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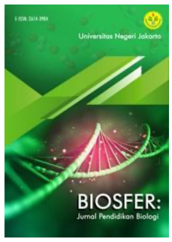

PjBL-STEAM approach to enhance students' creativity and science process skills in biology learning

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ABSTRACT

The advancement of knowledge and technology in the globalization period has had a significant impact on various aspects of life, the most notable of which is the educational sector. A comprehensive learning plan is required for the 21st century. The learning model is one of the critical components of learning that promotes active and interactive participation among students. Using an appropriate learning paradigm, a variety of experiences for students can be maximized. This study aims to examine the effect of the PjBL learning model with the STEAM approach on students' creative thinking skills and science process skills on environmental pollution material. This study was conducted at SMAN 112 Jakarta, Indonesia in class X. This research method is quasi-experimental with a quasi-experimental research design with multiple control groups. The total number of selected samples is 132 students. Based on the hypothesis test using MANOVA, there is an effect of the PjBL-STEAM learning model on students' creative thinking skills and science process skills ($p < 0.05$), so that the findings indicate that the PjBL-STEAM learning model has been proven to significantly influence students' creative thinking skills and science process skills in class X, on environmental pollution material.

INTRODUCTION

The era of digital transformation is defined as a century in which science and technology are experiencing rapid development. This phenomenon has a significant impact on all aspects, including the education sector (Williams & Mangan, 2016). The presence of technology, particularly in learning, can be perceived as both an opportunity and a challenge. A golden opportunity created by integrating technology into teaching and learning activities is student-centered learning (Kalyani, 2024). With proper use of technology, organizing learning designs in the classroom will optimize students' engagement. Biology learning can become more effective and efficient. Therefore, as educators, learning designs are needed that align with the needs of the 21st century (Stehle & Peters-Burton, 2019).

Learning designs that accommodate students' needs in the 21st century is defined as 21st-century learning (Duckworth & Yeager, 2015). This learning design stimulates active and interactive participation from students, thereby developing various student skills. One of these is thinking skills. In essence, thinking skills are vital processes for organizing experience and knowledge and serve as a foundation for learning, planning, creating, and reflecting. These skills are acquired through objectives and the overall learning process. Students require thinking skills to identify what they already know and what they don't, and to communicate this in the form of questions and/or statements. The development of thinking skills is the output of learning activities (Klimova, 2013). With thinking skills, students can open broader perspectives and accommodate knowledge, skills, and attitudes (Alsaleh, 2020).

Creative thinking skills are an essential component of the 4C skills required by students (Barus et al., 2024). These skills are understood as the entire series of cognitive activities students engage in, based on their capacities (Birgili, 2015). Students maximize their imagination and insight in solving problems. Students who possess creative thinking skills can generate innovations and alternative solutions by generating new ideas and concepts or viewing things from different and unusual perspectives (Greenberg, 2023). Students who master creative thinking skills perform well on tasks requiring process skills. This is because creative students often view problems from different perspectives, leading to novel approaches to scientific problems.

Creativity will influence process skills, one of which is science process skills (Kwangmuang et al., 2021). Yildiz & Yildiz (2021) defined science process skills as students' thinking skills used in conducting scientific processes, such as observing, interpreting, measuring, classifying, forming hypotheses, analyzing, drawing conclusions, and designing experiments. This skill is closely related to flexibility of thinking, an indicator of creative thinking skills (Hiğde & Aktamış, 2022). Creativity influences process skills because students are faced with complex scientific problems, requiring exploratory, flexible, and logically innovative thinking skills to deepen scientific investigations (Zulyusri et al., 2023).

In The Global Creativity Index (2015) which ranked countries based on 3Ts (Technology, Talent, and Tolerance) that shows their innovation potentials and capabilities, Indonesia ranked 86 on Creative Class out of 96, and 74 on Educational Attainment out of 120. This shows that students' creative thinking skills in Indonesia is generally low. Nurhamidah (2018) stated that this occured because during the learning activites, students are not necessarily targeted to involve in thinking process. Students became accustomed to learning that concentrates on the convergent thinking process, which resulted in struggling in solving problems that require creativity. It limited them from developing their creative thinking skills because the learning process is centered on memorization.

Creative thinking skills are not the only ones students need to develop. In biology learning, one of the essential thinking skills that students need to master is science process skills (Khamhaengpol, 2021). In an era when science and technology are advancing rapidly, these skills are needed by students to maintain a balance between technology use and scientific development (Prisecaru, 2016). Based on studies conducted by Behera (2023) and Kamarudin & Noor (2024), the average science process skill score of students in Indonesia is relatively low. Specifically, the findings of Elvanisi et al. (2018) showed low science process skill scores among high school students in Indonesia. Students' creative thinking skills and science process skills are still relatively low and require improvement. Developing these two skills is a crucial agenda in today's education world. Innovations in several aspects of learning are needed to build enthusiasm and intensify student focus, one of which is selecting an appropriate learning model (Thursina, 2023). Research by Hulyadi et al. (2024) demonstrates that project-based learning is a learning model designed to activate student participation in problem-solving.

This project-based learning is relevant in life, making it easier for students to interpret learning holistically rather than simply memorizing. Both learning models can be supplemented with additional learning variables, such as the STEAM approach, which accommodates a wide range of students' thinking skills (Aguilera & Ortiz-Revilla, 2021). The integrated project-based STEAM model combines the five aspects of STEAM into a student-focused learning framework, thereby advancing learning from the process to outcomes. Students play a significant role in addressing environmental problems and risks. Furthermore, the UNEP committee recognized education as a key agent of social change through training, skills, technology, infrastructure, and access to appropriate resources and information for environmental management.

Luhung & Yuniasih (2023) present various development data related to environmental quality in Indonesia. Indonesia still has several agendas to improve environmental quality. Research by Egbefo & Abdulganiyu (2024) demonstrates that human activities often conflict with the principles of sustainable development, which balance environmental protection and development. Indonesians rely on the exploitation of natural resources to foster economic growth, but this is not accompanied by efficient use of natural resources, which is inconsistent with the concept of Sustainable Development (Luhung & Yuniasih, 2023).

One of the most effective methods for addressing environmental issues is environmental education and learning (Permana et al., 2021). Students limited environmental knowledge impacts their awareness of protecting and preserving the environment (Artun & Özsevgeç, 2018). Based on a review of the literature, the PjBL-STEAM learning model is considered capable of providing students with a deeper understanding, enabling them to interpret environmental learning beyond memorization and toward concrete actions. However, measurements of the PjBL-STEAM learning model, in terms of students' creative thinking skills and science process skills on environmental pollution, have not been conducted, thus requiring further exploration of these two variables. This research aims to explore whether students' creative thinking and science process skills remain relatively low and require improvement. Developing these two skills is a crucial agenda in today's education world. Innovations in several aspects of learning are needed to build enthusiasm and intensify student focus, one of which is selecting an appropriate learning model (Thursina, 2023).

METHODS

Research Design

This research uses a quasi-experimental design with multiple control groups (Creswell, 2012; Gay et al., 2012), namely the learning model (PjBL-STEAM), while the dependent variables are students' creativity and science process skills. The design of this research is shown in Table 1.

Table 1
The Research Design

Group	Independent Variable	Post-test
Experiment (PjBL-STEAM)	X_E	O_1
Control 1 (PjBL-STEM)	$X_{K,1}$	O_2
Control 2 (PBL-STEAM)	$X_{K,2}$	O_3
Control 3 (PBL-STEM)	$X_{K,3}$	O_4

Note:
X_E: Experimental class (PjBL-STEAM); $X_{K,1}$: Control class 1 (PjBL-STEM); $X_{K,2}$: Control class 2 (PBL-STEAM); $X_{K,3}$: Control class 3 (PBL-STEM); O_1: Post-test experimental class; O_2: Post-test control class 1; O_3: Post-test control class 2; O_4: Post-test control class 3.

Population and Samples

The population in this research comprised all X-grade classes at SMAN 112 Jakarta, Indonesia, totaling 245 students and divided into seven classes. Samples were randomly taken from four classes. One class is the experimental class, and three classes are the experimental classes with different models. Sampling was carried out using the cluster random sampling technique.

Instrument

The data in this research include students' creative thinking skills and science process skills, encompassing both cognitive and psychomotor aspects. The cognitive aspects are derived from post-test scores, while the psychomotor aspects are derived from observation results. Data collection instruments also include observation and documentation. Instruments have been tested for items' validity and reliability. The validity of the creative thinking skills instrument, in the form of descriptive questions, was tested using the Pearson Product-Moment Correlation. The reliability test for the science process skills used the Kuder-Richardson (KR-20) method.

Procedure

The research procedure is preparation, implementation, and data collection. The preparation stage involves interviewing the teacher, preparing teaching materials and instruments, and validating the instruments. The implementation and data collection stages were completed by applying the learning models in four classes. The experimental class receives PjBL-STEAM treatment, while the control classes receive PjBL-STEM treatment, PBL-STEAM treatment, and PBL-STEM treatment. At this stage, cognitive aspect (based on post-test scores), and the psychomotor aspect (based on observation) were also taken. In the experimental class using the project-based learning (PjBL) model with the STEAM approach, learning activities began with orientation. The teacher greeted the students, checked attendance, and asked how they were. Next, before the treatment, the teacher explained the purpose of the pretest, and students completed it on creative thinking and science process skills. Afterward, the teacher presented the learning outcomes, and students were given scaffolding through questions about environmental pollution. The core activity begins with the teacher determining the essential question by asking students to identify two images related to different environmental conditions. Students are asked to identify the indicators of pollution in the images and determine the appropriate solution to address the environmental problem. Next, prepare a project plan by dividing students into several groups, with each group representing a different type of pollution. This is done so that each group can discuss a different topic. The teacher also provides the Student Worksheet "Atomic Act," which is used to track students' progress on their project and to attach their work results, including when preparing the project implementation schedule. The schedule is given to the teacher so they can monitor the project's implementation. Students conducted research according to their own timeline. After completing the project, a results assessment was conducted, with each group presenting their project. Other groups were also allowed to provide feedback and questions during the discussion. Finally, an evaluation was conducted. Before concluding the lesson, the teacher reinforced the learning concepts to the students. Finally, a post-test was conducted on creative thinking and science process skills to compare differences before and after the treatment. As a closing activity, a reflection questionnaire was administered to identify points students understood during the lesson and to provide notes for student self-awareness and understanding of the environmental pollution material.

Data Analysis Techniques

Data analysis was carried out using descriptive and inferential techniques. Descriptive analysis techniques were used to describe students' creative thinking skills and science process skills data. Inferential analysis techniques were carried out after the data is proven to be normal and homogeneous. The hypothesis is tested using MANOVA after the prerequisite analyses are met.

RESULTS AND DISCUSSION

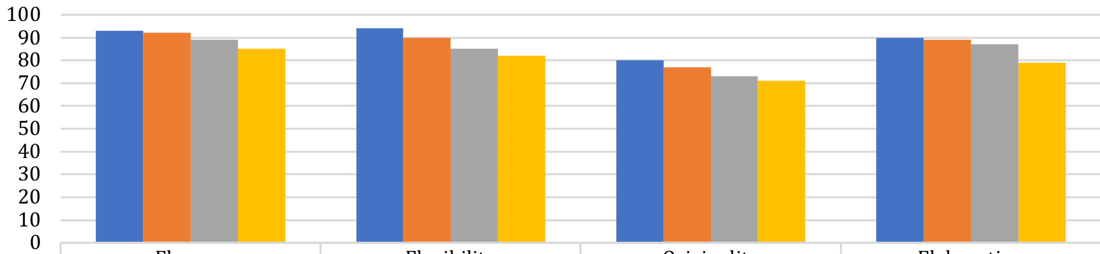
The assessment of students' creative thinking and science process skills was conducted after the treatment. This study involved four class groups. Class X5 was designated as the treatment group (experimental class) and used the PjBL-STEAM model. Class X2 served as the control group 1 and used the PBL-STEM model, class X6 served as the control group 2 and used the PjBL-STEM model, and class X7 served as the control group 3 and used the PBL-STEAM model. The data on students' creativity and science process skills are presented in Table 2.

Table 2

Descriptive analysis on creative thinking skills and science process skills

Data	Creative thinking skills				Science process skills			
	Experiment	Control 1	Control 2	Control 3	Experiment	Control 1	Control 2	Control 3
n	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00
Mean	84.00	82.00	82.00	80.00	86.00	84.00	81.00	80,00
Median	82.00	79.00	80.00	78.00	87.00	86.00	85.00	85.00
Std. Deviation	6.486	5.051	5.778	5.068	6.268	7.241	6.327	6.173
Minimum	73.00	72.00	71.00	70.00	75.00	67.00	76.00	75.00
Maximum	96.00	93.00	92.00	91.00	100.00	100.00	98.00	100.00

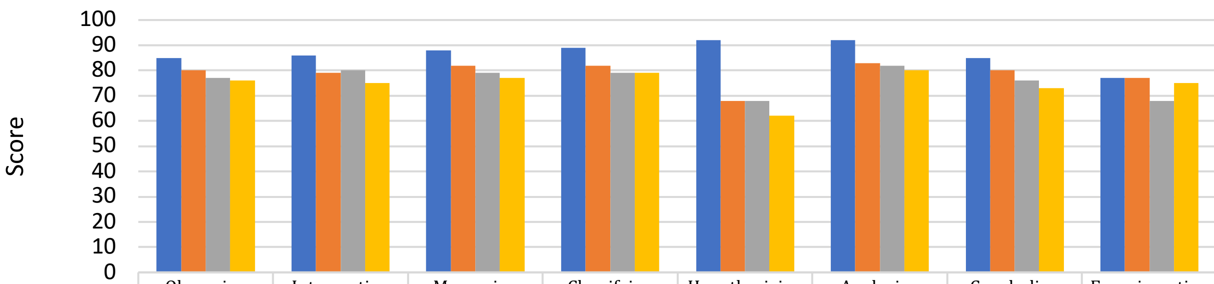
Table 2 shows that the average pretest scores for students' creative thinking skills did not differ significantly. The average pretest scores across the four classes that did not show a significant difference indicate that the initial abilities of students in the experimental and control classes were nearly equal, so there would be no bias in the research process. Sari (2021) noted that the scores of students from the four classes were generally balanced at the beginning of the learning process, before being given different treatments, making the sample suitable for the study. This indicates that the different learning models used in the four classes influenced students' creative thinking skills, with the experimental class (PjBL-STEAM) having a significant impact compared to the other three control classes. Students' abilities at the beginning, before being given different treatments, tended to be equal. Thus, post-test scores can be used as a reference to conclude whether different learning models can affect students' scores (Zulfa et al., 2025). The increase in students' post-test scores across the four classes indicates that the implementation of different learning models has led to a change. The class that experienced a significant impact was the experimental class (PjBL-STEAM).



	Fluency	Flexibility	Originality	Elaboration
PjBL-STEAM	93	94	80	90
PjBL-STEM	92	90	77	89
PBL-STEAM	89	85	73	87
PBL-STEM	85	82	71	79

Figures 1. The Average creative thinking skills score of each indicator.

The highest average post-test score across the experimental class and the three other control classes was observed for the fluency indicator (Figure 1). Consistent with research by Widiastuti (2022), the study found that among the creative thinking skill indicators, students were predominantly focused on fluency. This is evident in their ability to generate multiple answers and provide explanations appropriate to the questions' contexts. Meanwhile, the lowest average score was found in the Originality indicator. Research by Said et al. (2022) also showed that the originality aspect had the lowest score among the indicators. Siswono (2011) further emphasized that the Originality aspect is crucial for students to master, as it fosters more innovative ideas. Students' lack of experience solving open-ended questions creatively contributes to low scores on the originality indicator, so practice and familiarity are needed to develop students in this area. It can be concluded that students' creative thinking skills are significantly influenced by the project-based learning model with a STEAM approach.



	Observing	Interpreting	Measuring	Classifying	Hypothesizing	Analyzing	Concluding	Experimenting
PjBL-STEAM	85	86	88	89	92	92	85	77
PjBL-STEM	80	79	82	82	68	83	80	77
PBL-STEAM	77	80	79	79	68	82	76	68
PBL-STEM	76	75	77	79	62	80	73	75

Figures 2. The average science process skills score of each indicator.

Based on the data above, the highest average indicator scores on the post-test for both the experimental class and the other three control classes was observed in the Analysis indicator. Consistent with research by Darmayanti & Setiawati (2022), some students also mastered the Analysis indicator more than other science process skills indicators. Nafsah et al. (2019) further stated that the Analysis aspect of science process skills is closely related to students' ability to detail the information obtained, thus concluding that students can interpret data correctly and in detail. Meanwhile, the lowest average score for each indicator was found in the Hypothesizing aspect. Rizal et al. (2024) stated that most students still struggle with Hypothesizing. This is because students still lack a holistic understanding of the learning process. It is suspected that students hold misconceptions during learning, so further teacher facilitation is needed to prevent errors in their prior knowledge (Julita et al., 2019). Based on the figure above, the PjBL-STEAM class was deemed superior across all science process skill indicators. Thus, it can be concluded that students' science process skills are significantly influenced by the project-based learning model with the STEAM approach.

The effect of project-based learning with a STEAM approach on students' creative thinking skills and science process skills

Based on the research findings, across the four classes, the experimental class (PjBL-STEAM) showed a greater difference between pretest and posttest average scores for creative thinking skills than the three control classes. This was due to the innovative "packaging" of the PjBL-STEAM learning model, which encouraged students to improve the quality of their learning (Diniyah, 2024). Students were able to develop their creativity through project work as the primary stimulus in learning, supported by the five aspects of STEAM (Shalikhah, 2017). Furthermore, creative thinking skills were measured based on students' pretest and posttest scores, clearly demonstrating their development before and after the treatment. Across the four classes, it can be concluded that students in the experimental class (PjBL-STEAM) showed significant changes compared to the three other control classes. This tends to dominate the Very Good (13 students) and Good (18 students) categories, with only 2 students in the Fair category, and none in the Poor category. Through directed project work, students are guided to solve problems directly, thereby developing a range of skills (Wardani, 2025). Therefore, students are encouraged to make logical decisions, evaluate arguments, and even analyze information comprehensively. Students receive new information not just by memorizing it, but by interpreting it well through a series of discovery activities, like scientists (Undari et al., 2023).

Based on the results of the MANOVA hypothesis test, the Wilks' Lambda significance value was less than 0.05, indicating that the use of the project-based learning model with a STEAM approach significantly impacts creative thinking and science process skills among high school students, particularly regarding environmental pollution. The significant difference in posttest results for creative thinking and science process skills between the experimental class, which used the PjBL-STEAM learning model, and the control class, which used the PjBL-STEM, PBL-STEAM, and PBL-STEM learning models, is partly due to differences in syntax. Differences in the use of learning models and approaches influence learning outcomes, as reflected in students' posttest scores in creative thinking and science process skills.

In the experimental class (PjBL-STEAM), the teacher clearly understood the concepts and characteristics of learning using this model. Furthermore, students responded positively throughout the learning process. They actively asked questions, engaged in discussions, and even independently developed research plans. The students' work demonstrated a variety of models, including color, shape, and even content, as each group translated their research into infographics. This demonstrated the students' flexibility in presenting information. Furthermore, their elaboration skills in presenting information more engagingly were clearly demonstrated. Each group had its own state-of-the-art approach, demonstrating the authenticity of their infographics. The Fluency indicator was demonstrated by students in one group through the creation of a videographic. The video contained an appeal to maintain environmental cleanliness, with visuals and a storyline that felt relatable to the students. This intimate aspect helped other students feel the message more deeply, thus hopefully minimizing environmental pollution, at least in the surrounding area.

The project-based learning model, using the STEAM approach, has the same learning syntax as the PjBL learning model in general. The difference lies in the emphasis on the five STEAM aspects within each syntax. Research by West (2011) suggests that integrating learning approaches into a learning model does not change its syntax; rather, it maintains the existing syntax while emphasizing specific aspects of the chosen approach. This ensures that the key aspects and characteristics of the learning model and approach remain well represented and identifiable, without losing their fundamental essence (West, 2011).

The stages of the PjBL-STEAM learning model begin with determining essential questions (starting with an essential question) with an emphasis on the aspects of Science, Technology, and Art, preparing project planning (planning the project) with aspects of technology, engineering, and mathematics, preparing a project implementation schedule (creating the schedule) with aspects of Art and Mathematics, monitoring the implementation of the project (monitoring the progress) with aspects of science, technology, engineering, and art, assessing the outcome of the project (assessing the outcome) with aspects of Science and Art, and evaluating the experience (evaluating the experience) with Science and Mathematics (Asih et al., 2023).

The initial syntax of the PjBL-STEAM learning model is to determine an essential question (starting with one) with an emphasis on Science, Technology, and Art. After an initial apperception and motivation session, students are presented with two images depicting different river conditions and asked to identify the conditions depicted. This stage sharpens students' creative thinking skills in the Elaboration aspect. This is because students are asked to provide several reasons underlying why one of the images presented is polluted and to cite details supporting these arguments. A total of 90.4% of students have mastered this indicator. This aligns with research by Mardhiyana & Sejati (2016), which indicates that students have maximized their ability to elaborate, develop, add to, and enrich everything in detail. Moreover, students' science process skills in the analysis aspect are also practiced by analyzing the two images presented before drawing conclusions. The most prominent indicator of students' science process skills is the Analyzing aspect. This aspect is supported by data on student abilities, which largely indicate a tendency to analyze and evaluate the variables presented. In the experimental class, this aspect reached 92.4%, significantly higher than other science process skill indicators.

The second stage is to develop a project plan (planning the project) that covers aspects of Technology, Engineering, and Mathematics. In this stage, students are divided into groups to complete Student Worksheets (LKPD). Wijayanti (2020) stated that providing LKPDs systematically structures learning activities and allows students to explore their thinking skills, such as creative thinking and science process skills.

The student worksheet "Atomic Act" contains guidelines for completing the assigned project. In these LKPDs, students independently determine and discuss the technical aspects of their project. At this stage, students' science process skills are emphasized, particularly in the Designing Experiment indicator. They determine the research location, research methods, and develop a research timeline. The student worksheet also includes a section for recording findings and discussions. At the end of the project, students are asked to create an infographic based on their observations and analysis, which they share through their chosen social media platform. Thus, students' creative thinking skills in terms of Flexibility can be seen in how they process the information they receive (Mohanty, 2015).

Creating the project schedule, incorporating aspects of Art and Mathematics, is the third step in the PjBL-STEAM learning model. At this stage, students create a project timeline and determine the research location and methods. Students then begin dividing tasks and discussing the research time and location. Originality indicators at this stage emerge through students' creative problem-solving thinking (Luthfia, 2024). monitor the project's progress, incorporating aspects of science, technology, engineering, and art. at this stage, students submit their worksheets containing their research plans to the teacher. the teacher then provides questions and further suggestions regarding the research methodology they will undertake. The teacher acts as a facilitator, guiding students through the completion of projects (Yuna et al., 2025).

The fifth stage is to assess the project's outcome using the Science and Art aspects. Through this stage, students are asked to present the project they have created. In groups, students come to the front of the class and display the infographics they have designed. Each group has the right to convey opinions, suggestions, and questions to the presenter group. The discussion activity helps train students' science process skills for solving everyday problems (Chen, 2024). Through the discussion process, students will independently discover knowledge. Research conducted by Elvanisi et al. (2018) revealed that the ongoing discussion process influences students' science process skills, particularly in the aspects of Hypothesizing and Drawing Conclusions (Concluding). That being stated, students shall prepare arguments, supported by data, to strengthen the statements given. In addition to science process skills, students can develop creative thinking skills through discussion activities. This aligns with research by Abdullah & Suriyadi (2019), which concluded that creative thinking skills are beneficial for students' problem-solving. Therefore, implementing guided discussion forums within the PjBL-STEAM learning model can also improve the Fluency indicator, as students generate a range of ideas and alternative solutions to answer questions.

The final step in the PjBL-STEAM learning model is evaluating the experience, focusing on aspects of Science and Mathematics. After all groups have presented their findings, the teacher asks students to self-reflect. Through self-reflection, students can express their feelings and opinions regarding the learning they have undergone. They will actively identify their strengths and weaknesses in the learning process, helping the teacher reinforce points that are still poorly understood or not yet mastered by students. Not only teachers but also students will learn to understand their own needs and be motivated to learn more effectively. In line with research by Martincová et al. (2025), students who are able to self-reflect at the end of a lesson tend to have a higher level of understanding and make a much greater contribution to the learning process.

The project-based learning (PjBL) model is combined with the Science, Technology, Engineering, Art, and Mathematics (STEAM) approach, and multiple STEAM aspects are evident in the PjBL syntax (Katz-Buonincontro, 2018). The Science aspect of PjBL-STEAM is closely related to students' science process skills and dominates almost the entire PjBL-STEAM learning syntax. This is because, through science, students can master Biology material, such as environmental pollution. Ekawati (2017) explains that in science learning, there are three important aspects: process, product, and attitude. In the research conducted, these three aspects are fulfilled through projects designed directly by students. Students go through a series of research experiments (the process aspect) facilitated by LKPD, so that the teacher can monitor their performance.

In addition, after students conduct research, they produce various infographics (product aspect). Some create video documentation of research results, others create infographics, and so on. Furthermore, after conducting direct research, students internalize the knowledge they have acquired independently, resulting in changes in student behavior (attitudes). In the PjBL-STEAM learning model, technology is used in two ways: as a tool and as content. As a tool, technology is presented as a "bridge" to facilitate students' problem-solving. They will browse the internet to support the knowledge they need. Access to information on the internet can provide students with the information they need, thereby maximizing the quality of learning (Hill & Nelson, 2011).

Additionally, technology can also be used as learning content in environmental pollution. Students are guided to analyze the technology needed to solve environmental problems. By integrating technology as content, students can develop a range of thinking skills for analyzing problems using technology (Kelley & Knowlews, 2016). Students can develop Flexibility and Originality in creative thinking skills by linking technological functions to learning needs. The scientific process in the Technology aspect can include Interpreting, Measuring, and Classifying. This is because students must process their data before converting it into infographics or videographics, necessitating problem-solving analysis. One approach students use to disseminate information and raise public awareness is social media (Rizal et al., 2024). Students document their research and are then given the freedom to interpret their results according to their preferences. The Engineering aspect guides students in designing projects independently. Using projects as a key component of this learning allows students to practice the Engineering Design Process (EDP) to solve problems through the scientific process and fosters their creativity during project completion. Muttaqiin (2023) stated that the EDP aspect's emphasis on the project design process is a characteristic of STEAM learning.

The Art aspect is the creative aspect that unites STEM and transforms it into STEAM. In the Art aspect, science, technology, engineering, and mathematics become much more meaningful when integrated with creative elements (Yakman & Lee, 2012). In the PjBL-STEAM learning model, the Art aspect is evident in the research outputs they develop. Through the infographics and videographics they create, students demonstrate their flexibility in expressing themselves through art. Agustina (2019) states that creating infographics/videographics can facilitate students' presentations of the material they will present. This is because there is a process of actualizing the elements of students' creativity in pouring out the information, they get during project work into a more interesting and innovative form.

Mathematics is presented in several learning contexts, such as developing project plans, project implementation schedules, and evaluations. This aspect involves performing calculations, analyzing multiple variables, and drawing conclusions, which aligns with the Measuring and Concluding aspects of science process skills. At this stage of learning, students are closely connected to mathematical elements. This is because problem-solving methods necessarily use mathematical concepts, such as calculation, measurement, and comparison. Thus, the Mathematics aspect enables students' Fluency in thinking through analysis and evaluation.

Strengthened by the hypothesis test conducted, obtained a significance value of Wilks' Lambda of 0.001, which means H0 is rejected at $\alpha = 0.05$. This indicates that the project-based learning model with the STEAM approach has a significant effect on the creative thinking skills and science process skills of participants in environmental pollution material. This is reinforced by Blackley et al. (2018), who argue that integrating the STEAM approach into learning involves students in exploring contextual problems, thereby making them more creative and innovative. Then, El Sayary et al. (2015) added that not only are creative thinking skills developed in this learning model, but science process skills are also emphasized through direct student involvement in learning.

By integrating the STEAM approach into PjBL, students are challenged to solve problems through interdisciplinary projects. This involves combining creative thinking and processes to produce innovative products, utilizing scientific methods through elements of science and technology. This is in line with Vygotsky's (2014) theory, in which students with cognitive abilities use their thinking tools to observe, connect, evaluate, and consider issues to solve problems effectively and efficiently and achieve goals. In PjBL-STEAM learning, students are given ample opportunities to interact with their environment through group project assignments that rapidly develop their thinking skills. This serves as the foundation for improving students' thinking skills in this study, namely, creative thinking and science process skills.

The syntax of PjBL-STEAM directs students to explore their environment by stimulating their five senses (Wardani et al., 2023). This enables students to acquire knowledge consciously and independently due to their direct participation in the learning process. Students can develop creative thinking skills and science process skills through natural (spontaneous) reasoning and scientific processes (experiments) (Hamdiah, 2012). Throughout the learning process, even though learning is student-centered, teachers still provide scaffolding to facilitate students experiencing difficulties (Santosa et al., 2025). Vygotsky's theory further emphasizes sociocultural aspects, in which individual students' cognitive development is shaped not only by themselves but also by their social life and group (Nyeneng et al., 2020). In the PjBL-STEAM learning model, problem-solving is carried out in groups. Students' knowledge development is created through interaction with the social environment (Listiana & Fauziati, 2021). The learning they undertake is internalized because they actively engage in it. This influences the Zone of Proximal Development (ZPD), Vygotsky's theory, where students' potential knowledge emerges when they solve problems independently without the guidance of a more competent person, or in the formal school context, a teacher.

Anggun et al. (2025) suggest that Vygotsky's theory of students' proximal development has upper and lower limits that must be achieved. The lower limit is seen in students' ability to complete tasks and solve problems without teacher assistance. This is reflected in students' process of completing group-assigned projects. The upper limit is met if students can independently accept additional responsibilities or assignments (Anggun et al., 2025). Indicators that demonstrate students' ability to exceed the upper limit include student gain scores and the difference between the average pretest and posttest scores for creative thinking skills and science process skills, which have increased, indicating a positive change in learning outcomes following the PjBL-STEAM learning model. Constructivist-based PjBL-STEAM learning can enrich students' learning experiences through reflection, discussion, and collaborative thinking, thereby positively contributing to their intellectual and cognitive development (Tohari & Rahman, 2024). Vygotsky (2014) argued that social interaction is a crucial factor in students' cognitive development. This is because the learning process is more effective and efficient when students learn cooperatively with one another.

Research conducted by Habsy (2014), who analyzed the application of cognitive learning theory, found that learning can provide in-depth understanding and meaningful learning relevant to the characteristics of the PjBL-STEAM learning model. In line with this research, Muhibin & Hidayatullah (2020) also demonstrated that learning can run well when supported by accurate materials, learning models, school support, teacher roles, and adequate infrastructure. All of the aforementioned points were fully met during the research process. The material provided to students, specifically Environmental Pollution, aligns with Biology textbooks and is supplemented with up-to-date references, including supplementary learning modules in the form of PowerPoint presentations on Environmental Pollution. Furthermore, the technological aspect of STEAM emphasizes the use of technology as a tool and content to facilitate students' information retrieval.

School support, the role of teachers, and adequate infrastructure are demonstrated by the school's strong collaboration in facilitating optimal learning. This includes providing a projector in each classroom, which facilitates the transfer of information from teacher to student and from student to student. Teachers must also master the material and learning model used. The PjBL-STEAM model has proven effective and efficient in improving students' creative thinking skills and science process skills. This is because the learning is related to 21st-century thinking skills, such as creative thinking, collaboration, communication, and critical thinking (4C Thinking Skills) (Sari et al., 2025). It can be concluded that the PjBL-STEAM model can serve as an alternative for teachers in preparing students to face the challenges of the era of globalization.

CONCLUSION

The project-based learning model, combined with the STEAM approach, has a significant influence on students' creative thinking and science process skills regarding environmental pollution material. PjBL-STEAM has been proven to improve the creative thinking and science process skills of class X students. This research suggests that the project-based learning model with the STEAM approach is an alternative learning model that can improve students' creative thinking and science process skills in environmental pollution.

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