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The Effect of Problem-Based Learning Model on Generic Science Skills and Creative Thinking Skills in Science Learning

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Abstract: This study aims to examine the impact of the Problem-Based Learning (PBL) model on students' generic science skills and creative thinking abilities in chemistry subjects at the senior high school level. Using a quasi-experimental quantitative research method, the sample consisted of 60 students from two classes, selected through stratified random sampling. The instruments used included tests for generic science skills and creative thinking and a questionnaire to assess students' responses to the PBL model. Descriptive and inferential statistical analyses revealed that students in both the Chemistry Education and Chemistry study programs demonstrated significant improvements in generic science skills and creative thinking abilities when exposed to the PBL model. The regression analysis showed a positive and significant correlation, with PBL explaining 55% of the variance in generic science skills and 52% in creative thinking abilities. These findings suggest that PBL effectively enhances critical skills in science education and encourages active learning, problem-solving, and creative thinking among students. Thus, PBL can be considered a valuable pedagogical tool in modern science education.

Keywords: active learning, chemistry education, creative thinking, generic science skills, and problem-based learning.

▪ INTRODUCTION

In the modern era marked by the rapid development of science and technology, generic science and creative thinking skills are important competencies that students need. Generic science skills, such as observation skills, information processing, and scientific reasoning, are the basis for understanding and solving various complex science problems (Fitriani et al., 2020; Sarı et al., 2020; Sutiani et al., 2021). Meanwhile, creative thinking skills encourage students to produce new, innovative, and solution-oriented ideas needed to face increasingly dynamic global challenges (Wasehudin et al., 2021; Gao et al., 2022). Science learning not only focuses on mastering concepts and theories but also on developing generic skills and creative thinking so that students can adapt and actively contribute to a knowledge-based society (Sarkar et al., 2019; Hu & Guo, 2021; Priawasana & Muis, 2021).

Therefore, a learning approach is needed to integrate and improve these two abilities, one of which is through applying the Problem-Based Learning (PBL) model, which has been proven effective in honing students' cognitive skills and creativity. Conventional learning that is still widely applied in schools tends to focus on lecture methods and memorizing concepts, thus providing limited space for students to be actively involved in the learning process (Hoidn & Reusser, 2020; Isa et al., 2020; Sakinah et al., 2022). This often results in low generic science skills, such as analysis, data interpretation, and problem-solving, because students need help to apply their

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knowledge in real contexts. In addition, a passive and one-way learning approach also hinders the development of students' creative thinking skills, which should be honed through exploration activities, experiments, and discussions that challenge their imagination and critical thinking patterns (Cladis, 2020; Mustaqim et al., 2021; Ampartzaki & Kalogiannakis, 2023). As a result, students become less trained to deal with situations that require innovative and creative solutions, which are much needed in a changing world.

The low level of generic science skills and creative thinking skills indicates the need to reform more interactive and student-centered learning methods, such as problem-based learning models, to improve the quality of science learning in schools (Virtanen & Tynjälä, 2019; Aytaç & Kula, 2020; Bara & Xhomara, 2020). The Problem-Based Learning (PBL) model is an approach that places students at the center of the learning process by giving them tasks to solve real or contextual problems (Almulla, 2020; Djou et al., 2022; Razak et al., 2022). In PBL, students work collaboratively, seek information, discuss ideas, formulate hypotheses, and develop solutions based on their understanding (Hajarina, 2021; Magaji, 2021; Qondias et al., 2022).

This process hones generic science skills such as critical thinking, analysis, and application of scientific concepts (Sakliressy et al., 2021; Sutiani et al., 2021; Doyan et al., 2022). In addition, PBL also encourages creative thinking skills by inviting students to find various solutions and apply innovative approaches. With active student involvement, PBL overcomes the weaknesses of conventional learning and stimulates curiosity. This model provides a deeper learning experience and prepares students to face real-world challenges with a flexible and adaptive mindset.

Previous studies have shown that scientific inquiry-based learning models have a positive effect on students' generic science skills, as shown in a study at MTs Swasta Syamsyuddhuha, which observed an increase in students' generic science skills on simple plane material with higher results compared to conventional learning models (Raudhatillah et al., 2024). Then, research by Loka & Hakim (2024) showed that although evidence supports the effectiveness of learning models on generic science skills, this study was limited to more than just a few skills without further exploring students' creative thinking abilities. From here, there is a gap in research that comprehensively explores the effect of PBL on generic science and creative thinking skills.

The novelty of this study lies in its focus on examining the effect of the Problem-Based Learning (PBL) model, specifically on students' generic science skills and creative thinking skills, two aspects that have yet to be discussed in depth in the context of PBL. Although many previous studies have highlighted the effectiveness of PBL in increasing student engagement and conceptual understanding, there still needs to be a gap in research linking PBL to the development of generic science skills that include analytical skills, data processing, and applying scientific knowledge in real situations. In addition, this study also offers novelty by examining the relationship between generic science skills and creative thinking skills, providing a new perspective on how these two abilities can support each other in the learning process.

Thus, this study seeks to fill the gap in the existing literature and provide practical guidance for educators in implementing the PBL model to optimize the development of important skills needed by students in the modern era. This study aimed to determine the effect of the problem-based learning model on students' generic science skills and creative thinking abilities. Based on this, the hypothesis proposed is that the Problem-Based Learning model significantly improves students' generic science skills and creative thinking skills compared to conventional learning models.

To address this gap in the literature, this study aims to investigate the specific effects of a Problem-Based Learning (PBL) model on students’ generic science skills and creative thinking skills. The primary objective is to assess how the PBL model can enhance students’ ability to apply scientific concepts, analyze data, and solve real-world problems, while developing their capacity for innovative thinking and problem solving. Furthermore, this study aims to explore the potential relationship between generic science skills and creative thinking skills, by examining how the development of one can complement and strengthen the other in a PBL learning environment. By focusing on these dual competencies, this study hopes to provide valuable insights into how modern pedagogical approaches can better prepare students for the challenges of a rapidly evolving global society.

The research hypothesis is that the Problem-Based Learning (PBL) model has a significant positive impact on students’ generic science skills and creative thinking skills when compared to conventional teacher-centered learning methods. Specifically, it is expected that students who participate in PBL will demonstrate higher levels of proficiency in skills such as data interpretation, critical analysis, and problem solving, as well as demonstrate increased creativity in generating innovative solutions to real-world problems. This study will compare these results with the results of students undergoing a traditional learning approach, thereby providing empirical evidence on the effectiveness of PBL in fostering generic science competencies and creative thinking in students.

▪ METHOD

Participants

The population in this study were all grade XI students at SMAN 11 Kota Jambi. The sample studied was 60 students from grade XI at SMAN 11 Kota Jambi. Sampling was carried out using the stratified random sampling technique, which is a technique in which the population is divided into several homogeneous subgroups or strata based on certain characteristics, such as class or academic ability (Mulisa, 2022; Adeoye, 2023). The selection of classes XI F4 and F5 was based on the representation of varying academic abilities so that the study results could better represent the population. This stratification criterion allows for wider variations in academic ability.

Research Design and Procedures

This study used a quantitative approach with a quasi-experimental type. The quasi-experimental design was chosen because it allows the evaluation of the effect of independent variables on dependent variables in situations where random assignment to experimental and control groups is not possible (Cera et al., 2020; Schneider & Rohmann, 2021; Ballance, 2024). In the context of this study, random assignment is not feasible due to limited access or constraints that require pre-existing group divisions. Using a quasi-experimental design, researchers can overcome this limitation by using pre-formed groups as research samples.

Data were collected after the treatment was given, and statistical techniques were used to analyze whether there were significant differences between the groups that received the treatment and the groups that did not receive the treatment. This quasi-experimental design is useful in assessing the effectiveness of interventions in real conditions in the field so that the results obtained can be more relevant and applicable.

This research procedure begins with designing and developing a test of creative thinking ability and a generic ability test for students based on a predetermined conceptual framework. After that, the test is distributed to a randomly determined sample of students or through systematic selection. During the test-filling process, students are asked to answer questions about creative thinking abilities and generic skills to be measured. The collected data is then analyzed using statistical methods, such as descriptive analysis, to get an overview and inferential analysis to determine the influence between the variables studied. The following figure illustrates how this research procedure is performed.

Figure 1. Research procedures

Instruments

The research instruments used in this study include a generic science skills test, a creative thinking ability test, and a response questionnaire for using a problem-based learning model. The generic science skills test instrument measures indirect observation, scale awareness, symbolic language, logical framework, logical consistency, law of cause and effect, and modeling. The generic science skills test instrument consists of 15 statements on a Likert scale of 1-4. Meanwhile, the creative thinking ability test measures fluency, flexibility, originality, and elaboration in student thinking. The creative thinking ability test consists of 9 questions on a scale of 1-4. The questionnaire response using the problem-based teaching model measures material comprehension, learning motivation, problem-solving skills, collaboration and communication, and method suitability. The questionnaire response using the problem-based teaching model consisted of 10 statements with a Likert scale of 1-4. The data collection technique is carried out by providing test instruments that have been provided after treatment for each sample from the two study programs. The instrument grid is arranged based on response indicators to problem-based teaching models, generic science skills indicators, and creative thinking ability indicators, with question items adjusted to chemical reaction materials.

The content validity of each instrument has been verified through expert judgment, where the instrument is compiled based on indicators of generic science skills and creative thinking skills relevant to chemical reaction material (Damayanti et al., 2022). In addition, construct validity was tested using factor analysis to ensure that each item on the instrument corresponds to the measured dimensions (Taslidere, 2016). To ensure the instrument's internal reliability (consistency), Cronbach's Alpha coefficient was calculated for each instrument.

The generic science skills test demonstrates high reliability with a Cronbach's Alpha coefficient value of 0.8. Similarly, the creative thinking ability test exhibits good reliability, as indicated by a Cronbach's Alpha coefficient of 0.78. Furthermore, the response questionnaire for the problem-based learning model falls into the adequate reliability category, with a Cronbach's Alpha value of 0.75. As for the response grid to the use of the problem-based teaching model, generic science skills can be seen in the table 1. below:

Table 1. Response questionnaire grid to the use of problem-based teaching model

No	Aspect	Indicator	Number of questions	Question Number
1.	Material Understanding	Understanding Concepts	2	1.2
		Concept Application		
2.	Learning Motivation	Active Engagement	2	3.4
		Learning Interest		
3.	Problem-Solving Skills	Problem Analysis Skills	2	5.6
		Solution Creativity		
4.	Collaboration and Communication	Teamwork	2	7.8
		Effective Communication		
5.	Method Suitability	Relevance to Needs	2	9.10
		Difficulties in Implementation		
	Number of questions		10	

The questionnaire instrument responded to the use of the problem-based teaching model and consisted of 10 statements on a Likert scale of 1 to 4. The response categories for the use of problem-based learning models are divided into four based on interval scores. The Very Bad (Very Bad) category includes scores in the range of 10.00–17.40, while the Not Good (Not Good) category is in the interval of 17.50–24.90. The Good (Good) category includes scores between 25.00–32.40, and scores of 32.50–40.00 are included in the Very Good (Very Good) category. This division helps in spreading the level of acceptance or effectiveness of the problem-based learning model.

The general science skills test instrument used in this study was designed to measure seven general skills in the field of science. Each skill is associated with a specific indicator to assess students' scientific abilities. Indirect Observation measures students' capability to use measuring instruments in observing chemical experiments or natural phenomena for accurate data collection. Comprehension Scale evaluates students' sensitivity to natural objects and their understanding of numerical scales at both microscopic and macroscopic levels. Symbolic Language encompasses the understanding of chemical symbols, scientific terms, units in equations, mathematical problem-solving, and the interpretation of graphs, diagrams, and tables. Logical Framework focuses on recognizing patterns and grouping chemical objects or events based on their properties. Logical Consistency emphasizes drawing inductive conclusions and identifying patterns in chemical and physical properties through experiments. Law of Cause and Effect evaluates the ability to state and imagine relationships between variables in natural phenomena or chemical reactions. Lastly, Modeling assesses the ability to represent natural phenomena or chemical reactions through sketches, graphs, or models and interpret their meanings in physical or chemical terms.

The student science generic skills instrument consists of 15 statements with a Likert scale of 1 to 4. students' general science skills categories based on interval scores. The "Very Poor" category is in the score interval of 15.00–26.24, the "Poor" category is in the interval of 26.25–37.49, the "Good" category is in the interval of 37.50–48.74, and the "Very Good" category is in the interval of 48.75–60.00. The grid of instruments for the test of students' creative thinking ability can be seen in the table 2 below:

Table 2. Creative thinking ability test grid

No.	Aspect	Indicator	Number of questions	Question Number
1.	Fluency	Able to generate various ideas related to solutions to a problem	3	1.2.3
2.	Flexibility	Able to think from multiple perspectives	3	4.5.6
3.	Originality	Able to generate unique and new ideas in solving problems	2	7.8
4.	Elaboration	Able to develop and refine ideas	2	9.10
		Number of questions	10	

The instrument for students' critical thinking skills consists of 10 statements with a Likert scale of 1 to 4. The "Very Bad" category is in the score interval of 10.00–17.40, the "Not Good" category is in the interval of 17.50–24.90, the "Good" category is in the interval of 25.00–32.40, and the "Very Good" category is in the interval of 32.50–40.00.

Data Analysis

The data analysis technique in this study was carried out through data collection directly after the intervention or treatment was given. Data from research instruments, such as responses to problem-based learning models, generic science skills tests, and creative thinking ability tests, were analyzed using descriptive and inferential statistical techniques. Descriptive analysis is used to describe data characteristics, such as mean, median, and standard deviation (Katrakazas et al., 2020; Wang et al., 2020; Gonaygunta et al., 2023), while inferential analysis and multiple linear regression tests were used; to test the proposed hypothesis and determine whether there was an influence of the problem-based learning model on student's generic science skills and creative thinking abilities on chemical reaction mate-rials. Assume tests are carried out in the form before conducting the linear regression test. Of normality, multicollinearity, heteroscedasticity, and autocorrelation tests (Amijaya et al., 2020; Nazihah et al., 2023; Mardiat-moko, 2024). For inferential analysis, multiple linear regression was chosen to test the hypothesis and assess the effect of problem-based learning model on students' generic science skills and creative thinking ability in the context of chemical reaction materials. Multiple linear regression was chosen because of its ability to evaluate the combined effects of multiple predictors on a single dependent variable, in line with research.

▪ RESULT AND DISSCUSSION

The results of the descriptive analysis of the response to the use of problem-based learning models show differences in the responses of students from the Chemistry Education Study Program and the Chemistry Study Program. In the Chemistry Education Study Program, the average value (mean) of student responses to the use of problem-based learning models is 27.10, with a median of 27.00, and a minimum value range of 10.00 to a maximum of 40.00. In percentage terms, 8.33% of students are in the "Very Bad" category and 20% are in the "Not Good" category. This shows that 28.33% of students in the Chemistry Education Study Program gave a negative response to this learning model.

Meanwhile, in the Chemistry Study Program, the average (mean) of student responses was slightly higher, namely 27.50 with the same median, namely 27.00, and the same value range from 10.00 to 40.00. As many as 10% of students fall into the "Very Bad" category, and 25% into the "Not Good" category, bringing the total to 35% who gave a negative response to the use of problem-based learning models.

From these results, it can be seen that although the average response of the two study programs is almost the same, the percentage of students who gave a negative response in the Chemistry Study Program (35%) is higher than in the Chemistry Education Study Program (28.33%). This shows that students in the Chemistry Study Program tend to have more negative views on the use of problem-based learning models when compared to students from the Chemistry Education Study Program..

The results of the descriptive analysis of students' generic science skills using the problem-based learning model show differences between the Chemistry Education Study Program and the Chemistry Study Program. In the Chemistry Education Study Program, the average value of students' generic science skills is 2.35, with a median value of 2.00, a minimum value of 1.00, and a maximum value of 4.00. In this group, 8.4% of students are in the "Not Good" category, and 75% of students are in the "Good" category, while 16.6% are in the "Very Good" category. There are no students in the "Very Bad" category in this study program.

Meanwhile, in the Chemistry Study Program, t[R1], the average value of generic science skills is 2.56, with a median of 3.00, a minimum value of 1.00, and a maximum value of 4.00. No students in this group are in the "Very Bad" category. From the results of the average comparison, generic science skills in the Chemistry Study Program are slightly higher than in the Chemistry Education Study Program.

Statistical analysis results on students' creative thinking skills using problem-based learning models show differences in student responses from the Chemistry Education Study Program and the Chemistry Study Program. In the Chemistry Education Study Program, the average (mean) of student's creative thinking skills is 2.71, with a median of 3.00, a minimum value range of 1.00 and a maximum of 4.00. Most students in this study program are in the "Very Good" category, which is 66.7%. However, 11.6% of students are in the "Not Good" category, and 0% are in the "Very Bad" category.

On the other hand, in the Chemistry Study Program, the average (mean) of students' creative thinking skills is 2.69, with a median of 3.00, a minimum value range of 1.00 and a maximum of 4.00. The majority of students in this program are also in the "Very Good" category at 56.7%, while 3.3% of students are in the "Not Good" category, and another 3.3% are in the "Very Bad" category.

When compared between the two groups, the Chemistry Education Study Program has a percentage of students with poor creative thinking skills (categories "Not Good" and "Very Poor") of 11.6%, higher than the Chemistry Study Program, which only has 6.6% of students in the same category. The average creative thinking skills between the two groups are also almost the same, namely 2.71 for Chemistry Education and 2.69 for Chemistry.

The following presents the results of inferential statistics using multiple linear regression tests to see the influence of problem-based learning models on students' generic science skills and creative thinking abilities on chemical reaction materials. Before conducting the influence test, an assumption test was carried out as a normality test, a multicollinearity test, a heteroscedasticity test, and an autocorrelation test. The results of the data assumption test conducted in this study can be seen in the following table:

The normality test aims to check whether the residual (the difference between the observed and predicted values) follows the normal distribution (Alita et al., 2021; Demir, 2022; Guzik & Więckowska, 2023). The results of the data normality test in this study can be seen in the following table 3.

Table 3. Normality test results

Courses	Variable	Test Statistics	Significance (p-value)	Information
Chemistry Education	Response to the PBL Model	0.974	0.111	normal
	Generic Skills of Science	0.975	0.123	normal
	Creative Thinking Skills	0.980	0.089	normal
Chemistry	Response to the PBL Model	0.965	0.067	normal
	Generic Skills of Science	0.968	0.056	normal
	Creative Thinking Skills	0.970	0.059	normal

The table 3, shows the results of the normality test for the generic science skills test, the creative thinking ability test, and the response questionnaire to use the problem-based learning model, which was conducted for two study programs: Chemistry Education and Chemistry. The normality test using Shapiro-Wilk statistics showed that all data variables for both study programs had a p-value greater than 0.05. For the generic science skills test, the p-values are 0.123 for Chemistry Education and 0.056 for Chemistry, respectively, while for the creative thinking ability test, the p-values are 0.089 for Chemistry Education and 0.042 for Chemistry. The response questionnaire to the problem-based learning model showed a p-value of 0.111 for Chemistry Education and 0.067 for Chemistry. All p-values greater than 0.05 indicate that the data is normally distributed so that further statistical analysis can be performed validly, and the results can be interpreted accurately.

The multicollinearity test aims to determine whether a high or perfect correlation exists between independent variables in a regression model (Perez-Melo & Kibria, 2020; Gregorich et al., 2021). The results of the data multicollinearity test in this study can be seen in the following table 4.

Table 4. Multicollinearity test results

Courses	Variable	VIF (Variance Inflation Factor)	Tolerance
Chemistry Education	Response to the PBL Model	1.18	0.85
	Generic Skills of Science	1.20	0.83
	Creative Thinking Skills	1.25	0.80
Chemistry	Response to the PBL Model	1.22	0.82
	Generic Skills of Science	1.15	0.87
	Creative Thinking Skills	1.10	0.91

Based on the results of the 4, test, it can be seen that the VIF values for all variables are in a range that indicates the absence of significant multicollinearity, with numbers ranging from 1.10 to 1.25, well below the general threshold of 10. Similarly, a tolerance value ranging from 0.80 to 0.91 indicates that the proportion of variance not explained by other independent variables is quite high, so multicollinearity is not a major problem in this regression model. These results indicate that the linear relationship between the independent variables in this study is relatively low, and the data can be used for regression analysis without significant multicollinearity problems.

The heteroscedasticity test was carried out to determine whether, in a regression model, the residual variant was discomfort from one observation to another (Berenguer-Rico & Wilms, 2021; Simamora et al., 2022). The results of the data heteroscedasticity test in this study can be seen in the following table 5.

Table 5. Heteroscedasticity test results

Courses	Variable	Test Statistics	Significance (p-value)
Chemistry Education	Response to the PBL Model	1.10	0.312
	Generic Skills of Science	1.12	0.300
	Creative Thinking Skills	1.20	0.275
Chemistry	Response to the PBL Model	1.07	0.344
	Generic Skills of Science	1.05	0.367
	Creative Thinking Skills	1.18	0.290

Based on the test results 5, all p-values are above the general significance limit of 0.05, ranging from 0.275 to 0.367. This indicates that there is no pattern of non-constant residual variance in the data, and thus, the heteroscedasticity problem is not significant. In other words, the regression model used in this study did not show any residual variance inconsistencies, so it can be considered valid for further analysis.

The autocorrelation test aims to test whether there is a correlation between the perturbation error (residual) in the t-period and the error in the t-1 period (previous) in linear regression (Rauf et al., 2021). The results of the data autocorrelation test in this study can be seen in the following table 6.

Table 6. Autocorrelation test results

Courses	Variable	Test Statistics	Significance (p-value)
Chemistry Education	Response to the PBL Model	1.82	0.130
	Generic Skills of Science	1.85	0.120
	Creative Thinking Skills	1.80	0.140
Chemistry	Response to the PBL Model	1.87	0.120
	Generic Skills of Science	1.90	0.150
	Creative Thinking Skills	1.88	0.120

Based on the test results table 6, all p-values are above the significance limit of 0.05, with a range of p-values between 0.105 and 0.140. This indicates that there is no significant autocorrelation in the data, which means that the residuals in the regression model do not show a significant correlation pattern. Thus, the regression model used in this study can be considered valid for further analysis in the absence of autocorrelation problems.

The multiple linear regression test aims to test the influence of several independent variables on non-independent variables (Gomila, 2021). The results of the multiple linear regression test data in this study can be seen in the following table 7.

Table 7. Multiple linear regression test results

Variable Independent	Variable Dependent	Regression Coefficient (B)	Standard Error	t-value	p-value	R2
Problem-Based Learning Model	Generic Skills of Science	0.45	0.12	3.75	0.0007	0.55
	Creative Thinking Skills	0.38	0.11	3.45	0.0012	0.52

Based on the results of the above test, it can be seen that the regression coefficient of each variable is dependent, with a significant p-value (< 0.05) for both variables, namely generic science skills and creative thinking skills. The regression coefficient for generic science skills was 0.45 and for creative thinking ability was 0.38, suggesting that the problem-based learning model significantly affected both aspects. The R^2 values of 0.55 for generic science skills and 0.52 for creative thinking skills show that this model can explain about 52-55% of the variation in dependent variables. This indicates that the problem-based learning model effectively improves both skills in the context of chemical reaction materials.

The Problem-Based Learning (PBL) model is a learning approach in which students face real problems that require solving (Lou et al., 2017; Akben, 2019). PBL aims to stimulate critical and creative thinking skills, promote self-learning, and enhance in-depth understanding of concepts (Martinez, 2022). In the context of science, generic skills include the ability to analyze, observe, experiment, and solve problems related to science, while the ability to think

Creativity includes generating new, innovative, practical ideas for solving scientific problems (Zainiyati, 2010; Widodi et al., 2023). Applying the Problem-Based Learning Model significantly impacts students' generic science skills and creative thinking abilities (Rubiyati & Effendi, 2021; Fitriyani, 2022). Through PBL, students are exposed to situations requiring them to integrate knowledge and skills to develop analytical and experimental skills better (Chang et al., 2018; Kurniati et al., 2021). In addition, this model encourages students to think out of the box, improving their ability to come up with creative and innovative solutions to scientific problems.

This research aligns with the research conducted by Arifah et al. (2021), which found that applying the PBL learning model in physics learning for high school students significantly improved their critical thinking skills. Although PBL has proven effective in improving generic skills and creative thinking, there still needs to be more in its application, especially related to the variation in students' responses to this method (Putri et al., 2022; Raudhatillah et al., 2024). Some students may find it challenging to use approaches that demand active engagement and highly independent thinking, especially if they have yet to become familiar with unconventional learning methods. In addition, implementing PBL requires more teacher readiness regarding learning planning and facilitation, which is often an obstacle in schools with limited resources.

Problem-Based Learning (PBL) model positively impacts creative thinking skills. This can be explained by referring to constructivism theory, where students construct knowledge through relevant direct experiences, which enables them to think critically and creatively (Munawaroh et al., 2022). In addition, this finding can be supported by previous studies showing that PBL provides a context for meaningful learning, improves analytical skills, and motivates students to engage more deeply (Lou et al., 2017; Martinez, 2022). The discussion will be more in-depth and critical by connecting these results to theoretical frameworks and previous literature.

This study has not discussed its limitations comprehensively. To increase transparency, it is important to highlight potential bias in sampling, constraints that arise in quasi-experimental research designs, and challenges in generalizing the results. This is especially important considering that this study is limited to one research site, so the results may not fully represent the wider population.

Although the results of this study demonstrate the effectiveness of PBL, more concrete recommendations for educators would add practical value to the findings of this study (Lou et al., 2017). Discussion of how to implement PBL in the classroom in practice and the resources or training teachers need to implement PBL optimally would make these findings more implementable in everyday educational contexts. This study needs to provide suggestions for future research directions. Including suggestions, such as exploring the long-term impact of PBL implementation, its effects at different levels of education, or comparisons with other pedagogical methods, would demonstrate the contribution of this study to the development of PBL studies.

▪ CONCLUSION

Based on the study results, it can be concluded that the problem-based learning (PBL) model is effective in enhancing both generic science skills and creative thinking skills, with an effect size of approximately 0.52, indicating that this model explains around 52-55% of the variation in the dependent variables. These results highlight the model's significant role in facilitating skill development in the context of chemical reactions, fostering students' creativity, and encouraging them to discover innovative solutions. The broader implications suggest that the PBL model can support educational goals aligned with 21st-century skills by equipping students with critical thinking and problem-solving abilities necessary for a modern curriculum. To strengthen science education, practical recommendations for implementing PBL include structured integration into science curricula, allowing teachers and curriculum developers to effectively adopt this approach for a transformative impact on students' learning experiences.

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