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Applying the STEAM Integrated Project-Based Learning Model: Improving 21st Century Learning Outcomes and Skills

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ABSTRACT

This research aims to determine the effectiveness of the learning model of STEAM-integrated PjBL. The research aim is helping the learning process of students. This research was conducted at elementary schools in Malang city by taking two schools as samples, namely SDN Bareng 3 and SDN Dadaprejo 2. There were 27 grade V students who were used as samples in this study. The present investigation was conducted upon the Quasi Experiment Design with a control group. The results of the research conducted show that the application of the PjBL-based STEAM method is able to increase student learning achievement. This is evidenced by an increase in the average value of pre-STEAM implementers and after implementation. The average score of students before the implementation of PjBL-based STEAM was 48.02 and increased to 82.05 after the implementation of STEAM PjBL. The analysis of the data with t-test and effect size found that the STEAM-integrated PjBL improves the student learning outcomes to be in moderate influence. Additionally, the validity and reliability test results of the research instruments indicate that the measuring instruments used in this study are valid and reliable. We can say that the implementation of STEAM in PjBL can increase student academic achievement in elementary school. The results of this study provide a rationale for implementing innovative learning approaches to help students in Indonesia improve their communication, collaboration, and critical thinking skills, which are important aspects of 21st century skills.

Keywords: 21st century skills, basic education, learning outcomes, PjBL, STEAM

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INTRODUCTION

Research conducted in the last five years suggests that Students are expected to be able to improve their ability to face the 21st century with situations related to Volatility, Uncertainty, Complexity, and Ambiguity (VUCA) in the future. (Mohanta et al., 2019; Seow et al., 2019). The skills that are expected to appear in students are the ability to think critically, collaborate, be creative, and have good communication patterns. Today, these skills are the main thing needed to face the challenges of future jobs (Alismail, 2023; Bayley, 2022; Bray et al., 2023; Kaya et al., 2023; Peña-Ayala, 2021). Referring to these conditions, it is known that in Indonesia and several other developing countries, students still do not have the ability to think critically and creatively to compete at the global level. Learning in Indonesia has not yet penetrated into studies in general related to the job market that place analytical & creative thinking, AI, data literacy, and lifelong learning. The lack of a learning process that integrates this will make students not have the skills or competencies to compete globally. What should be done is to integrate the learning process with future needs in the form of *analytical & creative thinking skills*, *AI and data literacy through initial training in schools* (Dumitru & Halpern, 2023; Pandit et al., 2025).

Referring to this, the integration of these skills is important in the learning process because education aims to prepare students to face various global challenges and changing times (Borroni et al., 2021; Chen et al., 2023; Colim et al., 2022; Johnsen et al., 2024; Loyens et al., 2023; Qi et al., 2022; Santhosh et al., 2023). Therefore, educational paradigms must shift to foster these competencies, moving beyond rote memorisation to cultivate deeper understanding and practical application of knowledge (An, 2020).

The current study found that only 30% of students at the primary school level in Indonesia have basic competencies and the ability to collaborate based on global standards. This achievement is much smaller than OECD countries with an average achievement of 70%. This shows that the quality of education can hinder students' potential to compete in the global world in the future. To address this disparity, innovative pedagogical approaches are crucial for fostering essential 21st-century skills among students, particularly in developing nations (Huijser et al., 2015)

In addition, some literature found shows that some developed countries have successfully integrated STEAM education (Science, Technology, Engineering, Arts, Mathematics) with PjBL (Project-based Learning). Students' ability to analyse and be creative has increased significantly after implementing the integration of STEAM and PjBL (Chistyakov et al., 2023; Hawari & Noor, 2020; Megawati, 2024). However, in Indonesia, the process of implementing various education models is still uneven. The implementation is constrained by the lack of subject teacher resources and the inadequate training received by teachers. Several studies conducted show that Indonesia has

attempted to integrate various learning models that are relevant to the needs and development of students. These models include culture-based learning, technology-integrated learning, and approaches that focus on developing students' emotional intelligence. These models are believed to have a significant impact on student development and education in Indonesia as a whole (Jalaluddin et al., 2020; L. M. Kasmini, 2020; Mardhatillah et al., 2020).

LITERATURE REVIEW

Despite these efforts, challenges persist in the equitable and effective implementation of these innovative pedagogies across all regions and educational tiers in Indonesia, highlighting a gap between policy aspirations and practical classroom realities (Prahanı et al., 2023). The consistently low PISA scores in Indonesia, exacerbated by the recent pandemic, underscore the urgent need for effective pedagogical shifts, with Project-Based Learning being a promising approach to cultivate critical thinking and problem-solving skills across all educational levels (Khusna et al., 2022). Despite the government's initiatives to modernise education through internet access and online learning platforms like SPADA Indonesia, the overall quality and global competitiveness of Indonesian students remain a significant concern, necessitating a re-evaluation of current educational strategies (Ra et al., 2021; Samala et al., 2024; Thohir et al., 2021). One promising avenue is the integration of Project-Based Learning within the "Freedom to Learn" framework, which aligns with the goal of producing graduates who can adapt to evolving scientific and technological demands and societal dynamics (Camillo Lento, 2016).

Especially in Malang City, innovations in education have been implemented in various aspects of learning. SDN Bareng and SDN Dadaprejo 2 are among the schools that have successfully implemented learning with the latest innovations. Initial analysis conducted in these two schools showed that the teaching materials and teaching books are applied by the teacher and students not proven to be significantly effective in improving students' skills and development in high-level thinking. The findings conclude that there is an urgent need to implement a learning model that integrates 21st century skills holistically and systematically. The learning approach should be designed by integrating 21st century competencies that are relevant and appropriate to the needs of students and the times (González-Pérez & Ramírez-Montoya, 2022; González-Salamanca et al., 2020). This necessity is particularly pressing given Indonesia's rapidly increasing internet penetration and extensive use of social media, underscoring the potential for technology-enhanced educational approaches (Ra et al., 2021). The "Merdeka Belajar" programme, implemented by the Indonesian Ministry of Education and Culture, aims to address these educational challenges by promoting flexible learning and fostering creativity and innovation among students and educators alike (Sihombing et al., 2021).

This initiative aligns with the principles of 21st-century learning, emphasising student-centred approaches to cultivate critical thinking, collaboration, creativity, and communication skills (Hunaepi & Suharta, 2024; Sihombing et al., 2021). However, challenges persist in fully realising the programme's potential due to varying levels of teacher readiness and unequal access to facilities, especially between urban and rural areas (Mardhatillah, 2017; Samala et al., 2024). Therefore, further research is needed to explore the effectiveness of integrating Project-Based Learning with a focus on 21st-century skills within the "Merdeka Belajar" framework, particularly in diverse educational settings across Indonesia. This approach would facilitate the development of analytical thinking, problem-solving, and collaborative abilities essential for navigating complex real-world scenarios, thereby aligning with the broader goals of educational reform (Ace, 2007; Hidayatullah et al., 2021). Such an integration could also bolster the development of independent learning and critical thinking skills, which are crucial for students' academic and future career success (Aliftika et al., 2021). Moreover, addressing teachers' initial perspectives and providing systemic support for their professional development is crucial for the continuous success of such innovative educational policies (Thohir et al., 2021). The Merdeka Belajar-Kampus Merdeka policy, for instance, explicitly promotes student-centred learning and aims to cultivate competencies and skills relevant for future careers by emphasising critical thinking, problem-solving, collaboration, and creativity (Astuti et al., 2023).

This study was conducted to fill the gap of previous research by analysing the effectiveness of the STEAM-integrated Project-Based Learning (PjBL) model to improve student learning outcomes. The model is targeted to improve students' understanding academically and also strengthen adaptability to future learning challenges. Currently, the teaching and learning process experiences various challenges in the form of developing diverse learning media, student involvement in problem solving, and developing student potential according to their field of study. It is hoped that the focused development and appropriate application of methods in this research will make a worthy contribution to the global education literature and support the advancement of educational practices in Indonesia, especially basic education (Ananda et al., 2023; Kasmini et al., 2024).

METHODOLOGY

This research was conducted using a Quasi-Experiment Design Method. The practice is a type of field experiment that uses a control class group, even though its control over extraneous variables that influence the application of the experiment is not complete. This research design is based-on Nonequivalent Control Group Design, as illustrated in Figure 1:

Variables in this research include the independent and dependent variables known as the X and Y variables.X variable is the independent variable which is the PjBL

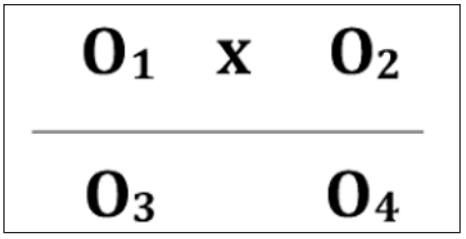

Figure 1. Nonequivalent control group design
Information:
O_1 and O_3 = Pre-Test (Test 1) of the control and experimental class groups.
X = Learning based on the STEAM integrated PjBL learning model.
O_2 and O_4 = Post-Test Measurements of the control and experimental group respectively

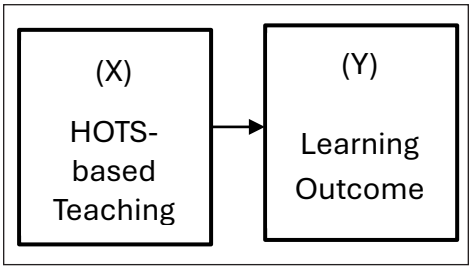

Figure 2. Research variables

learning model integrates the STEAM approach. The bound variable in this study, or also called the dependent variable, is the learning outcomes. These variables are illustrated in Figure 2.

The data of this research was conducted at BE 3 and DP 2 State elementary school. This study was conducted on the period 08-30 August 2024. Sampling was carried out using purposive sampling techniques, taking into account several criteria, including the curriculum used in schools, students' initial abilities, distance, and cooperation carried out by researchers with schools in Malang City. Referring to these criteria, the schools used as the location of the research are SD Negeri 3 Bareng and SD Negeri 2 Dadaprejo Malang City. The research was conducted in grade 5 (five) who were considered to have sufficient reasoning skills for the implementation of the research. The number of students who became the sample was 27 students consisting of 15 students at SD Negeri 3 Bareng as an experimental class and 12 students at SD Negeri 2 Dadaprejo as a control class.

Three forms of testing, documentation, and observation are dimensions of the method with which the data are collected in this study. Tests are used to measure the impact of improvement plan on the success of student learning, for example with test to describe process or performance quantitatively by gathering a factual data, such as Pretest (‘test before’) and Posttest (‘test after’) tests given to working and experimental group. There are 30 indicators used to assess that are developed by the researcher, but in Pre-Test and Post-Test there are only 24 data or points that are considered reliable and valid. Documentation: This is the way data referred to the process and outcomes of learning are recorded and kept (e.g. descriptions of the activities and materials used in the experiment). There was observation where qualitative information from the manner in which the students were engaging with the learning model and their enjoyment and engagement was gathered. There is also a questionnaire for observers to measure the level of effectiveness of the implementation of the STEAM integrated PjBL learning model to improve students’ learning outcomes.

The data in this study were analysed using the latest version of the Statistical Package for Social Sciences (SPSS) application. The validities, reliability, and homogeneities of the factors were investigated through Fisher's test. Normality tests are conducted and checked using Lilliefors test process. The data was also tested using Effect size and N-Gain analysis, including hypothesis testing with the t-test.

The normalised gain formula uses the following two calculation steps for the students' learning output improvement, with the interpretation criteria presented in Table 1:

$$\text{Normalised Gain (ng)} = \frac{posttest\ \ score\ -pretest\ \ score}{ideal\ \ score\ -pretest\ \ score}$$

Table 1
Normalised gain interpretation (ng) modified

Interpretation	Value
Decline	-1.00 ≤ng> 0.00
No increase	ng = 0.00
Low	0.00 <ng< 0.30
Keep	0.30≤ ng <0.70
Tall	0.70 ≤ng≤ 1.00

The criteria used for determining the effect size can be divided into several categories, each serving a specific purpose in evaluating the magnitude and significance of the effects, as presented in Table 2:

Table 2
Category: Effect size (es)

Category	Value
Small	es < 0.2
Keep	0.2 <es <0.8
Tall	es> 0.8

Before being used for research, the validity and reliability of the instrument must be tested first, so that it is proven valid and reliable as a tool to measure student learning outcomes. In this case, the instrument item is said to be valid if the significance value is less than 0.05 (sig<0.05), the instrument item is said to be invalid if the significance value is greater than 0.05 (sig>0.05). The results of the test for the validity of the indicator items are given as following:

Table 3
Results of the validity test

No	Value	Interpretation
1,2,4,5,6,8,9,10, 11,13,14,15,19	0.000	Valid
3,7,12,20	0.001	Valid
16	0.995	Not Valid
17	0.779	Not Valid
18	0.983	Not Valid

The validity test of the question items to be applied to students was found as shown in Table 3. There are 17 questions that have a significance value below 0.05 and are considered valid. Meanwhile, three questions had a significance value above 0.05 and were considered invalid. Referring to that, only 17 questions were applied to students to test students' abilities through the pretest and posttest. The questions were validated by learning instrument experts at the State University of Malang.

Tests, in themselves, are not reliable unless their reliability is high. A test must be reliable to be valid, but it can be reliable without always being valid. The reliability

of the indicators to measure the variables used was verified by the reliability test based on the cronbach alpha formula. Reliability data for the Cronbach alpha of an instrument is reliable at 0.60 and above. (Sugiyono, 2019). The following is a display of the results of the reliability test of the research instrument:

Table 4
Reliability statistics

Number of Items	Value
17	0.732

Table 4 shows that the reliability test for the research instrument exam questions yielded an r11 value of 0.732, which exceeds the acceptable threshold of 0.60 (0.732 > 0.60). This indicates that high reliability measures have been achieved. Additionally, the appraisal instrument for evaluating student learning outcomes (ECAs) in relation to teacher assessment reliability is reflected in the results found in Table 5.

Following the validity and reliability assessments for the 20 learning outcome questions, the researcher decided that 17 of these questions would be utilised in the final hypothesis test. The three questions that did not meet the dispersion criteria were excluded. Consequently, this research will focus on the following questions: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 19, and 20. Based on the validity and reliability testing results, these 17 items are regarded as having met a high standard and are considered suitable for measuring student learning outcomes.

RESULTS

The results of pretest and posttest of the experimental and control class are obtained that the achievement of the students is higher when is taught using STEAM integrated Project-Based Learning (PjBL) model. Research findings were indicated that the mean scores of students well in control and experimental groups were rising from their pretests to their posttest. The pre- and posrater and control class group were rated: Control group in the pre-post scores summations and test summary.

Table 5
Recapitulation of pretest and posstest scores

Indicator	Class			
	Experiment		Control	
	Pretest	Posstest	Pretest	Posstest
Total Value	825	1395	795	1195
Average	48,52	82,05	46,76	70,29

Referring to the table data, a clearer graphical picture of the results of the students' pretest and posttest can be produced. The following is a graph of the results of the student pretest and posttest research, as shown in Figure 3:

The findings indicated that the mean score of pretest and posttest in the experimental class has a higher value compared to the control class, as depicted by the graph above. The mean score of pretest in the eksperimental class was 48.52 and in the control group was 46.76. Experimental class average for posttest was 82.05 compared to 70.29 control class average.

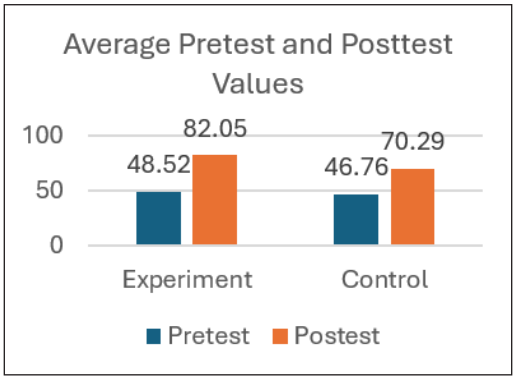

Figure 3. Average pretest and postest value

Refers to the results of student tests for the pretest and posttest in the experimental class that has rised significantly is shown that the STEAM integrated PjBL learning model can improve the students learning outcomes.

Normality Test

The data analysis required test is the test on the requirements or on the assumptions such as the normality test. But this is the thing that normalilty checks on data for the dealer should be done prior to of statistical distributions tests (i.e., regression analysis). Uniform data is good data. Kolmogorov-Smirnov test is as follows you obtain the sig and K-S where: significance If the significance (here Sig. of a test is higher than 0.05 the is normally distributed, if not implemented that has been assumed was not statistically normal. The results of the normality test are presented in Table 6.

The p-value is the same for Asymp product quality. Sig (2-tailed) is greater than 0.05 that is 0.078 as shown in SPSS output table. As shown based on the results of the normality test with Kolmogorov-Smirnov presented above, the data is normally distributed.

Table 6
Normality test

N	Asymp. Sig
27	0,078

Homogeneity Test

Homogeneity is then verified on normal distribution. The Fisher test provides a homogeneity test. The outcome of the data homogenous test calculation was presented in the attachment. If F(calculated) is smaller than F(table), then H0 is accepted, indicating that the data variance is homogeneous; if F(calculated) is greater than F(table), then H0 is rejected. The criterion of homogeneity employed to test the homogeneity of the data. Here are the outcome of the homogeneity testing of pretest and posttest:

Table 7
Results of homogenity test

Statistics	Pretest		Posttest	
	Experiment	Control	Experiment	Control
Fcal	3,46		3,61	
Table	4,23		4,23	
Conclusion	Homogeneous		Homogeneous	

Table 7 above shows the homogeneity test scores for pretest and posttest in the experimental and control classes. Fcal value for the pretest of experimental versus control group was 3.46, whereas the posttest Fcal of the experimental versus control was 3.61. As

it was observed that Fcal < Ftabel for all data from both classes we claim that the samples have equal variance and are homogeneus.

Hypothesis Test (t-Test)

The necessary test of data analysis was performed to think that the test results data of all the classes is homogeneous as well as uniform distribution with a period. Then data analysis is proceeded to the second step, namely, hypothesis testing, to decide if the influence exists or not. This hypothesis is analysed with t-test, as it follows: the Ho is accepted if the t count > t table as well as, it is rejected if t count < t table. The hypothesis test results for the experimental and control classes are presented in Table 8.

Table 8
Results of hypothesis test

T	Sig.
1.569	0.000

Table 8 indicates the hypothesis testing result, which is the value of test tcal > ttable = (1.569 > 0.684). So Ho is rejected, it states that the use of the PjBL model integrated with STEAM has a significant influence on student learning outcomes.

Coefficient of Determination (R^2)

The coefficient of determination, R^2, indicates the extent to which the independent variable (X) explains the variance in the dependent variable (Y). It represents the percentage of variance in Y that can be attributed to X. Thus, R^2 is useful for both making predictions and assessing the individual and combined effects of X on Y.

Table 9
Coefficient of determination

R	R Square	Adjusted R Square	Std. Error of the Estimate
.315	.291	.288	2.251

We know from above SPSS output Table 9 that the r square value is 0.291 and the r coefficient or determination r is 0.315. The value of coefficient of determination (R) include 31.5%. This diagram explains that partially there is the effect of learning model of integrated STEAM PjBL by 31.5% of the learning outcome of the fifth grader student's at Bareng 3 State Elementary School. In the meantime, the remainder of the variables (either not present in the regression equation or not modeled) have an impact on the other 100% - 31.5% = 68.5%.

Effect Size

The effect sizes are reported for the measurements in this study. There is also an effect size that allows us to estimate how one of our variables is predicting another variable. The effectiveness of the PjBL learning model with STEAM integration on student learning processes and outcomes can be determined by conducting testing with the effect size test. The effect size calculation in the present study yielded the following results, as presented in Table 10.

From the findings derived from these calculations, it is known that there is an impact on student learning outcomes that

Table 10
Effect size results

Class	N Gain	SD	Effect Size	Category
Experiment	82,0577	25,0011	0,3	Keep
Control	70,2905	22,9901		

can be cultivated by applying STEAM-integrated PjBL learning models. The number 0.3 listed in the table means that the contribution of such PjBL teaching material has weak but to a moderate influence on student learning outcome.

DISCUSSION

Recent studies have suggested that integrating STEAM into the Project-Base Learning (PBL) approach could enhance students' learning. It can also be used to develop critical thinking skills, collaboration, communication patterns, and student creativity in supporting the development of 21st century skills. The research in SDN Bareng and SDN Dadaprejo 2 has also showed that an approach of PjBL exercises at a PDISB can drive students to study curriculum material with interest, build the character, and drive student seriousness in the process of learning and teaching in schools. (Mardhatillah et al., 2019).

According to (Sari & Prasetyo, 2021) Based on the PjBL model, it may offer students the chance to learn actively and autonomously. This can improve critical thinking skills in students. The results or findings of this study are consistent with this statement by proving that the PjBL model integrated with STEAM can significantly improve the learning outcomes of students indicated by the improvement of the average score of 48.52 (before the treatment) to 82.05 (after the treatment) in the experimental group. HOT skills have a correlation with the enhancement of learning achievements based on (Chamisijatin et al., 2023). Research shows that students involved in project-based learning have complex problem-solving abilities. Furthermore, the integration of STEAM in project-based learning has been shown to positively influence various aspects of student disposition and knowledge, including attitude, confidence, and overall understanding of STEAM concepts (An, 2020).

This research shows that students' abilities have improved with the use of integrated STEAM PjBL to improve learning outcomes and 21st century skills. The research showed that the increase in student learning outcomes increased from 48.02 and increased to 82.05 after the implementation of PjBL integrated STEAM. This is in line with the results of previous relevant research. The results of the study showed that PjBL's integrated STEAM learning had an impact on improving students' skills in the components of science literacy, statistics, and students' ability to think critically. These results are also supported by student responses with improved learning outcomes and activities that become better (Oanh & Dang, 2025; Winarni et al., 2024)

Based on this context, research on the application of STEAM provides additional

diction in improving 21st century skills, especially in the focus of creative thinking skills and collaboration. (Rati et al., 2023) also stated that HOTS (Higher Order Thinking Skills) based teaching materials can improve student learning outcomes. The material is believed to be able to support the learning process with a project-based learning approach that focuses on developing high-level thinking skills in elementary school students (Hamzah et al., 2022; Purwati et al., 2024). Furthermore, project-based learning has been shown to improve overall student learning outcomes and scientific abilities by providing practical, hands-on experience, leading to more meaningful learning (Fitriani et al., 2023).

This approach enables students to develop essential problem-solving abilities and fosters engagement in authentic learning processes (An, 2020). This aligns with findings that emphasise the importance of active, inquiry-based learning environments for developing 21st-century skills such as critical thinking, creativity, and problem-solving (Huijser et al., 2015; Komala et al., 2020). This pedagogical framework, when implemented effectively, fosters a deeper understanding of scientific and mathematical concepts by integrating them with technological, engineering, and artistic elements (An, 2020; Chistyakov et al., 2023). Specifically, this integrated approach encourages students to engage in collaborative problem-solving, thereby enhancing their higher-order thinking skills and fostering a holistic understanding of complex subjects (Lu et al., 2021). This method allows students to develop practical skills that would otherwise be difficult to acquire, preparing them for real-world challenges (Jos Akkermans, 2018). This aligns with research demonstrating that project-based learning enhances cognitive and psychomotor skills, enabling students to apply knowledge in practical contexts and fostering critical thinking (Fitriani et al., 2023).

Based on various theories, the results of this study are considered relevant and in line with the theory of constructivism developed by Piaget. The research revealed that students can learn actively through exploration and interaction with their environment. The process of applying STEAM integrated with PjBL, Students will be active in the learning process and will not depend on information obtained passively so that students are directly and actively involved in the learning process. This allows students to build new understandings based on direct learning experiences. The process also has a link to Vygotsky's scaffolding theory, which emphasises that the teacher acts as a facilitator who provides temporary guidance. Students can gradually take control in learning independently. This aligns with the constructivist view that knowledge is actively constructed by learners through their engagement with the environment and collaboration with peers and instructors (Huijser et al., 2015). The PjBL model, particularly when integrated with STEAM, facilitates a learner-centred approach where students conduct research, synthesise theory and practice, and apply knowledge

to real-world scenarios (An, 2020). This pedagogical approach also aligns with Dewey's emphasis on experiential learning, where students learn by doing and reflecting on their experiences, thereby developing a deeper understanding of disciplinary content and strategic skills (Lu et al., 2021). This active engagement fosters a more profound understanding and retention of knowledge, contrasting with passive learning methods.

Moreover, the collaborative nature inherent in STEAM-integrated PjBL models, where students work in groups to solve challenging, open-ended problems, cultivates essential teamwork and communication skills (Jos Akkermans, 2018). This aligns with the notion that learning is an active, constructive process within a unique contextual environment, necessitating deeper awareness and ownership of ideas through collaborative engagement with practical problems (Schechter, 2011). Such approaches encourage students to explore and plan to learn activities, fostering curiosity and problem-solving abilities crucial for navigating complex real-world phenomena (Adriyawati et al., 2020; Lu et al., 2021). Furthermore, this framework encourages students to generate questions and actively participate in projects, thereby fostering a sense of ownership over their learning and promoting deeper engagement with the subject matter (Hidayat et al., 2024). This constructivist pedagogical approach, exemplified by Project-Based Learning, posits that knowledge is not passively received but actively constructed by learners through engagement with meaningful experiences and social interaction (Al-Kamzari & Alias, 2025; Boakye-Yiadom et al., 2024). Consequently, this paradigm emphasises student autonomy and the development of higher-order thinking skills through authentic problem-solving scenarios, rather than rote memorisation (Jensen et al., 2021). This further aligns with the concept of constructionism, where learners create tangible artifacts to demonstrate their understanding, thereby organising their learning and enhancing engagement (Balslev & Andersson, 2020). This pedagogical approach, by integrating problem-based learning and project-based learning with STEM and arts, promotes self-directed learning and fosters essential problem-solving skills, which are crucial for addressing complex, real-world issues (Schechter, 2011). This integrated approach is particularly effective in cultivating 21st-century skills, such as critical thinking, creativity, and collaboration, which are essential for navigating an increasingly complex global landscape (Mutanga, 2024; Velmurugan et al., 2023). Indeed, such pedagogical styles have been demonstrated to significantly enhance content knowledge retention, improve problem-solving capabilities, and strengthen critical thinking skills among learners (Mokoka et al., 2023). These approaches also boost self-efficacy and engagement in STEM subjects, concurrently increasing interest in pursuing STEM-related careers (Holgaard et al., 2023). This transformation from traditional pedagogical methods to constructivist frameworks like project-based learning and

flipped classrooms represents a significant shift towards student-centred learning that contextualises educational information and fosters solution development as a primary means of demonstrating understanding (Haase et al., 2023). This model challenges students to go beyond mere memorisation, fostering a deeper, more enduring comprehension of subjects (Mutanga, 2024). This shift towards active, experiential learning environments also significantly enhances learner self-efficacy and promotes a greater interest in STEM fields, directly addressing the need for a skilled future workforce (Geil et al., 2023; Napoleone et al., 2023; Otto et al., 2023). Moreover, these contemporary pedagogical strategies, including the integration of constructivist principles with technology, are crucial for preparing students for the challenges of the digital age by cultivating adaptable skills, interdisciplinary thinking, and lifelong learning habits (N, 2024). These approaches empower students to become proactive learners, capable of navigating complex information, and contributing innovative solutions to societal challenges (An, 2020; Otto et al., 2023). This includes developing robust teacher professional development programmes that equip educators with the necessary skills to integrate new technologies and foster a productive disposition in students, thereby empowering connected learners in a connected world (An, 2020). This paradigm shift necessitates a relational and transformative model of learning, moving beyond traditional academic skills to integrate essential learning dispositions, values, and attitudes necessary for the emerging networked society (Huijser et al., 2015).

This comprehensive framework emphasises the critical need for educational systems to evolve, incorporating strategies like inquiry-based learning and collaborative problem-solving to cultivate essential 21st-century skills (Adeoye et al., 2024). Such innovative pedagogies, including Project-based Learning and flipped classrooms, have demonstrated significant growth in student outcomes across mathematics and science courses compared to traditional instructional methods (Mokoka et al., 2023). Furthermore, project-based learning has been shown to improve student attitudes towards mathematics and enhance collaborative skills, while the flipped learning approach has garnered significant interest for its potential to engage both educators and students in the teaching and learning process (Rehman et al., 2024; Santhanasamy, 2022).

This study produces findings that show that learning outcomes with the STEAM-integrated PjBL model have improved well. The PjBL approach is not only relevant in the context of 21st century learning but also effective for improving student academic outcomes and achievements at various levels of formal education. Therefore, the integration of the PjBL model with STEAM can be considered as one of the innovative learning strategies to answer the challenges of education in the current and future digital era.

CONCLUSION

This study concludes that the STEAM-integrated Project-Based Learning (PjBL STEAM) model is considered effective for improving student learning outcomes in elementary schools. This study, which took the object of two elementary schools in Indonesia, was applied using the Quasi Experimental Design method and had good implementation results. The results showed that the application of the PjBL STEAM model could increase the average score of student learning outcomes from 48.52 to 82.05 in the experimental group. In addition, this STEAM PjBL model also contributes to the development of 21st century student skills, namely critical thinking, collaboration, and communication. The results of this study can be applied and extended to studies in other schools with the integration of PjBL and STEAM models and methods that can improve learning outcomes and foster students' higher order thinking skills among elementary schools.

This research has conducted hypothesis testing, effect size analysis, and the coefficient of determination. The test results concluded that the STEAM PjBL model has a moderate level of impact on improving student learning outcomes in elementary schools. The effectiveness of the PjBL model in this study increased by 31.5%. These results highlight the importance of implementing innovative learning models integrated with 21st century skills in education in primary schools. It aims to provide students with knowledge to better face global challenges in the future.

This research has implications for education in Indonesia and several countries that have pluralistic characteristics such as Indonesia. The concrete implications of research in elementary school learning are the implementation of models in various learning materials. PjBL's integrated STEAM learning can improve students' understanding of concepts and high-level thinking skills. Research can also be an evidence-based policy for the government in encouraging the implementation of innovative learning that is in line with the curriculum in Indonesia. This has the opportunity to improve students' ability to think critically and be relevant to the skills needed in the 21st century global workplace.

In general, this research may have limitations. The samples used are still on a narrow scale. Future research is expected to examine or examine more deeply the impact of PjBL STEAM in elementary schools and its influence in improving critical thinking, collaboration, and communication skills in students. Future research is also expected to have more diverse subject and object characteristics to justify specific educational problems and needs.

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