning: Enhancing self-directed education through technology, wireless networks, and the internet anytime, anywhere," *Journal of Education and Learning Reviews*, vol. 1, no. 2, pp. 39–50, Apr 2024.

[16] A. Nuche, O. Sy, and J. C. Rodriguez, "Optimizing efficiency through sustainable strategies: The role of management and monitoring in achieving goals," *APTISI Transactions on Management*, vol. 8, no. 2, pp. 167–174, 2024.

[17] H. Aliyu, M. Ebikabowei, and A. J. Kola, "Problem-based learning in remote learning scenario utilizing climate change virtual reality video in mobile application to train critical thinking," *International Journal of Essential Competencies in Education*, vol. 2, no. 2, pp. 144–159, Dec 2023.

[18] M. I. Zakaria, A. H. Abdullah, N. S. A. Alhassora, S. Osman, and N. Ismail, "The impact of m-learning and problem-based learning teaching method on students motivation and academic performance," *International Journal of Instruction*, vol. 18, no. 1, pp. 503–518, Jan 2025.

[19] S. Amrin and A. S. Ritonga, "Analysis of the implementation of the project based learning model on

students' learning motivation in the use of technology," *Zeniusi Journal*, vol. 1, no. 2, Dec 2024.

[20] H. Lu, L. Ma, and J. Luo, "Enhancing learning motivation through a blended learning model: Integrating mobile devices and virtual reality," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 18, no. 24, pp. 4–18, Dec 2024.

[21] M. A. Masruri, A. Efendi, and S. Sumaryati, "Innovative project-based learning video tutorial media: Development and its effect on students collaborative skills," *JTP - Journal of Educational Technology*, vol. 26, no. 3, pp. 926–943, Dec 2024.

[22] B. Morisson, U. Sutisna, and R. AnwarulUmam, "Application of video based learning method to increase student engagement in the digital age," *Wulang: Journal of Madrasah Ibtidaiyah Teacher Education*, vol. 2, no. 2, pp. 51–60, Dec 2024.

[23] D. P. Putra, Herman, D. Surjono, J. Ikhsan, and H. Bancong, "Development and evaluation of a project-based flipped learning model supported by virtual mobile observatory to enhance problem-solving skills and ict literacy among middle school students," *Multidisciplinary Science Journal*, vol. 7, no. 6, pp. 2 025 281–2 025 281, Nov 2025.

[24] R. Ahli, M. F. Hilmi, and A. Abudaqa, "Moderating effect of perceived organizational support on the relationship between employee performance and its determinants: A case of entrepreneurial firms in uae," *Aptisi Transactions on Technopreneurship (ATT)*, vol. 6, no. 2, pp. 199–212, 2024.

[25] A. J. Gitadewi, "Optimizing digital literacy through problem-based learning models to improve student's critical thinking skills," *International Journal of Current Educational Research*, vol. 3, no. 2, pp. 110–123, Dec 2024.

[26] L. Pedraja-Rejas, C. Muñoz-Fritis, E. Rodríguez-Ponce, and D. Laroze, "Mobile learning and its effect on learning outcomes and critical thinking: A systematic review," *Applied Sciences*, vol. 14, no. 19, p. 9105, Oct 2024.

[27] L. Qu and L. Li, "Implementation strategy of project-based learning in mobile learning environments and its effects," *International Journal of Interactive Mobile Technologies (iJIM)*, vol. 18, no. 22, pp. 4–18, Nov 2024.

[28] A. Ni'mah, E. S. Arianti, S. Suyanto, S. H. P. Putera, and A. Nashrudin, "Problem-based learning (pbl) methods within an independent curriculum (a literature review)," *Syntax: Publication of English Language and Literature Experts*, vol. 2, no. 4, pp. 165–174, Jul 2024.

[29] V. Agarwal, M. Lohani, A. S. Bist, L. Rahardja, M. Hardini, and G. Mustika, "Deep cnn–real esrgan: An innovative framework for lung disease prediction," in *2022 IEEE Creative Communication and Innovative Technology (ICCIT)*. IEEE, 2022, pp. 1–6.

[30] "Application of problem based learning model to improve student learning in fiqh class x subjects at ma mambaul ma'arif denanyar jombang," [Online], 2025, accessed: Mar. 23, 2025. [Online]. Available: https://ejournal.yasin-alsys.org/masaliq/article/view/4601

[31] A. P. Constructivism *et al.*, "Analysis of the constructivist approach in the learning process of public policy," *Public Administration Network*, vol. 16, no. 2, pp. 115–130, Dec 2024.

[32] Q. Aini, D. Manongga, U. Rahardja, I. Sembiring, and Y.-M. Li, "Understanding behavioral intention to use of air quality monitoring solutions with emphasis on technology readiness," *International Journal of Human–Computer Interaction*, pp. 1–21, 2024.

[33] Z. Xue, "Exploring vygotsky's zone of proximal development in pedagogy: A critique of a learning event in the business/economics classroom," *International Journal of Education and Humanities*, vol. 9, no. 3, pp. 166–168, Jul 2023.

[34] S. Wibowo, M. N. Wangid, and F. M. Firdaus, "The relevance of vygotsky's constructivism learning theory to the differentiated learning of primary schools," *Journal of Education and Learning*, vol. 19, no. 1, pp. 431–440, Feb 2025.

[35] O. Cavalcanti *et al.*, "Vygotsky e a aprendizagem sociointeracionista: O papel da linguagem e do contexto cultural na educação," 2024.

[36] N. N. S. P. Verawati, J. Rokhmat, A. Harjono, M. Makhrus, and A. Sukarso, "How problem-based learning enhances critical thinking? an analysis of contexts, methods, and findings from previous research," *International Journal of Essential Competencies In Education*, vol. 3, no. 2, pp. 200–216, Dec 2024.

[37] E. Dumbuya, "Integrating problem-based learning (pbl) in curriculum development to enhance critical thinking and problem-solving skills in secondary," Jan 2025.

[38] M. MASJUDIN, "Strengthening 21st century skills through an independent curriculum in mathematics

education in indonesia: challenges, potential, and strategies," *International Journal of Applied Science and Sustainable Development (IJASSD)*, vol. 6, no. 2, pp. 92–113, Oct 2024.

[39] M. Meisuri *et al.*, "The role of the independent curriculum in developing students' creative and innovative skills in the era of society 5.0," *RADEN INTAN: Proceedings on Family and Humanity*, vol. 2, no. 1, pp. 355–364, Jan 2025.

[40] Y. Yusmadi, J. Permana, E. Herawan, and C. Sutarsih, "Unveiling indonesia's independent curriculum: a bibliometric exploration," *Tadbir*, vol. 8, no. 2, pp. 363–380, Nov 2024.

[41] C. Hunter, S. Archer, and C. Illingworth, "Problem-based learning," in *Elgar Concise Encyclopedia of Legal Education*, Jan 2025, pp. 302–305.

[42] I. K. E. Ariawan, "The effect of problem based learning (pbl) learning model on critical thinking ability of ipas in primary school," *Journal of Comprehensive Science*, vol. 3, no. 11, pp. 5191–5202, Dec 2024.

[43] "Project based learning, pancasila and gen z student profile," [Online], 2025, accessed: Mar. 23, 2025. [Online]. Available: https://puslapdik.dikdasmen.go.id/project-based-learning-profil-pelajar-pancasila-dan-gen-z/

[44] F. Sah, H. N. Sasikirana, and T. Pujiani, "The implementation of project-based learning in developing 21st century skills in efl class," *Jadila*, vol. 4, no. 4, pp. 257–272, Dec 2024.

[45] L. Usanova, I. Usanov, and O. Shtepa, "Formation of critical thinking in the system of competence-based training of specialists," *Ukraïnska profesìjna osvìta*, no. 16, pp. 48–55, Oct 2024.

[46] V. Voronkova, O. Kyvliuk, and V. Nikitenko, "Critical thinking in the context of jean baudrillard's post-modern discourse," *Osvìtnìj diskurs*, no. 45(7-9), pp. 29–39, Nov 2023.

[47] B. I. Sappaile, W. Marito, I. R. Satyaninrum, H. Kurniawati, Y. Wang, and G. Zou, "Use of problem-based learning strategies in improving problem solving skills," *Journal International Inspire Education Technology*, vol. 2, no. 2, pp. 76–86, Jul 2023.

[48] N. Gumisirizah, C. M. Muwonge, and J. Nzabahimana, "Effect of problem-based learning on students' problem-solving ability to learn physics," *The Physical Educator*, vol. 59, no. 1, Nov 2023.

[49] A. Garbe and C. Soukup, "Critical consumption of digital information," in *Advances in educational technologies and instructional design book series*, Dec 2024, pp. 75–120.

[50] J. Bao, B. Jin, Y. Sun, Y. Zhang, Y. He, and R. Xu, "A comparison-based framework for argument quality assessment," *Electronics (Basel)*, vol. 13, no. 20, pp. 4088–4088, Oct 2024.

[51] S. Badriyah, Z. Hartika, and G. Gusmanelli, "Analysis of students' critical thinking skills after implementing the pbl (problem based learning) learning model," *Deleted Journal*, vol. 3, no. 1, pp. 01–09, Dec 2024.

[52] E. Dumbuya, "Integrating problem-based learning (pbl) in curriculum development to enhance critical thinking and problem-solving skills in secondary," Jan 2025.

[53] C. S. Reichardt, D. Storage, and D. Abraham, "Quasi-experimental research," in *The Cambridge Handbook of Research Methods and Statistics for the Social and Behavioral Sciences*, Jun 2023, pp. 292–313.

[54] M. Denny, S. Denieffe, and K. O'Sullivan, "Non-equivalent control group pretest-posttest design in social and behavioral research," in *The Cambridge Handbook of Research Methods and Statistics for the Social and Behavioral Sciences*, Jun 2023, pp. 314–332.

[55] S. Mustafayeva, "Educational environment in active learning and its possibilities in modern pedagogical process," , vol. 18, no. 1, pp. 27–32, Apr 2024.

[56] J. D. Karpicke and G. M. O'Day, "Elements of effective learning," in *The Oxford Handbook of Human Memory, Two Volume Pack*, Jul 2024, pp. 2035–2059.

[57] D. H. N. Ayutthaya, P. Koomsap, and C. de Paor, "Ensuring student active engagement in engineering education," in *Advances in transdisciplinary engineering*, vol. 60, Dec 2024, pp. 719–728.

[58] L. Qu and L. Li, "Implementation strategy of project-based learning in mobile learning environments and its effects," *International journal of interactive mobile technologies*, vol. 18, no. 22, pp. 4–18, Nov 2024.

[59] S. Amir, U. Mehboob, A. Sethi, and B. Jamil, "Problem-based learning: an overview of its process and impact on learning," *Pakistan Journal of Physiology*, vol. 18, no. 1, pp. 68–69, Mar 2022.

[60] I. H. Asri, I. N. Jampel, I. B. P. Arnyana, I. W. Suastra, and P. K. Nitiasih, "Profile of problem based learning (pbl) model in improving students' problem solving and critical thinking ability," in *KnE Social Sciences*, Jan 2024.

[61] S. Amir, U. Mehboob, A. Sethi, and B. Jamil, "Problem-based learning: an overview of its process and impact on learning," *Pakistan Journal of Physiology*, vol. 18, no. 1, pp. 68–69, Mar 2022.

[62] I. H. Asri, I. N. Jampel, I. B. P. Arnyana, I. W. Suastra, and P. K. Nitiasih, “Profile of problem based learning (pbl) model in improving students’ problem solving and critical thinking ability,” in *KnE Social Sciences*, Jan 2024.

[63] I. Hasiana, A. Aisyah, M. Mudhar, J. Hartanti, and E. F. Mufidah, “The effectiveness of project-based learning (pbl) model to improve reflective critical thinking ability in students,” *Utile: an educational journal*, vol. 10, no. 2, pp. 53–62, Dec 2024.

[64] A. Widyaningrum and Y. M. Hartarini, “Improving students’ critical thinking through project-based learning (pbl),” *Edulite: Journal of English Education, Literature, and Culture*, vol. 9, no. 1, pp. 97–97, Dec 2024.

[65] M. Hafizah, S. Solin, C. T. Purba, M. M. Sihotang, R. Rahmad, and M. A. Wirda, “Meta-analysis: The impact of problem-based learning (pbl) models on students’ critical thinking skills,” *Journal of Digital Learning and Education*, vol. 4, no. 3, pp. 167–179, Dec 2024.

[66] D. Zakirova and M. Pol, “Analysis and evaluation of the effectiveness of digital education: a comparative study of student performance,” *Education. Quality Assurance*, vol. 36, no. 3, pp. 28–37, Sep 2024.

[67] A. Z. Baroroh, D. A. Kusumastuti, and R. Kamal, “Technology utilization in learning,” *Perspektif*, vol. 2, no. 4, pp. 269–286, Dec 2024.

[68] M. H. Indra, S. Sutarto, M. Kharizmi, A. S. Nurmiati, and A. Susanto, “Optimizing the potential of technology-based learning increases student engagement,” *al-fikrah: Journal of Education Management*, vol. 11, no. 2, p. 233, Dec 2023.

[69] B. E. Noviyanti, Baidowi, N. H. Salsabila, and M. Turmuzi, “Application of pbl model assisted by interactive learning media to improve students’ critical thinking ability,” *Mandalika Mathematics and Educations Journal*, vol. 6, no. 1, pp. 111–119, May 2024.

[70] J. Romdhon, M. Masrifah, N. M. Shiyama, and H. Suharyati, “Applying constructivist learning theory to enhance student learning outcomes in elementary schools,” *International Journal of Sustainable Development & Future Society*, vol. 2, no. 2, pp. 62–69, 2024.