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Project-Based Learning on Science Process Skills and Learning Outcomes in High School Physics: A Quasi-Experimental Study on the Topic of Fluids

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ABSTRAK

Penelitian ini dilatarbelakangi oleh rendahnya keterampilan proses sains (KPS) dan hasil belajar siswa pada topik fluida di tingkat SMA. Tujuan utama penelitian ini adalah untuk mengkaji dampak penerapan model Pembelajaran Berbasis Proyek (PjBL) terhadap peningkatan KPS dan hasil belajar siswa. Jenis penelitian yang digunakan adalah quasi-eksperimen, dengan melibatkan dua kelompok, yaitu kelas eksperimen yang menerapkan PjBL dan kelas kontrol yang menggunakan metode pembelajaran langsung. Populasi penelitian adalah siswa SMA dengan sampel yang dipilih secara acak. Data dikumpulkan melalui tes objektif dan esai untuk mengukur KPS dan hasil belajar siswa, kemudian dianalisis menggunakan analisis statistik deskriptif dan Multivariate Analysis of Covariance (MANCOVA). Hasil penelitian menunjukkan bahwa penerapan PjBL memberikan dampak positif yang signifikan terhadap peningkatan KPS dan hasil belajar siswa dibandingkan dengan metode pembelajaran langsung. Simpulan dari penelitian ini adalah bahwa model PjBL merupakan pendekatan pedagogis yang efektif dalam meningkatkan keterampilan proses sains dan hasil belajar siswa pada topik fluida. Implikasi penelitian ini menunjukkan bahwa PjBL dapat menjadi strategi pembelajaran yang direkomendasikan untuk meningkatkan kualitas pendidikan sains di sekolah menengah atas.

ABSTRACT

This research was motivated by the low science process skills (KPS) and student learning outcomes on the topic of fluids at the high school level. The main purpose of this study is to examine the impact of the implementation of the Project-Based Learning (PjBL) model on improving PPP and student learning outcomes. The type of research used is quasi-experiment, involving two groups, namely an experimental class that applies PjBL and a control class that uses direct learning methods. The study population was high school students with a randomly selected sample. Data were collected through objective tests and essays to measure KPS and student learning outcomes, then analyzed using descriptive statistical analysis and Multivariate Analysis of Covariance (MANCOVA). The results show that the implementation of PjBL has a significant positive impact on improving PPP and student learning outcomes compared to direct learning methods. The conclusion of this study is that the PjBL model is an effective pedagogical approach in improving students' science process skills and learning outcomes on fluid topics. The implications of this study show that PjBL can be a recommended learning strategy to improve the quality of science education in high school.

1. INTRODUCTION

Science process skills (SPS) are crucial in high school physics education as they equip students to comprehend scientific concepts, apply them in real-world situations, and utilize scientific evidence for decision-making (Agustiani et al., 2022; Diana et al., 2019). SPS involves the capacity for critical analysis, effective problem-solving, and a deep comprehension of the natural world (Agustiani et al., 2022; Diana et al., 2019). However, student learning outcomes in physics, particularly in fluids, could be more satisfactory, indicating a need to enhance the quality of physics education (Agustiani et al., 2022; Diana et al., 2019). Research emphasizes the urgency of integrating SPS into physics instruction to improve students' learning experiences through a scientific approach (Agustiani et al., 2022; Diana et al., 2019). SPS not only assists

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students in gaining factual knowledge but also acts as a catalyst for the development of essential skills such as critical thinking, effective communication, collaborative abilities, and creative thinking (Darmaji et al., 2020; Hamidi et al., 2024). Therefore, the cultivation of SPS is crucial to equipping students with the necessary tools for effective learning, problem-solving, and personal growth (Darmaji et al., 2019; Maulidinah & Ekasari, 2023). In addition to SPS, student learning outcomes also require attention. The current learning outcomes of high school physics students require improvement, particularly in fluid dynamics (Agustiani et al., 2022; Diana et al., 2019). Research indicates that the correlation between interest, independent learning, and physics learning outcomes among students remains weak, highlighting the crucial role of teachers in fostering student engagement and commitment (Almasri, 2022; Bundick et al., 2014). Various innovative strategies have been proposed to enhance physics learning outcomes, including the utilization of contextual learning models, Android-based learning media, simulations as instructional ICT tools, cooperative learning models like Think Pair Share, and scaffolding-based worksheets within the discovery learning model (Agyei & Agyei, 2021; Ana et al., 2022; Hanifah et al., 2023; Nehe et al., 2023; Ntobuo et al., 2023). These findings underscore the importance of diverse pedagogical approaches and the utilization of technology to improve students' comprehension and performance in physics education. One learning model that has emerged as a potential solution to improve students' science process skills and overall physics performance among students is Project-Based Learning (PjBL).

Project-Based Learning (PjBL) is an educational approach that emphasizes students working on complex, realistic, and relevant projects. It involves students actively exploring real-world problems and challenges, often collaborating with their peers to investigate and find solutions. PBL focuses on students mastering key concepts and skills through hands-on, experiential learning rather than traditional lecture-based instruction (Chasani & Sari, 2023; Widyaningsih & Yusuf, 2020). This approach enhances student engagement and fosters critical thinking, problem-solving, and collaboration skills (Kolmos et al., 2021; Makkonen et al., 2021). In PBL, students are actively involved in the learning process, taking ownership of their education and developing a deeper understanding of the subject matter (Baharuddin et al., 2024; Fitriani et al., 2022). Students can apply theoretical knowledge to practical situations by working on projects, making learning more meaningful and impactful (Mulyani, 2020; Wickert et al., 2021).

PjBL has been proven effective in enhancing science process skills (SPS) and student learning outcomes. Research indicates that PjBL fosters the development of critical thinking, problem-solving, and collaboration skills through real-world projects (Subiyantoro, 2023; Wulandari & Nawangsari, 2024). Implementing PjBL has also been shown to increase student engagement, provide hands-on experience in science learning, and improve concept mastery and critical thinking skills (Darmawan, 2020; Parmiti et al., 2021). Moreover, PjBL is associated with an increase in creative and critical thinking skills in science and physics education (Hikmah et al., 2023; Zulyusri et al., 2023). PjBL also has a positive impact on physics learning outcomes. Research has demonstrated that PjBL significantly improves scientific learning outcomes across various educational levels, including high schools and physics (Google et al., 2023; Hidayah et al., 2024). This model is recognized for developing creativity, enhancing learning outcomes, and improving students' science process skills in physics learning (Radiansyah et al., 2022; Syukri et al., 2021). Furthermore, the effectiveness of PjBL in improving students' cognitive performance in physics has also been supported by research (Marlina & Wiyono, 2023; Paminto et al., 2023).

The characteristics of physics learning, which involve experimentation, observation, and problem-solving, are naturally aligned with the inquiry-based approach of PjBL (Bogador et al., 2024; Makkonen et al., 2021). The interactive and collaborative nature of PjBL enables students to explore real-world phenomena, apply theoretical concepts, and develop a deeper understanding of the subject matter, enhancing their scientific skills (Bogador et al., 2024; Makkonen et al., 2021). Furthermore, PjBL can foster a more engaging and effective learning environment, positively impacting students' attitudes, interests, and learning achievements in physics (Bilgin et al., 2015; Santyasa et al., 2020). The distinctive characteristics of PjBL, such as active participation, collaboration, and the creation of tangible artifacts, are also highly relevant to the practical and experimental nature of physics learning (Halmaida et al., 2020; Putri et al., 2023). Thus, PjBL represents a suitable model for involving students in meaningful and authentic physics learning experiences, ultimately improving their science process skills and physics learning outcomes. The characteristics of the fluid subject matter, which involve experimentation, observation, and problem-solving, are well-suited to the inquiry-based approach of PjBL. Through PjBL, students can actively participate, collaborate, and create tangible artifacts related to fluid concepts, enhancing their science process skills and understanding of physics. The novelty of this research lies in its focus on an in-depth analysis of the impact of implementing Project-Based Learning (PjBL) on science process skills (SPS) and student learning outcomes in high school physics, specifically on the topic of fluids, which is still rarely discussed in academic literature. This study aims to explore and explain how the application of PjBL can enhance science process skills and improve students' understanding of complex fluid concepts. By

identifying the differences in outcomes between the experimental group using PjBL and the control group using direct instruction methods, this research is expected to provide deeper insights into the effectiveness of project-based learning approaches in science education. The findings are expected to make a significant contribution to efforts to improve the quality of physics education and motivate teachers to adopt innovative pedagogical approaches in the classroom. Based on the aforementioned background, this research aims to investigate the impact of implementing the PjBL model on the enhancement of science process skills (SPS) and learning outcomes (LO) of high school students on the topic of fluids. Understanding the influence of PjBL on crucial aspects of physics learning is expected to contribute to improving education quality, particularly in physics at the high school level.

2. METHODS

The text describes the research methodology employed in the study. It states that the research utilized a quasi-experimental design, specifically a pre-test post-test non-equivalent control group design. The study population consisted of all 4 classes (134 students) of grade XI MIPA (Mathematics and Natural Sciences) at SMA Negeri 1 Pupuan. The sample was selected using simple random sampling, including 2 classes (72 students). The research adopted a quantitative approach, involving collecting three types of data from grade XI students on the topic of fluids: (1) students' science process skills measured through an essay test, and (2) students' learning outcomes evaluated through an objective test. The collected data was then analyzed using descriptive statistical analysis and MANCOVA (Multivariate Analysis of Covariance).

3. RESULT AND DISCUSSION

Results

Table 1 demonstrates an improvement in science process skills and learning outcomes for students after the intervention in both the experimental group (which implemented project-based learning) and the control group. However, the improvement was more significant in the experimental group. The average science process skills score increased from 10.39 to 22.36 in the experimental group, while it increased from 9.92 to 18.56 in the control group. A similar trend was observed in learning outcomes, with the experimental group's average rising from 7.22 to 16.61 and the control group's average increasing from 7.47 to 13.75. The larger standard deviation in the posttest indicates greater individual variation within both groups after the intervention.

Table 1. Description of Statistics, Skills, Science Processes, and Learning Outcomes

Variables	Statistics	Experimental class		Control Class	
		Pretest	Post-test	Pre-test	Posttest
Science process skills (SPS)	Mean	10.39	22.36	9.92	18.56
	SD	4.34	4.83	3.83	4.11
Learning outcomes (LO)	Mean	7.22	16.61	7.47	13.75
	SD	3.38	6.27	3.69	5.76

Before the MANCOVA analysis, prerequisite tests were conducted to ensure the validity of the results. Kolmogorov-Smirnov and Shapiro-Wilk normality tests confirmed the normal distribution of pretest and posttest data for both dependent variables ($p > 0.05$). Levene's homogeneity test indicated a similarity of variance between treatment groups for both variables ($p > 0.05$). Furthermore, Box's M test confirmed the homogeneity of the variance-covariance matrix between groups (Box's M = 1.291, F = 0.417, p = 0.741). The deviation test of linearity indicated that a linear regression model was appropriate to analyze the relationship between the pretest and posttest of science process skills (F = 1.803, p = 0.058). In addition, Pearson correlation analysis revealed a weak but significant positive relationship between science process skills and learning outcomes ($r = 0.585$, $p < 0.001$, $N = 36$). With all these assumptions met, the MANCOVA analysis can examine the effects of learning models on science process skills and learning outcomes.

Table 2. Summary of Multivariate Test Results

Effect	Value	F	Hypothesis df	Error df	Sig.
Pillai's Trace	.780	118.774[b]	2.000	67.000	0.000
Wilks' Lambda	.220	118.774[b]	2.000	67.000	0.000

Effect	Value	F	Hypothesis df	Error df	Sig.
Hotelling's Trace	3.545	118.774[b]	2.000	67.000	0.000
Roy's Largest Root	3.545	118.774[b]	2.000	67.000	0.000

Table 2 presents the results of the multivariate significance test to examine whether there is a significant difference between the two learning model groups overall in the combination of SPS and LO. All four statistics (Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root) gave consistent results, showing a highly significant difference between the two groups ($p < 0.001$). All four statistics indicate that the learning model significantly influences the combination of science process skills (SPS) and learning outcomes (LO) of physics students.

Table 3. Results of The Analysis of the Effect Test Between Subjects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	post_SPS	1277.770[a]	3	425.923	128.410	0.000
	post_LO	2229.061[b]	3	743.020	195.797	0.000
Intercept	post_SPS	740.137	1	740.137	223.141	0.000
	post_LO	2.964	1	2.964	0.781	0.380
pre_SPS	post_SPS	514.748	1	514.748	155.189	0.000
	post_LO	0.000	1	0.000	0.000	0.996
pre_LO	post_SPS	8.243	1	8.243	2.485	0.120
	post_LO	1366.286	1	1366.286	360.036	0.000
model	post_SPS	356.950	1	356.950	107.615	0.000
	post_LO	447.984	1	447.984	118.050	0.000
Error	post_SPS	225.550	68	3.317		
	post_LO	258.050	68	3.795		
Total	post_SPS	32795.000	72			
	post_LO	18448.000	72			
Corrected Total	post_SPS	1503.319	71			
	post_LO	2487.111	71			

Table 3 confirms that the observed differences in science process skills and learning outcomes are statistically significant. The analysis results highlight a notable difference in science process skills between students who engaged in project-based learning and those who received direct instruction ($F = 128.410$, $p < 0.05$). Similarly, the analysis reveals a significant difference in learning outcomes between the two groups, favoring the project-based learning approach ($F = 195.797$, $p < 0.05$).

Discussion

The results of this study indicate that there is a significant difference in science process skills (SPS) between students who learned using the PjBL and those who learned using the direct instruction model ($F = 128.410$, $p < 0.05$). This finding aligns with previous research that has demonstrated the superiority of PjBL in developing students' SPS through active involvement, real-world contexts, collaboration, and an inquiry-based approach (Anggrella & Sudrajat, 2024; Kause et al., 2022; Maharani & Yohandri, 2023; Minarni & Haryanto, 2023; Mufida et al., 2020; Novianto, 2023; Rusmini et al., 2021; Sembiring & Jahro, 2024; Setiyadi et al., 2024; Tuanany et al., 2023; Waluyo & Nuraini, 2021). PjBL has been the focus of extensive research about the development of science process skills (SPS). Various studies, including meta-analyses have shown the positive impact of PjBL on improving SPS (Sembiring & Jahro, 2024; Setiyadi et al., 2024). This study's results align with those studies, emphasizing the effectiveness of PjBL in enhancing students' thinking skills, which directly contributes to the improvement of SPS (Sembiring & Jahro, 2024; Setiyadi et al., 2024). Further research has shown that PjBL improves SPS in general and enhances creativity, critical thinking, and problem-solving skills (Kause et al., 2022; Minarni & Haryanto, 2023). Comparison of PjBL with conventional methods found that PjBL is more effective in improving SPS (Novianto, 2023; Rusmini et al., 2021).

Other studies also highlight the effectiveness of PjBL in enhancing SPS through various approaches. For instance, previous research demonstrated the positive impact of project-based e-learning with a STEAM approach, while similar research discussed the potential of project-based learning modules (Anggrella & Sudrajat, 2024; Mufida et al., 2020). Similar research provided further evidence of PjBL's effectiveness by demonstrating the validity, practicality, and usefulness of PjBL-based instructional design in improving

science literacy (Maharani & Yohandri, 2023; Waluyo & Nuraini, 2021). Comparative research by previous research also supports the superiority of PjBL in enhancing SPS compared to conventional models (Maharani & Yohandri, 2023; Tuanany et al., 2023). The effectiveness of electronic student worksheets based on PjBL in improving SPS. The available evidence suggests that PjBL is a promising approach to enhance SPS. Through engagement in real-world projects, collaboration, and problem-solving tasks, PjBL facilitates the development of critical thinking skills, creativity, conceptual understanding, and problem-solving abilities, all of which are essential components of SPS. These various studies provide further empirical evidence of the effectiveness of PjBL in improving students' SPS, particularly in the context of high school physics learning. Furthermore, by involving students in real-world projects and collaborative activities, PjBL not only deepens their understanding of physics concepts but also fosters essential skills such as creativity, communication, and collaboration (Angelina & Maryani, 2023; Maharani & Yohandri, 2023; Roslina et al., 2022). Evidence from various studies supports the effectiveness of PjBL in enhancing students' science process skills, particularly in the context of high school physics learning. By providing opportunities for students to learn directly, fostering collaboration and communication, and encouraging critical thinking and problem-solving, PjBL emerges as a powerful pedagogical approach to improve student's skills and understanding in physics education.

The text asserts that the current research results and previous relevant studies confirm that PjBL has a significant positive impact on students' SPS. This assertion is supported by consistent empirical evidence from various studies that demonstrate the superiority of PjBL in enhancing students' thinking skills, creativity, critical thinking, and problem-solving abilities. Through engagement in real-world projects, collaboration, and problem-solving tasks, PjBL facilitates the development of various essential components of SPS, such as conceptual understanding, data analysis skills, and the ability to design experiments. Thus, PjBL has proven to be an effective pedagogical approach in improving students' skills and understanding in science education, particularly in physics.

The results of this study reveal a significant difference in learning outcomes between students who learned using the project-based learning (PjBL) model and those who learned using the direct instruction model (MPL) ($F = 195.797$, $p < 0.05$). This research demonstrates that PjBL significantly positively impacts student learning outcomes compared to the direct instruction model (MPL). This finding aligns with previous research that has shown the superiority of PjBL in improving students' academic performance (Febriya et al., 2023; Pohan & Rambe, 2022; Tran & Nguyen Ngoc, 2023). Previous studies have highlighted various factors that contribute to the success of PjBL. Integrating PjBL with problem-solving skills and e-learning has been proven to improve the quality of learning and student learning outcomes (Twahirwa et al., 2021; Widyaningsih & Yusuf, 2020). Moreover, PjBL's emphasis on student autonomy and a stimulating learning environment also plays a crucial role in increasing student engagement and motivation, which ultimately has a positive impact on their learning outcomes (Makkonen et al., 2021; Tran & Nguyen Ngoc, 2023). The results of this study strengthen the existing evidence on the effectiveness of PjBL in improving student learning outcomes. The positive perception of teachers towards implementing PjBL and portfolio assessment in physics learning further emphasizes the potential of this approach. Thus, PjBL can be considered a promising learning model for enhancing students' overall learning outcomes.

The results of this study are consistent with previous research that has demonstrated the positive impact of student-centered pedagogical approaches, such as PjBL, on academic achievement. Factors such as student autonomy in the learning process, the development of problem-solving skills, and increased active student engagement in learning activities play a crucial role in the effectiveness of PjBL. Therefore, educators may consider integrating PjBL into their teaching practices to optimize student learning outcomes and facilitate deeper skills development. The text further elaborates on the positive impacts of PjBL on various learning outcomes. It highlights that PjBL not only improves cognitive and psychomotor learning outcomes, even in blended and online learning contexts, but also specifically enhances enthusiasm, critical thinking skills, and scientific performance in physics (Budiarto et al., 2024; Suryawati & Osman, 2018). Additionally, PjBL has been shown to improve cognitive and metacognitive learning outcomes effectively, as well as critical thinking, motivation, and creative thinking skills (Aska et al., 2022; Chasani & Sari, 2023). The text also cites previous research indicating that PjBL positively impacts various aspects of learning, including academic achievement, information literacy, collaboration, creativity, and student interest (Cioc et al., 2022; Muchsin & Mariati, 2020). It also highlights the adaptability of PjBL to diverse learning needs and its ability to enhance computational thinking, reasoning, and critical thinking skills (Saritepeci, 2020; Zhang et al., 2024). The successful implementation of PjBL across various disciplines, such as STEAM (Domenici, 2022; Lu et al., 2022). The text emphasizes the importance of design thinking and active learning techniques in creating meaningful learning experiences (Jia et al., 2023; Patil & Kamerikar, 2020). Furthermore, integrating immersive technologies like makerspaces further enriches project-based learning experiences (Enkin et al., 2021; Mills & Brown, 2022). PjBL has a significant positive

impact on student learning outcomes. It highlights that PjBL enhances academic achievement and fosters the development of various essential skills, such as information literacy, collaboration, creativity, critical thinking, and problem-solving. The flexibility and adaptability of PjBL make it an effective pedagogical approach to comprehensively improve students' learning outcomes. The findings of this study provide a significant contribution to understanding the effectiveness of Project-Based Learning (PjBL) in enhancing science process skills (SPS) and improving learning outcomes in high school physics, particularly on the topic of fluids. The research reveals that PjBL not only facilitates a deeper comprehension of complex fluid concepts but also promotes the development of essential SPS, such as observation, analysis, and experimentation. This study highlights the positive influence of PjBL in fostering active learning environments where students take a hands-on approach to their learning, leading to better retention and engagement.

The comparison between the experimental group using PjBL and the control group employing traditional direct instruction methods demonstrates that PjBL can lead to higher levels of student achievement and a more profound understanding of physics concepts. These findings underscore the need for innovative and student-centered approaches in science education, encouraging educators to integrate PjBL in the classroom. This study also suggests that PjBL can be an effective strategy to overcome challenges in teaching abstract and complex topics like fluid dynamics. A limitation of this research is that it only focuses on high school students and the topic of fluids. Future studies could explore the impact of PjBL across different levels of education and various scientific subjects. Additionally, research should include a more diverse sample to examine how factors like socioeconomic background and learning styles might influence the effectiveness of PjBL. Integrating interdisciplinary approaches, combining pedagogy with cognitive science, could also provide deeper insights into the benefits of PjBL for developing science skills.

4. CONCLUSION

The present study provides compelling evidence that PjBL substantially impacts science process skills (SPS) and student learning outcomes. The consistent empirical evidence from various studies underscores the efficacy of PjBL in enhancing students' thinking skills, creativity, critical thinking, and problem-solving abilities. The active engagement in real-world projects, collaborative learning experiences, and problem-solving tasks facilitated by PjBL foster the development of crucial components of SPS, including conceptual understanding, data analysis skills, and experimental design capabilities. The research findings highlight the effectiveness of PjBL as a pedagogical approach in improving students' skills and comprehension in science education, particularly within the context of high school physics.

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