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Integration of Problem-Based Learning And Chatbot in Enhancing Students' Critical Thinking Skills, Collaborative Skills, and Self-Regulation in Mathematics Learning For Grade IX Students at ABC School, Jakarta

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ABSTRACT

This Classroom Action Research examined the integration of Problem-Based Learning (PBL) and chatbot technology (ChatGPT) to enhance Grade IX students' critical thinking skills, collaborative skills, and self-regulation in mathematics learning. The study was conducted over three iterative cycles consisting of planning, action, observation, and reflection. The PBL model followed five stages: orientation, analysis, investigation, synthesis, and reflection, with ChatGPT integrated during the investigation stage to support inquiry and problem exploration. Data were collected using observation rubrics, validated questionnaires, and post-lesson teacher interviews.

The findings indicated consistent improvement across all targeted competencies. Students' critical thinking skills increased from Cycle 1 to Cycle 3, with more than 90% of students meeting the success criteria by the final cycle. Collaborative skills also improved steadily, with over 85% of students achieving the expected performance standard. Similarly, students' self-regulation showed notable development, as more than 90% of students reached the established success benchmark. These results suggest that the integration of chatbot-assisted PBL effectively supports the development of critical thinking, collaboration, and self-regulation in lower secondary mathematics learning.

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A B S T R A K

Penelitian Tindakan Kelas ini bertujuan untuk mengkaji integrasi model Problem-Based Learning (PBL) dan teknologi chatbot (ChatGPT) dalam meningkatkan kemampuan berpikir kritis, keterampilan kolaborasi, dan regulasi diri siswa kelas IX pada pembelajaran matematika. Penelitian dilaksanakan melalui tiga siklus tindakan yang meliputi tahap perencanaan, pelaksanaan, observasi, dan refleksi. Model PBL yang diterapkan terdiri atas lima tahap, yaitu orientasi, analisis, investigasi, sintesis, dan refleksi, dengan ChatGPT diintegrasikan pada tahap investigasi untuk mendukung proses inkuiri dan pemecahan masalah. Data dikumpulkan melalui rubrik observasi, kuesioner yang telah divalidasi, serta wawancara guru setelah pembelajaran.

Hasil penelitian menunjukkan peningkatan yang konsisten pada seluruh kompetensi yang diteliti. Kemampuan berpikir kritis siswa meningkat hingga lebih dari 90% siswa mencapai kriteria keberhasilan pada siklus akhir. Keterampilan kolaborasi juga menunjukkan peningkatan, dengan lebih dari 85% siswa memenuhi standar yang ditetapkan. Selain itu, regulasi diri siswa berkembang secara signifikan, ditunjukkan oleh lebih dari 90% siswa yang mencapai kriteria keberhasilan. Temuan ini menunjukkan bahwa integrasi PBL berbantuan chatbot efektif dalam mendukung pembelajaran matematika di jenjang SMP.

1. INTRODUCTION

Indonesia's *Golden Indonesia 2045* vision highlights the urgency of preparing a generation that is capable of competing globally. Nevertheless, the 2022 Programme for International Student Assessment (PISA) results placed Indonesia at 69th out of 80 participating countries, indicating persistent challenges in students' higher-order thinking and problem-solving abilities (OECD, 2022). These findings suggest that many students have not yet developed essential 21st-century skills, particularly critical thinking, self-regulation, and collaborative skills, which are crucial in mathematics learning.

One factor contributing to this condition is the dominance of teacher-centered instructional practices in mathematics classrooms. Such practices often limit opportunities for inquiry, reflection, and meaningful peer interaction. Consequently, students tend to rely heavily on teacher explanations, show low learning autonomy, and demonstrate limited engagement in collaborative problem-solving activities.

Critical thinking is commonly understood as a purposeful and self-regulated cognitive process that involves interpreting information, analyzing relationships, and evaluating solutions to support sound decision-making (Lai, 2011; Facione, 2011). In

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parallel, self-regulation enables learners to plan, monitor, and adjust their learning strategies independently, which is essential for sustained engagement and academic achievement (Zimmerman, 2002; Lai & Hwang, 2021). Collaborative skills, including communication, coordination, and active participation, support knowledge construction through social interaction and shared problem-solving processes (Hesse et al., 2015). When these competencies are insufficiently developed, students often exhibit low initiative, weak participation, and superficial conceptual understanding.

Preliminary classroom observations in lower secondary mathematics contexts indicate that students frequently struggle to analyze mathematical problems independently and participate actively in group discussions. Weak communication and coordination during collaborative tasks, as well as hesitation to ask questions or express ideas, further hinder effective learning engagement.

Problem-Based Learning (PBL) has been widely recognized as an instructional approach that addresses these challenges by engaging students in authentic problem-solving activities that promote higher-order thinking, collaboration, and learner autonomy (Mustikasari, 2022; Putri et al., 2023). Previous studies also suggest that technology-enhanced PBL environments can strengthen these outcomes by providing scaffolding and timely feedback (Rahmawati et al., 2021). At the same time, recent developments in artificial intelligence have introduced chatbot technologies, such as ChatGPT, which support learning through natural language interaction, immediate feedback, and guided reflection (Adamopoulou & Moussiades, 2020; Neo, 2022).

Despite the growing literature on PBL and chatbot-assisted learning, empirical evidence in mathematics education remains limited. In particular, there is a lack of Classroom Action Research that systematically integrates Problem-Based Learning with ChatGPT in lower secondary mathematics classrooms. Existing studies often examine PBL or chatbot use separately and rarely explore their combined implementation across iterative classroom action cycles or their simultaneous impact on critical thinking, collaborative skills, and self-regulation.

Therefore, this study focuses on Grade IX mathematics learning on trigonometry topics, implemented through a five-phase Problem-Based Learning model consisting of orientation, analysis, investigation, synthesis, and reflection. ChatGPT was integrated specifically during the investigation stage to support inquiry and problem exploration. Using a Classroom Action Research approach, this study aims to examine how the systematic integration of Problem-Based Learning and chatbot technology enhances students' critical thinking skills, collaborative skills, and self-regulation in mathematics learning.

2. METHODS

Research Design

This study employed a Classroom Action Research (CAR) design based on the model proposed by Kemmis and McTaggart, which consists of four cyclical stages: planning, action, observation, and reflection. The research was conducted over three iterative cycles with the aim of improving instructional practices and examining the integration of Problem-Based Learning (PBL) and chatbot technology in mathematics learning. CAR was selected because it allows systematic instructional refinement and real-time evaluation of pedagogical interventions in authentic classroom contexts (Burns, 2019; Rabgay & Kidman, 2023).

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Participants and Research Context

The participants were 14 Grade IX students from an international secondary school in Jakarta, representing diverse national backgrounds. The study was conducted in an Additional Mathematics class following the Cambridge International Curriculum. Although the number of participants was relatively small, this is consistent with the nature of Classroom Action Research, which emphasizes in-depth investigation of instructional improvement within a specific classroom setting. The limited sample size is acknowledged as a limitation of this study.

Research Procedure

Each CAR cycle followed a structured sequence of planning, action, observation, and reflection. During the planning stage, lesson plans and worksheets were developed using the five-phase PBL model. ChatGPT was integrated during the investigation phase to support students in exploring problems and formulating solution strategies. The action stage involved classroom implementation of the planned lessons. Observation was conducted using rubrics, questionnaires, and interviews to document students' learning behaviors. In the reflection stage, collected data were analyzed to evaluate the effectiveness of the intervention and to inform improvements for subsequent cycles.

Research Instruments

Multiple instruments were used to ensure data triangulation and to capture students' development in critical thinking skills, collaborative skills, and self-regulation. An overview of the instruments is presented in Table 1.

Variable	Instrument	Source	Scale	Item Details
Critical Thinking Skills	Questionnaire	Students	4-point Likert	9 items; interpretation, analysis, evaluation
	Rubric	Observer	Performance 1-4	3 indicators; observable performance
	Interview	Observer		6 semi-structured questions
Self-Regulation	Questionnaire	Students	4-point Likert	9 items; planning, monitoring, adjustment
	Rubric	Observer	Performance 1-4	3 indicators; observable learning behaviors
	Interview	Observer		6 semi-structured questions
Collaborative Skills	Questionnaire	Students	4-point Likert	9 items; communication, coordination, engagement
	Rubric	Observer	Performance 1-4	3 indicators; group interaction behaviors
	Interview	Observer		6 semi-structured questions
Integrated Problem Based Learning with Chatbot	Lesson Plan	Researcher		PBL stages
	Worksheet	Researcher		Investigation tasks with chatbot guidance
	Observation form	Observer	Checklist	Implementation fidelity

Table 1 Instruments of action research

Questionnaires were used to capture students' self-reported perceptions, while observation rubrics focused on observable learning behaviors. The combination of Likert-scale questionnaires and performance-based rubrics was intentionally applied to capture both subjective and behavioral dimensions of learning outcomes.

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Data Analysis

Qualitative data from observation rubrics and interviews were analyzed using thematic analysis to identify patterns in students' learning behaviors across the three cycles.

Quantitative data were analyzed using descriptive and inferential statistics. Item validity was examined using Pearson product–moment correlation, while internal consistency was assessed using Cronbach's Alpha. Data normality was tested using the Shapiro–Wilk test. Depending on data distribution, either paired-sample t-tests or Wilcoxon Signed-Rank tests were applied to examine differences between cycles. Students' learning improvement was measured using normalized gain (N-Gain) analysis.

Criteria for Success

The criteria for success were based on the school's academic standard. A student was considered successful if achieving a minimum score of 70% on the questionnaire or observation rubric. At the class level, the intervention was considered successful if at least 70% of students met this benchmark. The class success rate was calculated using the following formula:

$$\boldsymbol{Criteria\ of\ Success}\ (\boldsymbol{CS}) = \frac{\text{Number of students who meet the benchmark}}{\text{Total number of students}} \times \mathbf{100}\%$$

3. RESULTS AND DISCUSSION

This study employed a Classroom Action Research (CAR) design conducted over three iterative cycles, each consisting of planning, action, observation, and reflection. The instructional intervention integrated Problem-Based Learning (PBL) with chatbot technology, specifically ChatGPT, which was embedded in the investigation stage of the PBL process. The intervention aimed to enhance Grade IX students' critical thinking skills, collaborative skills, and self-regulation in mathematics learning.

Data were collected using a triangulated approach, including observation rubrics, validated questionnaires, and post-lesson teacher interviews. This combination of quantitative and qualitative data enabled a comprehensive analysis of students' learning development across the three action research cycles.

Students' critical thinking skills were assessed using indicators of interpretation, analysis, and evaluation. Figure 1 presents the overall development of students' critical thinking skills across the three cycles.

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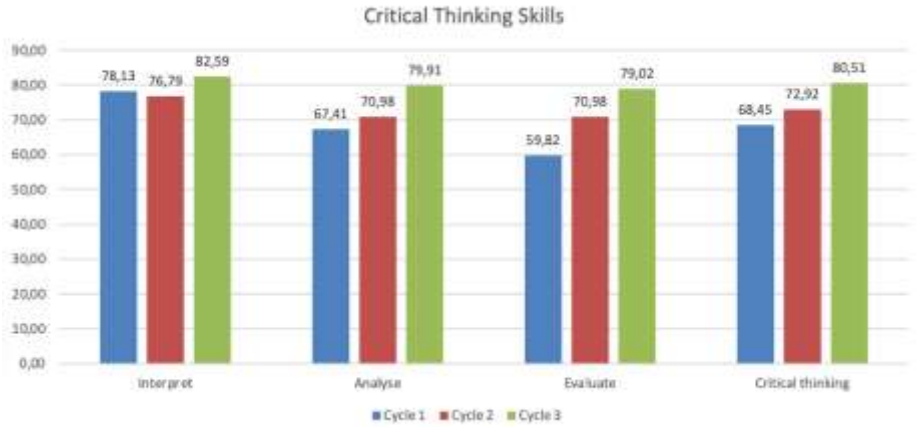

Figure 1. Development of Students' Critical Thinking Skills Across Three Action Research Cycles

As shown in Figure 1, the average critical thinking score increased consistently from Cycle 1 (68.45%) to Cycle 2 (75.39%) and further to Cycle 3 (80.51%). In Cycle 1, many students were able to interpret mathematical problems but struggled to analyze solution steps and justify their reasoning. After instructional revisions in Cycle 2, including clearer scaffolding and structured guidance on chatbot use during the investigation stage, students demonstrated improved analytical reasoning. By Cycle 3, most students were able to evaluate their solutions more systematically, resulting in a statistically significant improvement confirmed by a paired-sample t-test ($p = 0.022$).

Qualitative data from teacher observations indicated that ChatGPT functioned as a cognitive scaffold, allowing students to verify their reasoning, explore alternative solution strategies, and reflect on errors. This finding supports previous research highlighting the role of technology-assisted inquiry in promoting higher-order thinking.

Collaborative skills were measured based on indicators of communication, coordination, and engagement during group problem-solving activities. The overall trend of collaborative skill development across the three cycles is illustrated in Figure 2.

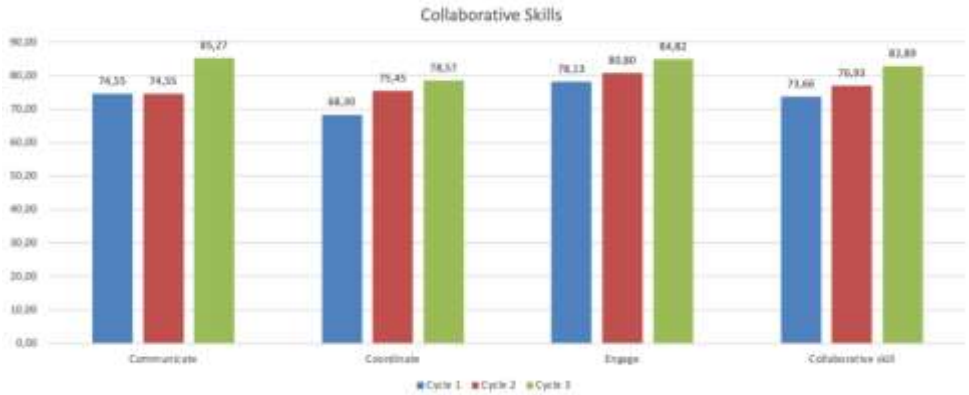

Figure 2. Development of Students' Collaborative Skills Across Three Action Research Cycles

Figure 2 shows a steady increase in collaborative skill scores from Cycle 1 (73.66%) to Cycle 2 (77.62%) and Cycle 3 (82.89%). In the initial cycle, students were generally willing to share ideas, but participation was uneven and group coordination was limited. The introduction of clearer group roles and chatbot prompts for joint discussion in Cycle

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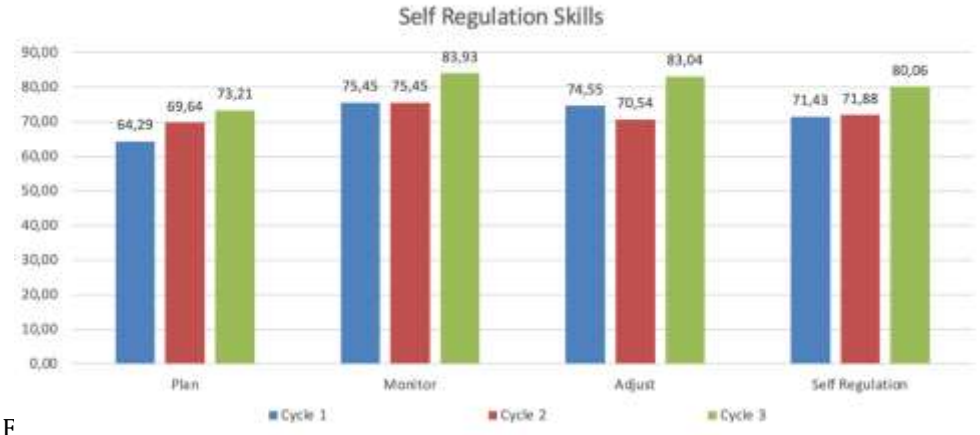
2 improved task coordination and peer support. By Cycle 3, students demonstrated greater confidence in expressing ideas and engaging actively in group discussions. The Wilcoxon Signed-Rank test indicated that this improvement was statistically significant ($p = 0.027$).

Teacher reflections suggested that collaborative use of the chatbot encouraged shared inquiry, as students frequently discussed chatbot responses together rather than relying on individual problem-solving. This collaborative interaction contributed to a more inclusive learning environment.

Self-regulation was assessed using indicators of planning, monitoring, and adjustment. Figure 3 illustrates the progression of students' self-regulation skills across the three learning cycles.



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As shown in Figure 3, students' self-regulation scores improved from 71.43% in Cycle 1 to 76.98% in Cycle 2 and reached 80.06% in Cycle 3. In the first cycle, students generally demonstrated adequate planning skills but showed limited ability to monitor their progress and adjust learning strategies. The integration of reflective tasks and chatbot-assisted feedback in Cycle 2 supported greater awareness of learning processes. By Cycle 3, most students independently used chatbot feedback to revise their problem-solving approaches, resulting in a highly significant improvement ($p < 0.001$).

Student feedback further confirmed that the chatbot served as a metacognitive aid, helping students identify mistakes and modify strategies, which aligns with theories of self-regulated learning. A summary of students' achievement across the three competencies is presented in Table 2.

Variable	Cycle 1	Cycle 2	Cycle 3	N-Gain	Sign Test	Students Achieving ≥70%
Critical Thinking	68.45%	75.39%	80.51%	Moderate to High	t-test ($p = 0.02233$)	92.86%
Collaborative Skills	73.66%	77.62%	82.89%	Moderate	Wilcoxon ($p = 0.02758$)	85.71%
Self-Regulation	71.43%	76.98%	80.06%	Moderate to High	t-test ($p = 0.00000641$)	92.86%

Table 2. Summary of Student Progress Across Learning Variables

Table 2 demonstrates a consistent increase in average scores and success rates across all variables from Cycle 1 to Cycle 3. By the final cycle, the majority of students met or

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exceeded the minimum success criterion of 70%, indicating that the integrated PBL and chatbot intervention had a strong and sustained impact on students' learning outcomes.

4. CONCLUSION

This study investigated the integration of Problem-Based Learning (PBL) and chatbot technology (ChatGPT) to enhance Grade IX students' critical thinking skills, collaborative skills, and self-regulation in mathematics learning. Through three cycles of Classroom Action Research, the findings demonstrated consistent improvements across all three competencies. Students showed better ability to interpret and analyze mathematical problems, engage more actively in group discussions, and manage their own learning processes. Statistical analyses indicated that these improvements were significant, with most students achieving the established success criteria by the end of Cycle 3.

The integration of ChatGPT during the investigation stage of PBL played a supportive role in scaffolding students' thinking processes. The chatbot functioned as a cognitive and metacognitive aid by helping students clarify concepts, verify solution steps, and reflect on errors without replacing teacher guidance or peer collaboration. When combined with structured PBL stages, this integration fostered a more student-centered learning environment that encouraged inquiry, collaboration, and self-regulated learning.

Despite these positive outcomes, this study has several limitations. The number of participants was relatively small and limited to one Grade IX class, which may affect the generalizability of the findings. In addition, the duration of the intervention was confined to three action research cycles, and the study was conducted within the context of an international school, which may differ from other educational settings. Future research is recommended to involve larger samples, longer implementation periods, and diverse school contexts to further examine the effectiveness of chatbot-assisted PBL in mathematics learning.

5. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

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