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Effect of project based learning with STEAM integration on students' problem-solving skills

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Abstract

The 21st-century competition demands superior human resources equipped with skills to compete globally. One of the skills considered essential in the 21st century is problem-solving. This study focuses on the implementation of the PjBL-STEAM model for 10th-grade high school students. The purpose of this research is to examine the effect of the PjBL-STEAM model on students' problem-solving skills. This research is a quasi-experimental study using a Pretest-Posttest Control Group design. The population consists of all 10th-grade learning groups, totaling ten groups, with a total of 280 students. The sample includes classes X BIO 7 and X BIO 8, selected through purposive sampling, and the instrument used is a problem-solving skills test. Based on inferential analysis using the Mann-Whitney U test, it was concluded that the PjBL-STEAM model has a significant effect on students' problem-solving skills. This finding is reinforced by descriptive analysis results, which show an average increase in problem-solving skills of 16.33 points, from a low category to a good category. Based on these data, it is concluded that the PjBL-STEAM model positively influences students' problem-solving skills. The implications of this study suggest that teachers can integrate the STEAM-based PjBL model as a strategy to prepare students to face real-world challenges that require complex problem-solving abilities.

Abstrak. *Persaingan abad 21 memerlukan sumber daya manusia yang unggul dengan keterampilan yang siap bersaing secara global. Salah satu keterampilan yang dianggap penting pada abad 21 adalah keterampilan pemecahan masalah. Penelitian ini memfokuskan pada penerapan model PjBL-STEAM tingkat SMA kelas X. Tujuan dari penelitian ini adalah untuk melihat pengaruh model PjBL-STEAM terhadap keterampilan pemecahan masalah peserta didik. Jenis penelitian yang digunakan adalah penelitian eksperimen semu dengan desain Pretest-Posttest Control Group. Populasi dalam penelitian ini adalah seluruh rombongan belajar (rombel) kelas X yang terdiri atas sepuluh rombel. Jumlah populasi dari sepuluh rombel sebanyak 280 siswa dan sampel yang digunakan yaitu kelas X BIO 7 dan X BIO 8, pengambilan sampel dalam penelitian ini diperoleh dengan menggunakan teknik purpusive sampling serta instrumen yang digunakan adalah lembar tes kemampuan pemecahan masalah. Berdasarkan hasil analisis inferensial menggunakan uji Mann-Whitney U, didapatkan kesimpulan bahwa terdapat pengaruh signifikan model PjBL-STEAM terhadap kemampuan pemecahan masalah peserta didik. Hal ini diperkuat dengan hasil analisis deskriptif yang menunjukkan peningkatan kemampuan pemecahan masalah peserta didik dengan selisih rata-rata sebesar 16,33, dari kategori kurang menjadi kategori baik. Berdasarkan data tersebut disimpulkan bahwa terdapat pengaruh model PjBL-STEAM terhadap kemampuan pemecahan masalah peserta didik. Implikasi dari penelitian ini dapat menjadi dasar bagi guru untuk mengintegrasikan model PjBL berbasis STEAM sebagai upaya mempersiapkan peserta didik menghadapi tantangan dunia nyata yang membutuhkan kemampuan pemecahan masalah yang kompleks.*

A. Introduction

Competition in the 21st century requires superior human resources equipped with globally competitive skills. The development of human resources is a primary concern of the government and forms the foundation for Indonesia's future growth and progress (Diana & Sukma, 2021). A key aspect of developing superior human resources is through education. According to Lase (2019), improving the quality of human resources through educational pathways, from primary and secondary education to higher education, is essential to keeping pace with the developments of the Fourth Industrial Revolution. The National Education Association has identified vital 21st-century skills known as the "4Cs": critical thinking, creativity, communication, and collaboration (National Education Association, 2014).

Schools can help students navigate the rapidly evolving landscape of science and technology in the 21st century by fostering higher-order thinking skills and other abilities that enable them to adapt to fast-paced changes and challenges (Mu'minah & Suryaningsih, 2020). Consequently, education in Indonesia must adapt to the growing digitalization of society (Rahayu et al., 2022). In alignment with this need, the Ministry of Education, Culture, Research, and Technology (Kemendikbud Ristek) launched the 2013 Curriculum, which emphasizes 21st-century skills, requiring educators to master and implement these learning strategies effectively (Sartono et al., 2020).

Among the essential 21st-century skills is problem-solving, which enables students to identify problems, understand their causes, and develop solutions (Nurhayati et al., 2021). McGunagle and Zizka (2020) also explained that A&D HR professionals identified the top job skills as problem-solving, adaptability, data-gathering, teamwork, and proactivity, highlighting these as the most in-demand employability skills. Therefore, it is crucial to prepare students for this. According to Setiani et al. (2020), one factor contributing to students' lack of problem-solving skills is the ineffective application of learning strategies by teachers in the classroom.

Project-based Learning (PjBL) is a learning model that can enhance students' problem-solving abilities by integrating new knowledge through real-world experiences (Darmadi, 2017). The PjBL model provides opportunities for students to explore content and collaborate in meaningful ways (Fatmawati et al., 2011). Purnomo and Ilyas (2019) further explain that PjBL involves organizing projects around five criteria: centrality, driving questions, constructivist inquiry, student autonomy, and realism (Kemdikbud, 2014).

Despite its potential, the application of PjBL to improve problem-solving skills in addressing global challenges of the 21st century is often suboptimal, as it tends to focus on conceptual understanding and project creation without adequately engaging in problem construction and product design. Therefore, a suitable 21st-century learning approach for enhancing problem-solving skills is the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach, which connects disciplines and provides students with a holistic learning experience (Windasari et al., 2020). This aligns with Septiani (2016), who states that STEAM integrates various fields to focus the educational process on solving real-world problems.

The integration of PjBL with STEAM (PjBL-STEAM) aims to provide students with the opportunity to explore ideas, develop products, and enhance design skills, thereby effectively improving their problem-solving abilities (Sa'ida, 2021). According to Adriyawati et al. (2020), PjBL-STEAM also enhances students' curiosity and enables them to conduct simple scientific investigations. In the learning process, students have become more willing to ask questions and have the ability to seek relevant and credible information to obtain answers. The stages of PjBL-STEAM include five steps as outlined by Laboy & Rush (2010), namely Reflection, Research, Discovery, Application, and Communication.

Modern science education, particularly in biology, aims to inspire students to understand interconnected scientific processes and address the socio-scientific challenges faced by society (Suwono et al., 2017). Emphasizing the potential of STEAM in the curriculum is crucial, as it is part of active constructivist learning and aligns with the Merdeka Curriculum, where students actively construct knowledge through projects within STEAM learning. However, research on the potential of PjBL-STEAM in the Merdeka Curriculum, particularly in biology, remains limited, as biology education often emphasizes rote learning, making integration with STEAM challenging (Coates, 2020).

Several previous studies support the use of PjBL-STEAM, including research by Windasari et al. (2020), which indicates that the implementation of PjBL-STEAM enhances students' problem-solving abilities. Additionally, Natty et al. (2019) concluded that learning activities in PjBL-STEAM effectively stimulate the development of problem-solving skills as part of children's cognitive development. This is further reinforced by research conducted by Sigit et al. (2022), which recommends the PjBL-STEAM learning model to assist middle school students in understanding a concept. This is supported by their findings, which demonstrate an overall improvement in ecological concept mastery. These supporting studies indicate that the STEAM-based PjBL model can positively contribute to enhancing students' problem-solving abilities.

Based on the issues outlined above, this study aims to examine the influence that can enhance students' problem-solving skills through PJBL-STEAM learning. The novelty of this research lies in the researcher's intention to conduct experiments using the PjBL model, which is syntactically problem-based and will be integrated with the STEAM approach. To date, there has been no research addressing the potential of PjBL-STEAM within the Merdeka Curriculum, particularly focusing on Biology studies. This is due to the assumption that biology learning tends to be memorization-oriented, making it challenging to integrate with the STEAM approach. Through the PjBL-STEAM, it is hoped that this will prepare students to face real-world challenges that require complex problem-solving skills.

B. Material and method

The study employed a quasi-experimental research design with a quantitative approach. Two classes were selected for the research: one class served as the experimental group (PjBL-STEAM), specifically Class X.7, and the other as the control group (PjBL), specifically Class X.8. The research utilized a pretest-posttest control group design, as detailed in Table 1.

Table 1 Pretest posttest control group research design

Class	Pretest	Treatment	Posttest
Experiment	O_1	X_1	O_2
Control	O_3	X_2	O_4

(Source: Arikunto, 2013)

Description:
X_1 = Implementation of the PjBL-STEAM model
X_2 = Implementation of the PjBL model
O_1 = Level of problem solving before implementating PjBL-STEAM
O_2 = Level of problem solving after implementating PjBL-STEAM
O_3 = Level of problem solving before implementating PjBL
O_4 = Level of problem solving after implementating PjBL

This study utilized the PjBL-STEAM and PjBL models, comprising three main stages: preparation, implementation, and conclusion. During the preparation stage, observations were conducted at the research site, and permission was obtained from the school to select two classes as samples. The curriculum was analyzed to identify the subject matter to be taught, and discussions were held with Biology teachers to understand the commonly used teaching methods. Research instruments, including Teaching Modules, Student Worksheets (LKPD), and evaluation questions (pretest and posttest), were also prepared. Following the preparation of these instruments, validation and processing of the research documents were carried out.

The implementation phase consisted of five sessions. The first session involved administering a pretest in both the experimental and control classes, using essay questions to assess problem-solving skills. The subsequent three sessions involved the learning process, applying the PjBL-STEAM learning syntax, including stages such as posing essential questions, product planning and design, scheduling, project monitoring, testing results, and evaluating the learning experience. In the final session, a posttest was administered to measure problem-solving skills post-intervention.

The concluding stage of the research involved data processing and analysis using descriptive and inferential statistical methods to assess the impact of the PjBL-STEAM model on students' problem-solving abilities. Conclusions were then drawn from the results of the analysis. Table 2 illustrates the differences in the implementation stages of PjBL and PjBL-STEAM.

Table 2 The differences in the implementation stages of PjBL and PjBL-STEAM

Phases	PjBL	PjBL-STEAM
Determining the essential question	Students identify the key issues derived from a news report	Students identify the key issues derived from news articles by integrating concepts from various STEAM disciplines
Designing the product plan	Students design the project plan based on the established essential questions. Most students create posters	Students design the project plan by considering aspects of science, technology, engineering, art, and mathematics. Some students design an automatic waste collection system using microcontrollers, a waste-sorting robot, electric cars, and eco-coolers
Developing the production schedule	Students develop a schedule to complete the project according to the established plan	Students develop a schedule that integrates time for each STEAM discipline in the production process
Monitoring the activity and progress of the project	Students monitor the activity and progress of the project during its implementation	Students monitor the activity and progress of the project by incorporating feedback from various disciplines within STEAM
Testing the results	Students test the project results according to the established criteria	Students test the project results using an interdisciplinary approach, relating the outcomes to practical applications within the STEAM context
Evaluation of the learning experience	Students evaluate the learning experiences gained during the project	Students evaluate their learning experiences with an emphasis on how the integration of STEAM affects their understanding and skills

Table 3 STEAM components that students must achieved

STEAM components	Explained
Science	Concept of Environmental Change
Technology	Using Canva to design a product
Engineering	Utilizing every element in Canva to design and create a product
Art	Designing the product's appearance to be engaging and educational
Mathematic	Every element in Canva used in the design composition is carefully considered

Table 4 Categorization of the problem solving levels

No	Ability level	Categories
1	0-49	Very poor
2	50-69	Poor
3	70-79	Fair
4	80-89	Good
5	90-100	Very good

Source: Arikunto (2009)

Data were collected using a problem-solving ability test sheet, designed to evaluate students' skills in addressing issues related to the Biology topic of Environmental Change. The test was administered twice—before and after the implementation of the PjBL-STEAM and PjBL learning models—with six questions aligned with problem-solving indicators. The integration of STEAM into the completed project is as Table 3. Data analysis techniques included descriptive statistical analysis and inferential statistical analysis. The categorization of the results from the descriptive statistical analysis of problem-solving skills is presented in Table 4.

Additionally, inferential statistical tests included normality tests, homogeneity tests, and hypothesis testing. The hypothesis test employed was the Mann-Whitney U Test. The hypothesis is formulated as follows: if the significance value (2-tailed) is ≥ 0.05, then H_0 is accepted, indicating that there is no significant difference in problem-solving skills between the PjBL-STEAM class and the PjBL class. Conversely, if the significance value (2-tailed) is < 0.05, then H_1 is accepted, indicating that there is a significant difference in problem-solving abilities between the PjBL-STEAM class and the PjBL class (Sugiyono, 2015).

C. Results and discussion

The results of the descriptive analysis of problem-solving abilities in both the PjBL-STEAM class and the PjBL class are presented in Table 5. Based on Table 5, it is evident that the average problem-solving skill score of students taught through the PjBL-STEAM model increased with an average difference of 16.33. Additionally, the average problem-solving skill score of students taught through the PjBL model also showed an improvement, with an average difference of 8.27. The average pretest scores in both classes were relatively close, indicating that the initial abilities in the PjBL and PjBL-STEAM classes were nearly equivalent. However, the average posttest score in the PjBL-STEAM class was higher than the average posttest score in the PjBL class. The average scores for each indicator of students' problem-solving abilities taught using the PjBL-STEAM model refer to Table 6.

Table 5 Descriptive analysis of student's problem-solving abilities

Statistic	Problem-solving ability score			
	PjBL-STEAM		PjBL	
	Pretest	Posttest	Pretest	Posttest
Minimum Score	33,3	50	25	37,5
Maximum Score	87,5	95,8	87,5	87,5
Mean	63,73	80,06	63,97	72,24
Standard Deviation	11,648	12,641	14,010	11,910
Sample Size	36	36	36	36

Table 6 Average indicators of student's problem-solving abilities using the PjBL-STEAM model

Problem solving indicators	Pretest score	Categories	Posttest score	Categories
Understanding the problem	71,1	Fair	81,9	Good
Planning the solution	72,9	Fair	80,9	Good
Solving the problem according to the plan	53,4	Poor	71,5	Fair
Conducting re-check	46,5	Very poor	70,8	Fair

Table 7 Average indicators of student's problem-solving abilities using the PjBL model

Problem solving indicators	Pretest score	Categories	Posttest score	Categories
Understanding the problem	68,75	Poor	77,7	Fair
Planning the solution	64,2	Poor	81,5	Good
Solving the problem according to the plan	56,25	Poor	73,6	Fair
Conducting re-check	54,8	Poor	69,4	Poor

Table 8 Hypothesis testing of student's problem-solving abilities using the Mann-Whitney U test

	Results
Mann Whitney	366.500
Sig. (2-tailed)	0.001

The problem-solving skill indicator scores for students before being taught with the PjBL-STEAM model were rated as fairly good for understanding the problem and planning the solution, as low for solving the problem according to the plan, and very poor for re-check. After instruction with the PjBL-STEAM model, the problem-solving indicators showed a good rating for understanding the problem and planning the solution, and a fairly good rating for solving the problem according to the plan and re-check. Table 7 are presented the average indicators of students' problem-solving abilities taught using the PjBL model.

The problem-solving skill indicator scores for students before being taught with the PjBL model were all categorized as poor. After instruction with the PjBL model, the scores improved, with a good rating for planning the solution, a fairly good rating for understanding the problem and solving the problem according to the plan, and a low rating for re-evaluating. A detailed explanation of the improvement in problem-solving indicators will be further discussed in the discussion section.

Hypothesis testing was further conducted using the non-parametric Mann-Whitney U Test. The results of the Mann-Whitney U Test on students' problem-solving abilities are presented in Table 8. Based on the results of inferential analysis using the Mann-Whitney U Test, it was concluded that the PjBL-STEAM model significantly influences students' problem-solving abilities. This conclusion is supported by the descriptive analysis, which shows an average improvement of 16.33 points in students' problem-solving skills, indicating a shift from the 'poor' to the 'good' category. The PjBL-STEAM model's effectiveness in enhancing problem-solving skills can be attributed to its structured approach, which are described one by one.

The first phase, asking basic questions through an approach reflection and research, at this stage students are directed to face situations related to everyday life or the surrounding reality. From the beginning of the basic question giving phase, students are given problems that are directed at STEAM solutions. Researchers used several problems in news articles regarding environmental changes in South Sulawesi. The purpose of the problems presented to students is to encourage the learning environment to be more active in finding solutions to the problems presented. In this phase, it corresponds to the problem solving indicator, namely that students can identify/understand the problem.

This is in accordance with opinion by Larmer & Mergendoller (2015) that with an emphasis on fundamental questions and problem solving, it can improve students' critical skills, including the ability to solve problems effectively. Apart from that, Mulyani (2019) also revealed that STEAM in learning focuses on solving problems in real daily life. STEAM shows students how the concepts, principles, techniques of science, technology, art and mathematics are used in an integrated manner to develop products, processes and systems that benefit human life.

The second phase, designing product planning with an approach discovery, at this stage students who have been formed into heterogeneous groups together exchange opinions to find solutions to problems through the student worksheets that have been given. Researchers help students provide articles that are relevant to solutions to environmental change problems and after discussing it with their respective group friends, students are able to create product planning designs that will be made. This second phase is the phase that is most able to encourage students' problem solving skills because at this stage students are asked to design product designs.

The designs created by students are directed towards integrating science, technology, engineering, art and mathematics. In the Science aspect, students consider solution concepts for the given problems, such as an automatic waste collection system using microcontrollers, a waste-sorting robot, electric cars, and an eco-cooler. In the Technology aspect, students are given the freedom to choose applications for designing their projects; most students select Canva as their design tool. For the Engineering aspect, students use elements in Canva to create a simple design. In the Art aspect, students are evaluated on their ability to design aesthetically. Meanwhile, in the Mathematics aspect, students are assessed based on their calculations and effective use of Canva elements.

This second phase corresponds to the problem solving indicator, namely planning a solution. This is in line with research conducted by Bevan et al. (2015) that involvement in product design and manufacturing activities directly contributes to improving students' problem solving skills. That's what Lachapelle et al. (2014) said that the introduction of engineering principles through product design activities in schools can improve students' problem solving abilities.

The third phase, preparing a manufacturing schedule with an approach discovery, at this stage students are asked to prepare a schedule for making a project with their respective group friends which will be implemented for two weeks. At this stage, what the researcher does is apart from guiding the students to set their schedule, the researcher also guides the students to find out what tools and materials are used in making their project and then write it down on the students' worksheet. This is in line with opinion of Gunawan et al. (2018) that the PjBL-STEAM model can increase cooperation between students. Apart from that, research of Sa'adah & Mawardi (2019) also explains that students' enthusiasm increases because project-based learning or interaction between students increases because they work in groups.

The fourth phase, monitoring project activity and development with an approach application. At this stage, each group has designed a solution project for environmental changes in the Canva application. The activity of monitoring the activity and development of students' projects was carried out in two meetings. Larmer et al. (2010) emphasize the importance of continuous assessment and monitoring of students' project activity and development in PjBL to ensure that learning objectives are achieved. Likewise, Thomas (2000) summarizes various studies to show that continuous monitoring and feedback during the project is very important for the success of PjBL and helps students to stay focused and develop according to the project goals.

The fifth phase, testing the results with the approach communication. At this stage each group presents the results of their project and other groups provide responses to the project. By having discussion activities followed by presentations, it will provide many opportunities for students to learn to communicate orally. According to Jandja and Lutfi (2018) that problem-solving abilities cannot be obtained just like that, they must be supported by active, communicative and student-oriented learning so that they can help students solve the problems they face. It is also in line with research by Diyas (2012) that the presentation stage makes students very active and compete to express opinions and ask questions about the problems being discussed. Students are trained to express opinions and defend their opinions.

The sixth phase, evaluate the learning experience with the approach communication. At this stage the researcher responds to each project produced by the group and then also provides conclusions and reflections on the Environmental Change material. According to Larmer & Mergendoller (2015) that effective evaluation of learning experiences in PjBL helps teachers identify areas that need improvement and ensures that students get the full benefit of the project-based learning approach. Likewise, Thomas (2000) believes that it is important to systematically evaluate the PjBL learning experience to ensure that students not only complete the project but also achieve the desired learning goals. In this research, after learning using the PjBL-STEAM model, there was an increase in the indicator category of problem solving skills. Students show an increase in indicators of understanding problems, planning solutions, resolving problems according to plan and checking again.

In the indicator for understanding the problem, students have shown an improved ability to define the problem, recognize its relevance, and formulate key questions that need to be addressed. This progress is attributed to the use of diverse learning resources. Articles and case studies provided as references enrich students' understanding of the topics studied, helping them connect issues to broader concepts and find relevance between theory and practice. According to Asiyah et al. (2021) understanding the problem is a crucial first step in the problem-solving process. Without a strong understanding, the solutions generated tend to be inadequate or even irrelevant.

Furthermore, regarding the indicator for planning solutions and solving problems according to the plan, students' ability to create a structured plan is attributed to the guidance provided by the researcher during the planning stage, particularly in facilitating the initial steps. This guidance offers a framework for students to develop more systematic plans, including through the provision of articles as references for problem-solving. Students can identify the necessary stages and allocate time effectively. According to Tambunan (2019), a structured plan not only aids students in problem-solving but also enhances efficiency and effectiveness in the learning process. Similarly, Deswita et al. (2018) state that students who can create structured plans demonstrate a deep understanding of the problem and the ability to organize the steps for resolution logically.

In the indicator for conducting checks, students demonstrate improved ability in evaluating the results of their work. They are capable of identifying errors and deficiencies in the solutions produced in their projects. This improvement is attributed to the feedback received from teachers and classmates during or after the completion of the project, enabling students to evaluate their work more effectively. This feedback can direct them to errors they may not have previously recognized. The ability to evaluate one's own work results is an important metacognitive skill. Students who are used to checking again tend to be more independent and responsible in learning. Likewise with the opinion of Palennari et al. (2021)

that the application of problem solving methods in learning has advantages, because apart from providing students with information, it also allows students to actively think, communicate, and search and process data, which ultimately allows them to conclude better. This increase in problem solving indicators reflects that the PjBL-STEAM model is able to improve students' problem solving skills.

This finding is in line with research conducted by Triprani et al. (2023) that the application of PjBL-STEAM learning can influence students' problem-solving abilities. Increased problem-solving abilities occur because at each meeting, students are trained to identify, analyze, conclude and create a work. Students in STEAM classes are required to solve real-world problems and engage in ill-defined tasks become well-defined outcome through cooperation in groups (Lumbantobing & Azzahra, 2020).

This research can provide solutions or information for implementing the PjBL-STEAM model in biology learning, especially Environmental Change material. PjBL-STEAM helps teachers and students understand real world problems and connects them to how students learn to solve these problems, which is a real application of 21st century learning.

D. Conclusion

Based on the results of the research and the discussion above, it can be concluded that there is an influence of PJBL-STEAM model on students' problem-solving skills. Further research could focus on the long-term effects of PjBL-STEAM learning on students' problem-solving skills in schools. Additionally, it is important to explore various contexts and subjects that can be integrated with this learning model to understand its full potential in enhancing students' learning skills.

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