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The effect of the PjBL-STEAM model on students' creative thinking and scientific communication skills in biotechnology

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Abstract
This study aims to examine the effect of the Project Based Learning (PjBL) model integrated with the STEAM approach on students' creative thinking and scientific communication skills in biotechnology learning. The research was motivated by the uneven development of these skills among junior high school students in science learning. A quantitative approach was employed using a Posttest Only Control Group Design. The sample consisted of two ninth-grade classes at SMP Negeri 9 Surakarta selected through random sampling. The experimental class was taught using the PjBL-STEAM model, while the control class used the Problem-Based Learning (PBL) model. Data were collected through descriptive tests assessing creative thinking and scientific communication skills, and analyzed using MANOVA after confirming normality and homogeneity. The results showed that the PjBL-STEAM model had a significant positive effect on both skills, with a Wilk's Lambda value of 0.446, $F = 46.24$ for creative thinking, $F = 44.47$ for scientific communication, and a significance level of $p = 0.000$ (< 0.05). The experimental class achieved higher average posttest scores (82 for creative thinking and 73 for scientific communication) compared to the control class (63 and 55, respectively). These findings indicate that the PjBL-STEAM model effectively enhances students' creative thinking and scientific communication skills in biotechnology, highlighting its potential as an innovative and integrative learning approach in science education.

1. Introduction

The integration of the Project-Based Learning (PjBL) model with the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach in biotechnology learning offers great potential to strengthen 21st-century competencies, especially creative thinking and scientific communication skills. Both skills are essential in preparing students to face global challenges that demand innovation, collaboration, and effective communication of scientific ideas. The National Education Association (NEA) emphasizes creativity and communication as two of the four "4C" skills, alongside collaboration and critical thinking, that students must master to thrive in a knowledge-driven era (Mu'minah & Suryaningsih, 2020). Creativity as one of the key drivers of innovation, bridges knowledge and imagination, enabling abstract ideas to be transformed into tangible outcomes (Lavonen & Korhonen, 2017).

Creative thinking skills are particularly crucial in science education, where students are expected to apply conceptual understanding to real-world contexts. These skills encourage learners to think divergently, generate alternative solutions, and adapt flexibly to dynamic problems (Piirto, 2011; Septikasari & Frasandy, 2018; Tabieh et al., 2020). However, several studies have revealed that the development of creative thinking in science classrooms remains uneven. Kurnia et al. (2021) and Purwanti et al. (2024) report that teacher-centered instruction tends to restrict students' exploration of ideas. Similarly, Milga Shari et al. (2024) note that limited opportunities for open-ended learning hinder students from connecting scientific concepts to daily life situations. At the same time, Kurniawan et al. (2020) and Sarwanto (2016) explain that creative thinking is strongly related to scientific communication skills that the ability to express data driven arguments coherently, both orally and in writing. Lubis et al. (2024) and Ummiah & Fuadiyah (2024) highlight that many students still struggle to communicate scientific reasoning effectively due to the lack of appropriate learning models that integrate creativity and communication simultaneously.

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Field findings at SMP Negeri 9 Surakarta further support these concerns. Based on interviews conducted on March 10, 2025, science teachers reported that learning activities such as group discussions, experiments, and presentations have attempted to foster students' creative thinking and communication skills. Some students have demonstrated the ability to ask questions, propose alternative solutions, and present data-based arguments. However, these abilities are not evenly distributed, many students remain passive, hesitant to experiment with new ideas, and struggle to organize thoughts systematically when presenting or writing scientific reports. This indicates that despite ongoing efforts, students' mastery of creative thinking and scientific communication remains suboptimal and requires a more integrated, consistent approach that simultaneously develops both competencies.

To address these challenges, the Merdeka Curriculum encourages the application of contextual and student-centered models such as Project-Based Learning (PjBL), Inquiry-Based Learning, and Problem-Based Learning (Permendikbudristek No. 16 of 2022). PjBL facilitates active learning through authentic projects that connect classroom concepts to real-life applications (Rahayu et al., 2017). When combined with the STEAM approach, which emphasizes interdisciplinary design thinking, students are further motivated to innovate by integrating scientific, technological, and artistic perspectives (Siti et al., 2021). Empirical studies by Azalia et al. (2024) and Fitriyah & Ramadani (2021) confirm that PjBL-STEAM effectively enhances creative thinking indicators such as fluency, flexibility, and originality. However, previous research has rarely examined how PjBL-STEAM simultaneously improves scientific communication, especially in biotechnology learning, which naturally requires both creativity and communicative competence.

Therefore, this study aims to analyze the effect of the PjBL-STEAM model on students' creative thinking and scientific communication skills in biotechnology learning. By integrating these competencies in one instructional design, the research seeks to provide a comprehensive learning framework that not only promotes innovation through project work but also empowers students to communicate scientific reasoning effectively. This study is expected to contribute new insights into the application of PjBL-STEAM in science education and offer practical implications for teachers in implementing more meaningful and creative learning experiences.

2. Method

This study employed a quantitative approach with a quasi-experimental design, specifically the Posttest Only Control Group Design. This design was chosen because it allows comparison between two existing groups that cannot be fully controlled or randomly assigned while still maintaining internal validity through statistical equivalence testing prior to the treatment (Krishnan, 2019). In this design, one group received treatment using the Project-Based Learning (PjBL)-STEAM model, while the other acted as a control group using the Problem-Based Learning (PBL) model with a discussion method. The research design is shown in Table 1.

Table 1.Research Design

Group	Treatment	Posttest
A	X1	O1
B	X2	O2

The study was conducted at SMP Negeri 9 Surakarta, located on Jl. Sekar Jagat I Jegon, Surakarta, Central Java. The school is a public junior high school with adequate facilities to support project-based and technology-oriented learning, making it suitable for STEAM-based implementation. The research was carried out during April–May 2025, coinciding with the ninth-grade students' study of Biotechnology, a topic that integrates scientific concepts with creative project development.

The population in this study consisted of all ninth-grade students at SMP Negeri 9 Surakarta, totaling 284 students across nine classes (IX A–IX I), with an average of 32 students per class. The sample included two classes: class IX G as the control group and class IX H as the experimental group, each comprising 32 students. Both groups had relatively similar academic characteristics, as determined by the results of the final summative assessment (PSAS) from the previous semester. The sample selection was conducted using a cluster random sampling technique, as the population was naturally grouped into intact classes. Prior to sample determination, a normality test using the

Kolmogorov–Smirnov method and a homogeneity test using Levene's test were performed on students' PSAS scores to ensure the equality of academic ability across classes. The results showed that all classes were normally distributed (Sig. > 0.05) and homogeneous (Sig. = 0.347 > 0.05). After confirming these conditions, two classes were randomly selected, and an Independent Sample t-test was conducted to verify their equivalence. The results indicated that classes IX G and IX H had no significant differences (Sig. = 0.001 > 0.05), confirming that they were statistically comparable before treatment.

The independent variable in this study was the PjBL-STEAM learning model adapted from Fleming (2000), which integrates science, technology, engineering, arts, and mathematics into a creative and contextual project-based learning process. The dependent variables were creative thinking skills and scientific communication skills. Creative thinking was measured using Torrance's (1987) indicators, which include fluency, flexibility, originality, and elaboration, while scientific communication was assessed using Spektor-Levy et al. (2008) indicators, namely information retrieval, scientific reading, listening and observing, scientific writing, information representation, and knowledge presentation.

Data collection was conducted through a posttest with essay questions. The creative thinking Data collection was carried out through a posttest administered after the learning process in both groups. The posttest was designed in the form of essay questions to assess students' creative thinking and scientific communication skills. The creative thinking test consisted of eight essay questions, two for each indicator, while the scientific communication test consisted of twelve essay questions, also two for each indicator. Each question was scored using a detailed rubric with a score range from 0 to a maximum score depending on the difficulty level. The total score for each indicator was then converted using the formula:

$$Score = \frac{Total\ score\ for\ each\ indicator}{Maximum\ score\ for\ each\ indicator} \times 100 \quad (1)$$

The results of the calculation are then converted according to the categories in Table 2 and Table 3.

Table 2. Conversion of Creative Thinking Skills Scores

Scores	Categories
81 – 100	Very Creative
61 – 80	Creative
41 – 60	Moderatly Creative
21 – 40	Less Creative
0 – 20	Not Creative

(Ekawati & Sumaryanto, 2011)

Table 3. Conversion of Scientific Communication

Scores	Categories
81 – 100	Very Good
61 – 80	Good
41 – 60	Average
21 – 40	Low
0 – 20	Very Low

(Ekawati & Sumaryanto, 2011)

The data obtained from the posttest were analyzed using descriptive and inferential statistical methods. Descriptive analysis was used to determine the mean scores and percentage distribution for each indicator, providing an overview of students' performance in both groups. Before testing the hypothesis, assumption tests were conducted using the Shapiro–Wilk test for normality and Levene's test for homogeneity. The main hypothesis was analyzed using Multivariate Analysis of Variance (MANOVA) with a significance level of 0.05. This statistical method was selected because the research involved two dependent variables (creative thinking and scientific communication) tested simultaneously to determine whether there was a significant effect of the PjBL-STEAM model compared to the PBL model. The results of this analysis provided a comprehensive understanding of how the PjBL-STEAM model influences students' learning outcomes, both in developing their creative thinking and in enhancing their scientific communication skills.

3. Results and Discussion

3.1. Result

Class IX G was used as the control class, while class IX H was used as the experimental class. There were 31 students in class IX G and 32 students in class IX H. The treatment for class IX G as the control class was to use the Problem-Based Learning model. Class IX H as the experimental class used the Project-Based Learning (PjBL)-STEAM model.

3.1.1. Creative Thinking Skills

Data on students' creative thinking skills were obtained through a posttest consisting of essay questions administered to both the control and experimental classes after the learning process. The results of the analysis comparing the posttest scores of the two groups are summarized in Table 4, which presents the average, minimum, and maximum scores of students' creative thinking skills.

Table 4. Summary of Creative Thinking Skills Data for Students in the Control Class and Experimental Class

Data Description	Posttest Control Class	Posttest Experimental Class
Average	63	82
Score Minimum	50	57
Score Maximum	83	100

As shown in Table 4, there was a clear difference between the creative thinking skills of students in the control and experimental classes. The experimental class, which was taught using the PjBL-STEAM model, achieved an average score of 82, categorized as very creative, while the control class, which used the PBL model with discussion, achieved an average score of 63, categorized as creative. Furthermore, the experimental class also obtained a higher minimum score (57) and maximum score (100) compared to the control class (50 and 83, respectively). These results indicate that the application of the PjBL-STEAM model had a positive effect on enhancing students' creative thinking skills. The students in the experimental group demonstrated greater fluency, flexibility, originality, and elaboration in generating ideas and solving problems than those in the control group, as shown in Figure 1.

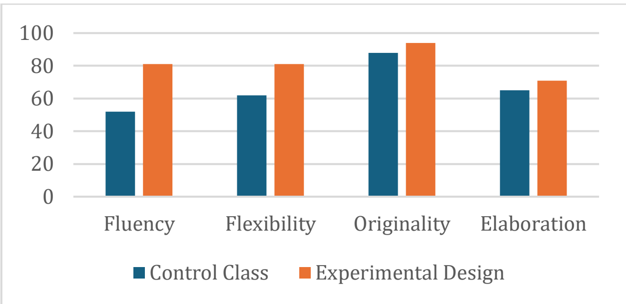


Figure 1. Creative Thinking Indicator Score Comparison Chart

As shown in Figure 1, the experimental class outperformed the control class across all indicators of creative thinking. In the fluency indicator, the experimental class scored 80, far above the control class which only scored 52, indicating the students' ability to generate more ideas. The flexibility indicator also showed the superiority of the experimental class with a score of 81 compared to 62 in the control class, indicating a more flexible and diverse ability to think in solving problems. Meanwhile, in terms of originality, although both classes showed high results, the experimental class was still superior with a score of 94 compared to 88 in the control class, indicating that students were able to come up with more unique and original ideas. As for the elaboration indicator, the difference was not too significant, with the experimental class scoring 71 and the control class scoring 65, but it still showed that the experimental students were better at developing and elaborating ideas.

3.1.2. Scientific Communication

Scientific communication data were obtained through a posttest consisting of essay questions administered to both the control and experimental classes after the learning activities. The comparison of scientific communication scores between the two groups is presented in Table 5, which summarizes the average, minimum, and maximum scores achieved by each class.

Table 5. Summary of Scientific Communication Scores for Students in the Control Class and Experimental Class

Data Description	Posttest Control Class	Posttest Experimental Class
Average	55	73
Score Minimum	41	54
Score Maximum	74	93

As shown in Table 5, the experimental class achieved a higher overall score in scientific communication compared to the control class. The experimental group reached an average score of 73, categorized as good, while the control class scored an average of 55, categorized as average. In addition, the experimental class obtained higher minimum (54) and maximum (93) scores compared to the control class (41 and 74, respectively). These results indicate that the use of the PjBL-STEAM model contributed to better student performance in scientific communication. Students in the experimental group were more capable of retrieving, interpreting, and presenting scientific information effectively, suggesting that the integrated STEAM-based learning approach enhanced their ability to communicate scientific ideas clearly and systematically.

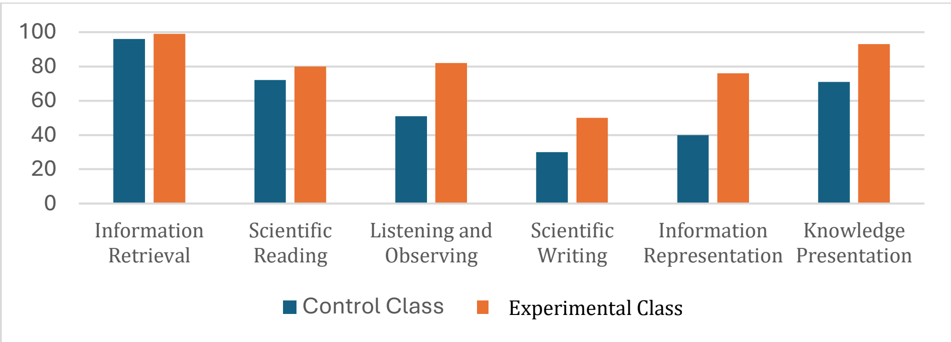


Figure 2. Scientific Communication Indicator Scores Comparison Chart

As presented in Figure 2, the scientific communication skills of students in the experimental class were generally higher than those in the control class across all indicators. In terms of information retrieval, both classes showed very high and almost equal results, with an average score of 99 for the experimental class and 96 for the control class, indicating good information retrieval skills. However, differences began to appear in terms of scientific reading, where the experimental class scored 80 and the control class scored 72, indicating better scientific text comprehension in the experimental class. A striking difference was seen in listening and observing, with a score of 82 for the experimental class and only 51 for the control class, indicating that the experimental class students were more active in listening and observing scientifically. The experimental class also excelled in scientific writing with a score of 50, while the control class only scored 30, indicating better scientific writing skills. A significant advantage was also seen in the information representation indicator, with a score of 76 in the experimental class and 40 in the control class, indicating more effective data visualization skills. Finally, in the knowledge presentation indicator, the experimental class scored 93, much higher than the control class, which scored only 71, indicating better, more confident, and more systematic knowledge presentation skills.

The research data obtained has been tested for normality and homogeneity. The results obtained are normal and homogeneous data. After conducting the prerequisite tests (normality and homogeneity), the next step is to conduct a hypothesis test. The Manova (Multivariate Analysis of Variance) test was conducted to test the effect of the PjBL-STEAM model on students' creative thinking and scientific communication skills together. The results of the MANOVA test are presented in Table 6.

Table 6. MANOVA Test Results

Source of Variation	Dependent Variable	Wilk's Lambda	F	Sig.	Average of Experiment Class	Average of Control Class
Class	Creative Thinking Skills	0,446	46,24	0,000	82	63
	Scientific Communication	0,446	44,47	0,000	73	55

Table 6 shows that the Sig. value is 0.000. This means that the PjBL-STEAM model has an effect on students' creative thinking and scientific communication skills with a Sig. value of 0.000 (< 0.05). Therefore, H_1 is accepted and H_0 is rejected.

3.2. Discussion

3.2.1. The Effect of PBL on Creative Thinking and Scientific Communication Skills in Control Class

The application of Problem-Based Learning (PBL) in the control class showed limited results in enhancing students' creative thinking and scientific communication skills. Although PBL emphasizes problem solving, the learning process remained relatively structured and teacher-centered, providing less opportunity for students to explore new ideas independently. As a result, students' creativity did not develop optimally because the activities were more procedural and lacked open-ended challenges that stimulate innovation (Damondamon & Aliazas, 2025). This finding is in line with (Suciari et al., 2021), who state that PBL tends to improve conceptual understanding but does not fully support creativity if student autonomy is limited. In terms of scientific communication, students in the control class were still heavily dependent on teacher guidance during discussions and presentations, which affected their confidence in articulating scientific arguments. This suggests that while PBL supports reasoning through inquiry, it is less effective in cultivating independent communication skills when compared to project-based approaches such as PjBL-STEAM.

3.2.2. The Effect of PjBL-STEAM on Creative Thinking and Scientific Communication Skills in Experimental Class

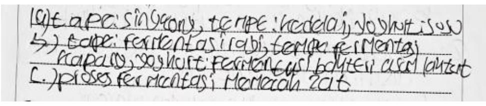
The implementation of PjBL-STEAM in the experimental class significantly enhanced students' creative thinking and scientific communication skills. Students' active involvement in project planning, experimentation, and presentation gave them ample opportunities to explore new ideas and develop innovative solutions. For example, in the yogurt-making project, students integrated concepts of fermentation from science with principles of technology, mathematics, and art to produce a creative and marketable product. This finding supports Thomas (2000), who emphasizes that meaningful investigation in project-based learning encourages creativity and scientific reasoning. It also aligns with the findings of Lu et al. (2022) and Spektor-Levy et al. (2008), which highlight that STEAM-based learning strengthens students' ability to express scientific information effectively. Furthermore, the collaborative process in PjBL-STEAM encouraged students to think reflectively and analytically when facing challenges, which supports Vygotsky's theory of social constructivism, stating that social interaction and collaboration are key to higher-order cognitive development (Liu & Matthews, 2005; Pinar et al., 2025; Zhusupkalieva et al., 2025).

3.2.3. Creative Thinking Skills

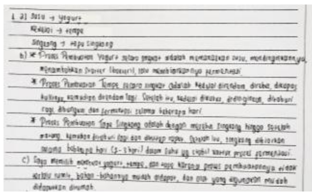
Fluency

Based on Figure 1, the fluency indicator in the experimental class reached a score of 80 and was categorized as "Creative" (Table 2), while the control class only reached a score of 52 or "Moderately creative." The difference of 28 points shows a significant effect of PJBL-STEAM implementation on students' ability to generate many ideas. The experimental class ranked third in the fluency indicator after originality (94) and flexibility (81), but higher than elaboration (71). This shows that students were able to generate various ideas, although not very deeply.

According to Torrance (1987), fluency refers to the ability to produce numerous ideas in response to a given stimulus, reflecting the breadth of thinking. In this study, fluency was evident when students proposed various products derived from fermentation, such as yogurt, tempeh, and tape, along with ideas for flavor variations and preservation methods. This suggests that students could connect the concept of biotechnology to real-life applications. Fatmah (2021) notes that PjBL-STEAM enhances fluency because it encourages students to explore diverse solutions through hands-on experimentation. This finding aligns with constructivist theory (Fosnot, 2013), which emphasizes that direct scientific experience, such as observing microbial fermentation, promotes active knowledge construction and the generation of creative ideas (Pinar et al., 2025).

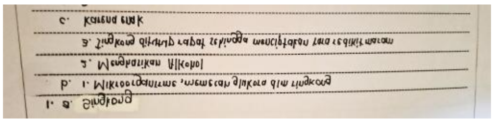


Low Scores



High Scores

Figure 3. Sample Answers for Fluency Questions in the Experimental Class



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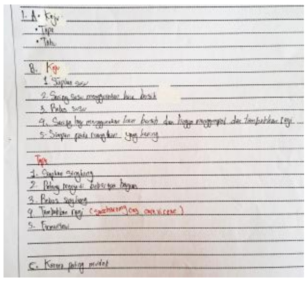


High Scores

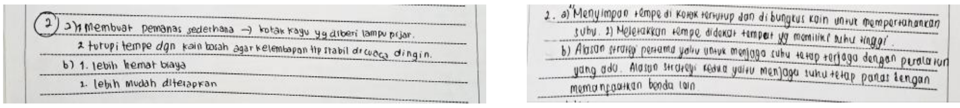
Figure 4. Sample Answers for Fluency Questions in the Control Class

Based on Figure 3 and Figure 4, there is a difference in creative thinking ability (fluency) between the experimental and control classes on these questions. Students in the experimental class with high scores were able to answer all parts of the questions completely and coherently, demonstrating fluency in producing logical and scientific ideas. In contrast, students in the experimental class with low scores only mentioned products without explaining the process, resulting in limited ideas. Students in the control class with low scores showed an inability to answer comprehensively, writing down only a few products without explaining the process and reasoning. Even the high-scoring answers were not optimal because they only contained some of the ideas requested. This shows that the fluency of students in the control class has not developed optimally compared to the experimental class.

Flexibility

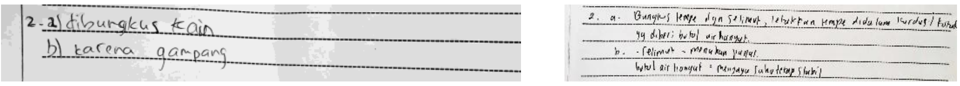
The Flexibility indicator in the experimental class reached a score of 81 (category "Very creative"), 19 points higher than the control class, which only reached a score of 62 ("Creative"). This shows that experimental students are more capable of thinking flexibly and adjusting their approach to problem solving. Flexibility is the second highest indicator after originality and slightly above fluency.

According Torrance (1987) flexibility reflects the ability to view problems from various standpoints and switch approaches when necessary. The PjBL-STEAM model allowed students to modify their methods for example, finding alternative ways to maintain optimal fermentation temperature without heating equipment, such as using insulating materials or regulating air exposure. This demonstrates their understanding of temperature's role in microbial growth within the context of biotechnological processes. Panduweni et al. (2024) reported that flexibility improves significantly under PjBL-STEAM because students are encouraged to link scientific theory with practical strategies. This supports Fosnot's (2013) view that real-world experimentation and discussion help learners internalize flexible reasoning.



Low Scores High Scores

Figure 5. Sample Answers for Flexibility Questions in the Experiment Class



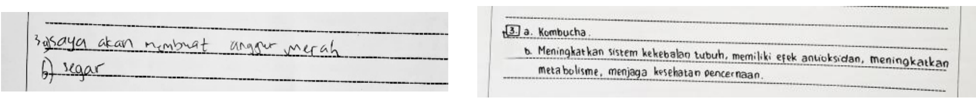
Low Scores High Scores

Figure 6. Sample Answers for Flexibility Questions in the Control Class

The Figure 5 and Figure 6 above shows the answers of the experimental and control classes to the Flexibility question, in which students were asked to provide two alternative strategies for overcoming cold temperatures without heating equipment in the tempeh fermentation process. Students in the experimental class with High Scores were able to provide complete and logical answers, such as wrapping the ingredients in warm cloth or storing them in a closed container, accompanied by appropriate reasons. This reflects flexibility in thinking, namely the ability to see problems from various perspectives. In contrast, students in the experimental class with Low Scores were only able to provide one strategy without any reasons, thus obtaining the minimum score. A similar pattern was also seen in the control class, where some students only provided one strategy without explanation. However, some control students with high scores were still able to answer completely and obtain maximum scores, even though flexibility of thinking was generally more prominent in the experimental class.

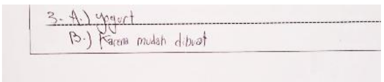
Originality

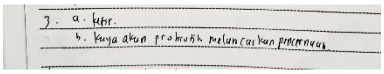
The originality indicator recorded the highest score in the experimental class, namely 94 ("Very creative"), higher than the control class, which also scored high at 88 ("Very creative"). This achievement surpassed other indicators such as Flexibility (81), Fluency (80), and Elaboration (71), demonstrating the effectiveness of PJBL-STEAM in encouraging the emergence of unique and original ideas. This indicates that the PjBL-STEAM model effectively promoted originality by allowing students to express unique and innovative ideas (Srivastava, 2016). In this study, students designed creative fermented drink products using local ingredients such as corn, honey, and tropical fruits, and explained their benefits, connecting scientific knowledge about fermentation and lactic acid bacteria with community-based innovation. According to Torrance (1987), originality measures the uniqueness of ideas compared to conventional responses. (Widiyatmoko et al., 2024) also found that integrating science and creativity in biotechnology projects strengthens students' ability to propose novel solutions. This result supports Fosnot's (2013) constructivist perspective that open-ended learning tasks stimulate divergent thinking and the creation of new knowledge.



Low Scores High Scores

Figure 7. Sample Answers for Originality Questions in the Experimental Class





Low Scores High Scores

Figure 8. Sample Answers for Originality Questions in the Control Class

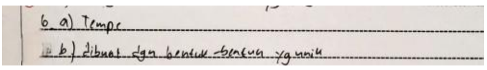
Based on the Figure 7 and Figure 8 above, students' ability in the originality indicator can be seen from their answers to the question asking for ideas for fermented drinks made from natural ingredients found around the house, along with an explanation of their benefits. Students in the experiment class with high scores were able to come up with unique, uncommon, and relevant ideas, such as creating drinks from local ingredients with logical benefits, for example, boosting the immune system or improving the digestive system. This demonstrates original thinking because the ideas presented are not imitative or generic. In contrast, students in the experiment class with low scores were only able to mention ideas without explaining their benefits accurately. Some answers even listed benefits that were not directly related to fermentation, thus limiting their value.

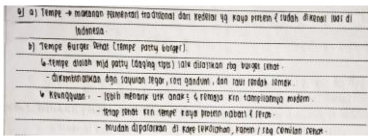
A similar pattern was also seen in the control class, where students with High Scores were still able to provide creative answers accompanied by strong reasons, although the number was smaller than in the experimental class. In contrast, control students with Low Scores provided answers that tended to be general, less innovative, and the reasons given were not supportive, such as simply writing “easy to make” without explaining its connection to the fermentation process, which shows that the level of originality of their ideas was still underdeveloped.

Elaboration

The elaboration indicator in the experimental class showed a score of 71 and was categorized as “Creative,” while the control class obtained a score of 65 with the same category. Although the results were quite good, elaboration was the indicator with the lowest score when compared to originality (94), flexibility (81), and fluency (80). This shows that the students in the experimental class were able to develop and elaborate on ideas, but the depth and detail of their ideas still needed to be improved to match their ability to produce unique and diverse ideas.

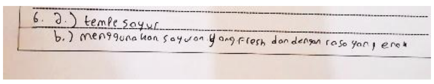
In this study, elaboration appeared when students expanded their fermentation product concepts by describing ingredients, nutritional values, packaging design, and marketing potential. According to Torrance (1987), elaboration is the ability to add details that make ideas more complete and meaningful. Widiyatmoko et al. (2024) note that PjBL-STEAM facilitates elaboration by requiring students to develop final products through iterative feedback and peer review. From a science content perspective, this process helps students connect scientific understanding, such as the role of microorganisms and pH changes in fermentation with technological and social applications, deepening both their conceptual and creative mastery (Chang et al., 2023).

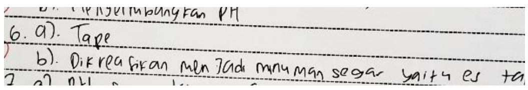




Low Scores High Scores

Figure 9. Sample Answers to Elaboration Questions Experimental Class





Low Scores High Scores

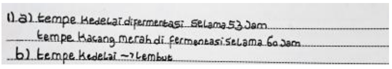
Figure 10. Sample Answers to Elaboration Questions Control Class

Students in the experiment class with high scores were able to demonstrate good elaboration skills by developing their ideas comprehensively, not only mentioning types of traditional fermented foods, but also explaining innovations that are relevant to modern trends and public tastes. This elaboration was evident in their clear reasoning, description of nutritional benefits, and the appeal of the products offered. In contrast, students with low scores in this class only mentioned the types of foods without further explanation of their innovations, thus failing to demonstrate adequate elaboration. A similar pattern was also seen in the control class, where students with high scores were quite capable of developing ideas, but their explanations were still limited to aspects of taste or appearance, without considering health aspects or social relevance. Control students with low scores were only able to mention traditional foods without conveying innovative ideas. In general, students in the experimental class were more consistent in conveying ideas in detail and depth, showing that the PJBL-STEAM approach is effective in encouraging the development of more complete and meaningful ideas.

3.2.4. Scientific Communication

Information retrieval

Based on Figure 2 and Table 3, the Information retrieval indicator obtained the highest score in scientific communication, namely 99 in the experimental class and 96 in the control class, both of which are classified as “Very Good.” This shows that students from both classes have strong abilities in accessing and collecting information, possibly because they are accustomed to using digital search technology. Compared to other indicators such as Scientific writing (50) and Listening and observing (82), this ability is a solid foundation for students' scientific literacy. Information retrieval includes the skills of searching, selecting, and evaluating information from various media, both print and digital (Spektor-Levy et al., 2008). Research by Sukma & Qosyim (2025) states that collaborative learning encourages an increase in students' ability to actively search for scientific information, even though there are still obstacles to accessing scientific articles. Cognitivist theory (Mcleod, 2003) supports this finding, emphasizing that retrieving information activates prior knowledge schemas and promotes deeper understanding of IPA concepts such as microbial activity and enzyme function during fermentation.



Low Scores

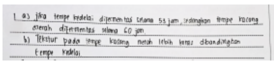
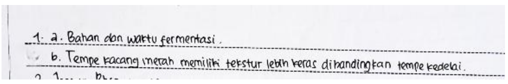

High Scores

Figure 11. Sample Answers to Information Retrieval Questions in the Experimental Class



Low Scores

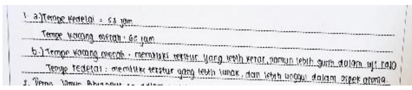

High Scores

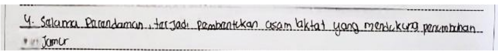
Figure 12. Sample Answers to Information Retrieval Questions in the Control Class

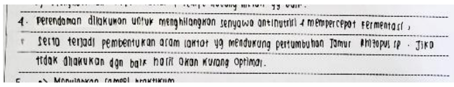
Based on Figure 11 and Figure 12, students in the experiment class with High Scores were able to identify specific and accurate information from the reading, such as the differences in fermentation time and texture between red bean tempeh and soybean tempeh. In contrast, students with Low Scores only answered partially with inaccurate explanations. A similar pattern was also seen in the control class, where students with high scores were able to answer correctly, while students with low scores had difficulty filtering important information from the text. This shows the need to improve reading skills and focus on understanding the content of the reading material in depth.

Scientific reading

The Scientific reading indicator shows a score of 80 in the experimental class with a “Good” rating and 72 in the control class with a “Good” rating. Although still below Information retrieval, this indicator shows that students are able to understand scientific texts quite well, especially students in the experimental class. The achievement of this indicator is higher than Scientific writing (50) and Information representation (76), but still below Knowledge presentation (93).

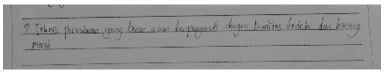
This indicator refers to the ability to understand the content of scientific texts, identify main ideas, and summarize and interpret the information presented. Students need to be familiar with the structure of scientific articles in order to analyze the content and relate it to their existing knowledge (Spektor-Levy et al., 2008). Research by Cici Mayani et al. (2023) and Sukma & Qosyim (2025) shows that students have improved in reading scientific texts, especially in recognizing important parts such as the conclusion and main content of a text. This is in line with cognitivism, which emphasizes the importance of active mental engagement when reading, where learners process information systematically and relate it to prior knowledge to achieve meaningful understanding (Mcleod, 2003). Science perspective related to this, these skills show that students could link textual information about fermentation chemistry to observable phenomena, demonstrating integrated literacy in science.

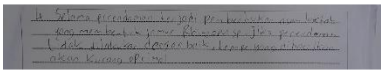




Low Scores High Scores

Figure 13. Sample Answers to Scientific Reading Questions in the Experimental Class





Low Scores High Scores

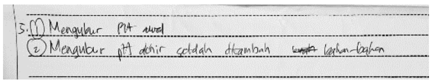
Figure 14. Sample Answers to Scientific Reading Questions in the Control Class

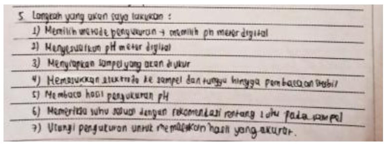
Based on the Figure 13 and **Figure** 14 above, it shows examples of students' answers to questions with scientific reading indicators. Students were asked to explain how the soaking process affects the final result of tempeh based on readings containing three main points. Students in the experiment class with High Scores successfully identified all the important information, namely the elimination of antinutrients, the formation of lactic acid, and its impact on the texture of tempeh, which demonstrates good scientific reading skills in filtering and summarizing information comprehensively. In contrast, experimental students with low scores only mentioned one point, namely the formation of lactic acid, indicating a limitation in understanding the content of the reading completely. In the control class, students with high scores were only able to mention two of the three points, showing that although they understood the reading sufficiently, their understanding was not yet fully in-depth. Meanwhile, students with Low Scores in the control class were unable to answer correctly and their answers did not match the content of the reading, reflecting difficulties in effectively extracting factual information from scientific texts.

Listening and observing

The achievement of the Listening and Observing indicator in the experimental class reached a score of 82 in the “Very Good” category, while the control class only scored 51 in the “Moderate” category. This places this indicator as the third highest in scientific communication in the experimental class after Information Retrieval and Knowledge Presentation. These results show that the PjBL-STEAM approach successfully improved students' ability to actively listen to information and observe scientific phenomena. In comparison, the achievement of this indicator was much higher than Scientific writing and Information representation, confirming that the observation process in project activities was more effective than representation or writing.

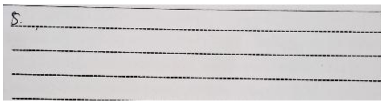
These skills include the ability of students to pay attention to lectures, discussions, or scientific presentations with focus. Students must also be able to identify the important points of a discussion, ask relevant questions, and provide logical responses to the information received (Spektor-Levy et al., 2008). Research by Sukma & Qosyim (2025) shows an increase in students' observation skills after participating in collaborative learning, especially through discussion and direct observation of phenomena. This activity encourages students to pay closer attention to and analyze the data obtained. These results are in line with cognitivism theory, which views observation as part of the processing of sensory information into working memory, which is then actively organized and interpreted by students. This process strengthens the encoding of information into their cognitive structures (Mcleod, 2003).

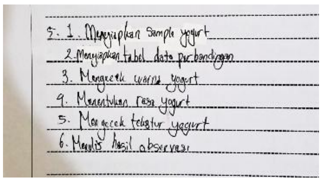




Low Scores High Scores

Figure 15. Sample Answers for Listening and Observing Questions in the Experiment Class





Low Scores High Scores

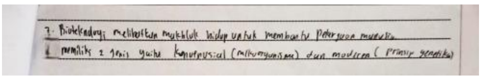
Figure 16. Sample Answers for Listening and Observing Questions in the Control Class

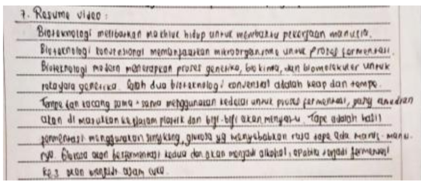
This question measures students' ability to design observation procedures to obtain accurate scientific data. Students are challenged to detail five systematic steps that must be taken when observing changes in the pH of soy yogurt to which ingredients such as fruits, corn, and honey have been added. Based on Figure 15, students in the experimental class with high scores were able to answer all five steps correctly. Students with low scores only mentioned two steps, namely "measuring the initial pH" and "measuring the final pH," which indicates a lack of understanding of the logical sequence in scientific observation. High-scoring students in the control class provided complete answers, while low-scoring students did not provide any relevant steps at all and did not even attempt to answer, reflecting a significant weakness in their ability to design observation procedures.

Scientific Writing

The Scientific writing indicator had the lowest score among all scientific communication indicators. The experimental class only achieved a score of 50 in the "Average" category, while the control class scored 30 in the "Low" category. These results show that although project-based learning provides space for exploring ideas, students' ability to convey information in writing in a scientific format is still limited. Compared to other indicators such as Scientific reading (80) or Information representation (76), scientific writing skills need special attention in the development of scientific communication skills.

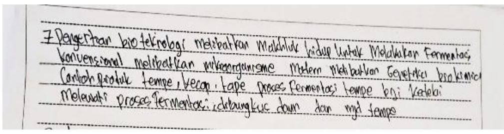
This ability includes writing reports, articles, or scientific essays with a clear structure and appropriate language. Students must be able to convey their ideas or findings systematically, using appropriate scientific terms and supporting their arguments with valid evidence (Spektor-Levy et al., 2008). Improvements in scientific writing skills can be seen in students' ability to convey ideas in their own words and compile more structured reports (Cici Mayani et al., 2023; Sukma & Qosyim, 2025). These writing activities demonstrate students' engagement in understanding and reorganizing the information they have learned. These findings are very much in line with cognitivism theory, which explains that learning to write involves the process of organizing and transforming information into a cognitive structure so that it can be communicated logically and meaningfully (Mcleod, 2003).





Low Scores High Scores

Figure 17. Sample Answers to Scientific Writing Questions in the Experimental Class



Low Scores High Scores

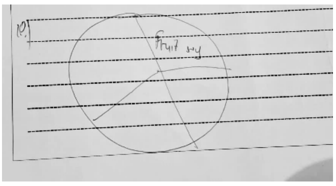
Figure 18. Sample Answers to Scientific Writing Questions in the Control Class

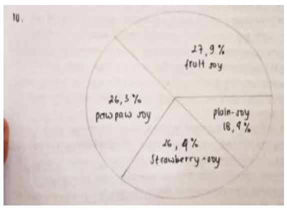
This question assesses students' ability to write a summary that covers six key points from the video content. The experimental class showed significant results, where students with High Scores were able to identify and summarize the six main points in sequence. This demonstrates a comprehensive understanding of the video content and good scientific writing skills. Meanwhile, students with Low Scores in the experimental class were only able to include two important points, indicating that even though they had watched the video, they still had difficulty sorting out relevant information and organizing it coherently. In the control class, High Scores only reached 4 points because although they were able to understand part of the video content, students tended to be incomplete in compiling their summaries. Low Scores in the control class showed a result of 0 because no answers were given, indicating a lack of motivation or difficulty in conveying information in the form of scientific writing.

Information representation

The Information representation indicator shows a striking difference between the experimental class and the control class, with scores of 76 (category "Good") and 40 (category "Low") respectively. This achievement places the indicator in the fourth highest position in students' scientific communication skills, after Information retrieval, Knowledge presentation, and Listening and observing. These results indicate that the PjBL-STEAM approach contributes positively to students' ability to present scientific data or information visually through graphs, tables, or other symbols. Compared to Scientific writing (50) and Scientific reading (80), information representation skills are at an intermediate level, indicating that students still need improvement in communicating scientific ideas visually to be more effective.

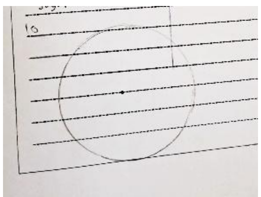
Visual representation skills are very important because they can help simplify complex concepts, organize information, and facilitate audience understanding (Spektor-Levy et al., 2008). In the study by Sukma & Qosyim (2025), representation skills improved significantly after students were involved in group discussions and project-based learning. This reinforces the theory of cognitivism, which states that learning becomes more effective when complex information is presented in visual form, because visualization supports the processing and storage of information in long-term memory more efficiently (Mcleod, 2003).

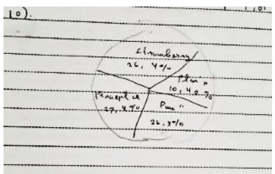




Low Scores High Scores

Figure 19. Sample Answers to Information Representation Questions in the Experimental Class





Low Scores High Scores

Figure 20. Sample Answers to Information Representation Questions in the Control Class

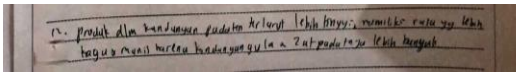
Figure 19 and Figure 20 show students' answers to the information representation indicator question, which required students to create a pie chart showing the differences in soluble solids content in soy yogurt products. The answers of students in the experimental class who had high scores demonstrated excellent data representation skills. The pie charts they created included the types of soy yogurt products and the amounts of soluble solids completely and accurately, in accordance with the information in the reading. The neatly and proportionally arranged diagrams illustrate that students are able to read numerical data and convert it into an informative visual form. In contrast, students with low scores did not complete the diagram or only presented irrelevant parts of the diagram, indicating that they were not yet able to convert textual data into meaningful visualizations.

Students in the control class with high scores also successfully compiled accurate and informative pie charts. They listed all products and dissolved solids content accurately. However, students with low scores did not complete the task or created charts that did not reflect the content of the reading. This shows that some students still have difficulties understanding data and organizing it into visual forms (H. Y. Chang et al., 2024).

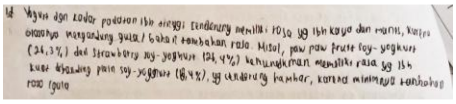
Knowledge presentation

Knowledge presentation ranked second highest after information retrieval, with a score of 93 in the experimental class in the "Very Good" category and 71 in the control class in the "Good" category. These results indicate that students in the experimental class were able to convey information and ideas verbally and visually very well, possibly because the project activities encouraged them to frequently discuss and present their group work. Compared to other indicators such as scientific reading and information representation, students' presentation skills were much stronger and played an important role in the overall success of scientific communication.

This skill includes conveying information verbally and visually in a clear and interesting manner. Students need to master presentation techniques, whether in the form of seminars, group discussions, or through media such as posters and multimedia, so that the message conveyed is well received by the audience (Spektor-Levy et al., 2008). This ability reflects an understanding of concepts and the ability to relate information to the theories that have been learned. These findings are supported by Mcleod (2003), who explains that knowledge transfer occurs when learners reorganize information based on personal understanding. In the context of Science, this means that students could explain the relationship between fermentation, sugar concentration, and taste, showing mastery of both scientific content and communication skills.

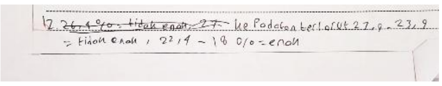


Low Scores

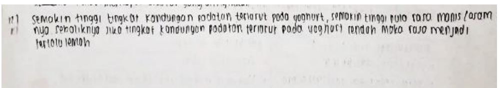


High Scores

Figure 21. Sample Answers to Knowledge Presentation Questions in the Experiment Class



Low Scores



High Scores

Figure 22. Sample Answers to Knowledge Presentation Questions in the Control Class

The Figure 21 and Figure 22 above shows the answers of students in the experimental and control classes to the knowledge presentation indicator question. Students in the experimental class with high scores were able to clearly convey that the higher the dissolved solids, the sweeter the yogurt tastes, while the lower the dissolved solids, the more sour the taste. Their answers demonstrate their ability to analyze data and present it in the form of accurate scientific descriptions (H. Y. Chang et al., 2024). In contrast, students with low scores were only able to mention one effect, for example, only mentioning sweetness without mentioning the opposite condition. This shows that their understanding of the overall concept is still not fully developed.

Control class students with high scores were able to answer two effects completely and correctly, demonstrating their ability to convey information from the table data well. However, students with low scores gave incorrect or irrelevant answers. Some did not associate dissolved solids with taste, or answered speculatively without any basis in the reading. This indicates difficulty in conveying scientifically based information.

4. Conclusion

Based on the findings, the implementation of the Project Based Learning (PjBL) model integrated with the STEAM approach had a significant and positive effect on students' creative thinking and scientific communication skills in biotechnology learning, with a significance value of 0.000. This model effectively fostered active student engagement through authentic, collaborative, and meaningful project activities that integrated multiple disciplines cohesively. The results showed that, in creative thinking skills, the indicators categorized as "very creative" were flexibility and originality, while those classified as "creative" were fluency and elaboration. In scientific communication skills, the indicators of information retrieval, listening and observing, and knowledge presentation were categorized as "very good", information representation and scientific reading as "good", and scientific writing as "average". Overall, these findings indicate that the PjBL-STEAM model successfully enhances students' creative thinking abilities while strengthening their scientific communication skills, supporting its potential as an effective and integrative learning approach in science education.

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All authors have equal contributions to the paper. All the authors have read and approved the final manuscript.

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