Jurnal Pijar MIPA
https://jurnalfkip.unram.ac.id/index.php/JPM

ISSN 1907-1744 (Print)
ISSN 2460-1500 (Online)

Integrating Artificial Intelligence into Problem-Based Learning to Enhance Self-Regulated Learning

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Received: May 23, 2026. Accepted: July 30, 2026. Published: August 18, 2026

Abstract: Technological advancements in the digital age have brought significant changes to the learning process; however, students' self-regulated learning skills in science education still need to be improved, particularly in their ability to plan, monitor, and evaluate the learning process. Therefore, technology-based learning innovations such as Artificial Intelligence (AI) are needed to provide rapid and personalized feedback to support Self-Regulated Learning (SRL). This study aims to determine the effect of integrating Artificial Intelligence (AI) into the Problem-Based Learning (PBL) model on students' Self-Regulated Learning (SRL) skills in science education. This study employs a quantitative approach with a one-group experimental design, involving 17 students in the experimental class and 10 students in the replication class, selected through purposive sampling. The research instrument consists of a Self-Regulated Learning questionnaire. Data analysis was conducted using descriptive statistics, the Shapiro-Wilk normality test, and a one-sample t-test for hypothesis testing. The results showed that the mean Self-Regulated Learning (SRL) scores of students in the experimental class were 90.12 and 92.40 in the replication class, both falling into the high category, and the data were normally distributed with significance values of 0.842 and 0.589, respectively ($p > 0.05$). The results of the hypothesis test showed a p-value of 0.000 for the experimental class.

Keywords: Artificial Intelligence; Problem-Based Learning; Science Learning; Self-Regulated Learning.

Introduction

Technological advancements in the digital age have truly transformed many industries, including education. Integrating technology into learning has brought about significant changes in the teaching methods used and experienced by teachers and students. However, there are certainly challenges in applying technology in education in the digital age. One of the challenges that must be addressed is that teachers must be able to understand the curriculum to integrate it with technology, the inadequacy of facilities, and, of course, the level of teachers' abilities and skills in their teaching [1].

The quality of education in Indonesia remains low, as it has not yet reached its full potential, and previous learning objectives have not yet been achieved [2]. In an effort to improve the quality of education, the learning process emphasises conceptual understanding as a crucial outcome for students, especially in the subject of Natural Sciences (*IPA*). Conceptual understanding is the foundation for grasping principles and theories. Therefore, students must first master the concepts that make up a principle or theory in order to fully understand it [3]. Good conceptual understanding helps students apply the knowledge they have gained to solve various problems in daily life. However, in reality, many students struggle to deeply understand science concepts. This may be due to teaching methods that lack interactivity and low student engagement in the learning process. Even though students may achieve good academic results, this does not necessarily mean they truly understand the concepts being taught. If students truly understand these concepts well and have mastered them, positive academic outcomes will certainly be achieved [4]. If students understand and master these concepts, optimal learning outcomes can be achieved. Therefore, improving conceptual understanding is essential to improving student learning outcomes.

One way to enhance self-regulated learning is by using the PBL (Problem-Based Learning) model. Problem-Based Learning (PBL) is a learning strategy that "engages" students in actively solving complex problems in realistic situations. PBL can be applied at the subject level, within a subject unit, or across the entire curriculum [5] This problem-based learning model is one alternative that can be used to improve students' conceptual understandingThe Problem-Based Learning (PBL) model is a learning approach that uses real-world problems as the foundation for the learning process from the surrounding environment as a basis during the learning process, enabling students to build knowledge and understand concepts by applying critical thinking skills to solve those problems [6].

However, to create a more engaging and efficient PBL (Problem-Based Learning) model, learning tools that support the learning process are needed. One such tool is AI (Artificial Intelligence)-based learning technology. The emergence of artificial intelligence has had a major effect on the advancement of educational technology, as it supports more effective learning processes and can be tailored to the individual needs of each student [7].

Science learning is often perceived as difficult by students because the material taught is abstract and theoretical. Therefore, the teaching model used in schools

How to Cite:
N. R. Bakri, A. H. Odja, D. D. Paramata, C. S. Payu, and M. Mursalin, "Integrating Artificial Intelligence into Problem-Based Learning to Enhance Self-Regulated Learning", *J. Pijar.MIPA*, vol. 21, no. 4, pp. 776–780, Aug. 2026. https://doi.org/10.29303/jpm.v21i4.12199

must help students solve problems and engage all students in the classroom learning process [8]. With the Problem-Based Learning (PBL) model, educators can encourage and motivate all students to be actively engaged in learning activities. Problem-Based Learning is a teaching approach that encourages students to think critically, improve problem-solving skills, and build connections between their knowledge and real-life problems. The curriculum focuses on mastering key concepts and principles in a particular field of study, actively engaging students in inquiry-based activities, problem-solving, and a variety of meaningful tasks [9].

In the learning process, adaptive technology greatly helps students understand the material more deeply and independently. One way to do this is by utilizing artificial intelligence (AI)-based features available on smartphones. The primary goal of artificial intelligence (AI) is to create machines that can learn, understand, plan, and adapt so they can complete tasks independently [10]. The use of Meta AI and ChatGPT helps to easily integrate technology into learning while improving the quality and engagement of the learning experience [11].

Two AI technologies that are becoming increasingly popular among students are Meta AI and ChatGPT, which can be accessed directly through WhatsApp and Google. Through this feature, students can interact directly with AI-based chatbots simply by sending text messages in the apps they already use daily. AI can even help students understand material on an individual basis and tailor learning approaches to each student's specific needs [12]. The advantage is that no additional apps are required; with just WhatsApp and Google, students can access learning assistance anytime and anywhere.

Research by [13] indicates that the integration of Problem-Based Learning (PBL) and Artificial Intelligence (AI) has the potential to enhance students' Self-Regulated Learning (SRL). Furthermore, various previous studies have also demonstrated that PBL and AI can improve student learning outcomes and motivation. However, these studies still have limitations, as they primarily focus on learning outcomes and have not examined students' baseline levels of Self-Regulated Learning. Furthermore, the integration of PBL and AI has not yet been comprehensively examined within a single, cohesive framework, particularly in science education. Therefore, this study aims to analyze students' baseline Self-Regulated Learning and examine the integration of PBL and Artificial Intelligence in science education as an effort to strengthen the novelty of the research.

Although previous studies have widely discussed the implementation of Problem-Based Learning (PBL) to foster student autonomy, research that specifically integrates Generative Artificial Intelligence (AI) features, such as ChatGPT and Meta AI via ubiquitous daily applications like WhatsApp, into science-specific PBL remains scarce. The novelty of this study lies in exploring how this seamless and personalized AI-assisted PBL model structurally intervenes in junior high school students' self-regulation during science learning. Based on this gap, this study aims to examine the effect of this integration on students' independent learning. Therefore, we hypothesize that the integration of Artificial Intelligence into the Problem-Based Learning model has a significant, positive impact on enhancing students' Self-Regulated Learning (SRL) in science education

Research Methods

This study employs a quantitative descriptive approach, a method aimed at objectively describing a population using numerical data analyzed statistically [14], to analyze the initial level of students' Self-Regulated Learning/SRL) in science learning. The research subjects were seventh-grade students at SMP Negeri 3 Satap Tabongo and SMP Negeri 1 Bulango Selatan. The sampling techniques used were total sampling, a method where the sample size equals the population [15] and voluntary sampling, which involves selecting participants who are willing to complete the questionnaire. The instrument used was an SRL questionnaire covering planning, monitoring, and self-evaluation. The data obtained were analyzed descriptively to describe the initial condition of students' self-regulation abilities.

The integration of Artificial Intelligence (AI) into the Problem-Based Learning (PBL) model is implemented at every stage of the learning process. During the problem-orientation stage, AI is used to help students understand the problem through initial information gathering. During the organization and investigation stages, AI is utilized to support the exploration of solutions, provide recommendations for learning resources, and help students validate information. Furthermore, during the presentation of results stage, AI is used to assist in preparing reports or presentations, while during the evaluation stage, AI is utilized as a reflection tool to help students assess their learning processes and outcomes

Table 1. Research Design

Group	Treatment (X)	Result (Posttest)
Experiment	AI-Assisted PBL	O_1
Replication	AI-Assisted PBL	O_2

Description:
X = The intervention involved the implementation of an AI-assisted Problem-Based Learning (PBL) model
O^1 = Self-Regulated Learning in the Experimental Class
O^2 = Self-Regulated Learning in the Replication Class

The research instruments used were a Self-Regulated Learning (SRL) questionnaire covering aspects of learning planning, monitoring, and evaluation, and a learning achievement test as supporting data. The instruments had undergone validity and reliability testing. Data collection was conducted by distributing the questionnaire after the treatment was administered. Data analysis utilized descriptive statistics to identify data trends, as well as inferential statistics through a normality test specifically the Shapiro-Wilk test where the Shapiro-Wilk test is one of the alternative procedures for assessing normality [16], and hypothesis testing using the One-Sample t-test is a testing procedure for a single examples with mechanisms where the mean derived from a single variable is compared to specific constant value [17]. Hypothesis testing was conducted to determine whether the sample mean differed from the established reference value. The data were analyzed using a one-sample t-test to

determine whether the students' average Self-Regulated Learning (SRL) scores met a certain standard. A score of 75 was used as the benchmark because it represents the Minimum Passing Criteria (KKM) in effect at the study school, as stated by [18]. The national passing target is expected to be at least 75, serving as a basis for assessing students' SRL achievement.

The research data were analyzed using a one-sample t-test to determine whether the students' average Self-Regulated Learning (SRL) scores differed significantly from the established benchmark. A score of 75 was used as the benchmark because it represents the Minimum Passing Score (MPS) in effect at the study school. The formula for the one-sample t-test used is as follows:

$$t = \frac{\overline{x - \mu 0}}{\frac{s}{\sqrt{n}}}$$

Description:
$\bar{x}$ = sample mean
$\mu 0$ = reference value (75)
s = sample standard deviation
n = sample size

Results and Discussion

This study was conducted at two different schools, with one class from each school serving as the research sample. The first class, consisting of 17 students, was designated as the experimental class, while the second class, consisting of 20 students, served as the replication class

Table 2. Results of the descriptive analysis of self-regulated learning.

Class	N	Min	Max	Mean	Std. Dev	Category
Exp.	17	71	118	90.12	13.465	High
Repl.	10	60	117	92.40	15.515	High

Based on the descriptive statistics, the mean score for Self-Regulated Learning in the experimental class was 90.12, falling into the high category, while in the control class it was 92.40, also in the high category.

Table 3. Normality Test Results

Class	Shapiro-Wilk		
	Statistic	df	Sig.
Eksperiment	.965	10	.842
Replication	.943	10	.589

Based on the results of the data normality test at SMPN 3 Satap Tabongo, it was found that Fi ≥ K at a significance level of α = 0.05. This indicates that the research data for the experimental class at SMPN 3 Satap Tabongo has a normal distribution. Meanwhile, the data analysis results for SMPN 1 Bulango Selatan showed that Fi ≥ K at the α = 0.05 significance level. These findings indicate that research data for the replication class at SMPN 1 Bulango Selatan are normally distributed. Thus, the Self-Regulated Learning (SLR) data from both the experimental and replication classes are normally distributed. Therefore, the assumption of normality in that study has been met, allowing the analysis to proceed using a parametric statistical test, namely the one-sample t-test.

Table 4. Results of the One-Sample t-Test

Class	Test Value = 75					
	t	df	Sig. (2-tailed)	Mean diff.	95% Confidence of the Difference	
					Upper	Lower
Exp.	4.628	16	.000	15.118	8.194	22.042
Repl.	3.547	9	.006	17.400	6.302	28.499

The results of the one-sample t-test with a reference value of 75 show that the experimental class yielded a t-value of 4.628 with a significance level of 0.000 ($p < 0.05$), while the replication class yielded a t-value of 3.547 with a significance level of 0.006 ($p < 0.05$). This indicates that the mean SRL of the students in both classes is significantly higher than the reference value. In addition to statistical significance, the effect size was calculated using Cohen's d to determine the practical significance of the intervention. Based on calculations of the t-value, sample size, and mean difference, a Cohen's d value of approximately 1.12 was obtained in the experimental class and 1.12 in the replication class, which falls into the large effect category. This indicates that integrating Artificial Intelligence into the Problem-Based Learning model has a strong impact on students' Self-Regulated Learning. This substantial impact can be theoretically validated through Barry Zimmerman's cyclic framework and Paul Pintrich's SRL model, which highlight how the AI-assisted PBL model actively drives the three core dimensions of self-regulation. First, in the planning (forethought) dimension, AI features like ChatGPT or Meta AI act as personalized facilitators that help students deconstruct abstract science problems, set clear goals, and map out independent inquiry strategies. Second, in the monitoring (performance) dimension, the seamless accessibility of AI via daily devices empowers students to conduct real-time cognitive monitoring, cross-checking their scientific concepts and arguments as they progress. Finally, in the evaluation (self-reflection) dimension, AI provides instant, objective, and specific feedback, enabling students to critically evaluate their problem-solving pathways and adapt their learning behaviors. Thus, the integration of AI does not merely offer technological assistance; it structures an adaptive, student-centered ecosystem that systematically nurtures students' metacognitive and motivational components in the digital age.

The research findings indicate that students' Self-Regulated Learning (SRL) falls in the high category, suggesting that their self-regulation skills still need development. The integration of Problem-Based Learning (PBL) with Artificial Intelligence (AI) supports students' self-regulation processes at every stage of learning. During the problem orientation stage, the use of AI helps students understand the context of the problem more quickly through access to a variety of information. This encourages the emergence of the planning aspect of SRL, in which students begin to set learning goals and develop problem-solving strategies. This improvement can be explained by the theory of Self-Regulated Learning [19], which states that SRL involves three main stages: planning, monitoring, and evaluation. Thus, the observed improvement in SRL

indicates that the implemented learning process has effectively facilitated these three aspects.

During the investigation phase, integrating AI into PBL enables students to explore various solutions, validate information, and receive immediate feedback. This process contributes to monitoring, as students actively control their thought processes and the strategies they employ. Furthermore, during the evaluation stage, AI helps students reflect on the learning outcomes they have achieved, thereby strengthening the self-evaluation aspect of SRL. Thus, the integration of AI and PBL not only affects learning outcomes but also directly influences the improvement of the key components of Self-Regulated Learning, namely planning, monitoring, and self-evaluation [20].

Findings from this study, which indicate a significant effect, may be influenced by several factors. First, implementing an AI-assisted PBL model enables students to actively participate in learning activities, thereby enhancing their self-regulation skills. The combination of PBL and AI technology creates an active, responsive, and adaptive learning process that enhances students' motivation and independence[21]. AI technology serves not only as a teaching aid but also as a collaborator in a learner-centered learning process. Third, the characteristics of problem-based learning, which require students to think critically and independently, also contribute to enhancing students' self-regulated learning (SRL) [22]. Third, the characteristics of problem-based learning, which require students to think critically and independently, also enhance students' Self-Regulated Learning (SRL). The core objective of the PBL model is not only to impart knowledge to students, but also to improve their critical thinking skills and problem-solving abilities, as well as to encourage them to actively construct their own knowledge[23].

The high average Self-Regulated Learning (SRL) scores achieved by students in both classes, placing them in the high category, can be theoretically validated using a cyclical framework [24], wherein the syntax of AI-assisted Problem-Based Learning (PBL) dynamically triggers three phases of student self-regulation. In the forethought phase, the problem orientation inherent in PBL is bolstered by the capabilities of AI tools (such as Meta AI and ChatGPT), which offer personalized support to help students independently establish goals and problem-solving strategies. Subsequently, during the performance phase, the flexibility of accessing AI via mobile devices facilitates independent cognitive monitoring as students actively investigate scientific concepts. The cycle concludes optimally in the self-reflection phase, where the study's evaluation instruments align with AI's role in providing instant feedback, thereby enabling students to assess and reflect on the critical-thinking strategies they employed to address learning challenges.

Although the average scores in the replication class were higher than those in the experimental class, this difference may be attributed to several factors, such as differences in student characteristics, a smaller class size that allowed for more effective learning, and the possibility that students in the replication class were better prepared to participate in Problem-Based Learning supported by Artificial Intelligence.

In line with the findings of previous research conducted by Lanio & Odja, the implementation of the Problem-Based Learning (PBL) model can foster students' independent learning through active engagement in the learning process. Furthermore, the use of Artificial Intelligence (AI) also helps students monitor and manage their learning process more independently. Thus, although the results of this study did not show significant differences, these findings still support the notion that AI-assisted PBL has the potential to gradually develop students' self-regulated learning[25].

Conclusion

Based on the research findings, it can be concluded that the integration of Artificial Intelligence (AI) into the Problem -Based Learning (PBL) has a significant effect on improving students' Self-Regulated Learning (SRL) in science education, as reflected in students' ability to plan, monitor, and evaluate their learning process independently. This demonstrates that AI-supported PBL has the potential to serve as an innovative learning strategy relevant to educational needs in the digital age; practically, these findings have implications for science teachers to utilize AI technology as a supportive tool in implementing PBL, particularly in providing rapid feedback, facilitating independent exploration, and assisting students in managing their learning processes, while schools may consider integrating AI technology to support the development of students' learning autonomy; however, this study has limitations in the form of a relatively small sample size and the absence of a control group, so the generalizability of the results remains limited; therefore, future research is recommended to use a stronger experimental design involving a control group and a larger sample size, as well as to explore the integration of AI into other learning models or at different educational levels to enrich studies related to Self-Regulated Learning.

Author's contribution

N. R. Bakri: involved in the conceptualization of the research, data collection, data analysis, and the drafting of the initial version of the article. A.H. Odja: contributed to the design of the methodology, research supervision, and finalization of the manuscript. D.D. Paramata: involved in reviewing and editing the manuscript. C. S. Payu: contributed to the review and validation. Mursalin: involved in the overall supervision of the research and validation

Acknowledgements

The researchers express their gratitude to the principals, teachers, and students at SMP Negeri 3 Satap Tabongo and SMP Negeri 1 Bulango Selatan for their support in completing this study.

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