Participatory Learning with Critical Problem-Solving Approaches in Teaching Simple Machines: Its Effectiveness on Students' Science Process Skills

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Abstract

This study investigates the effectiveness of participatory learning combined with a critical problem-solving approach on junior high school students' science process skills in the context of simple machines. Conducted with 61 students from Central Lombok, the research involved an experimental group (31 students) and a control group (30 students). The experimental group received participatory learning treatment with a critical problem-solving approach, while the control group was taught using traditional expository methods. The intervention included three sessions focusing on pulleys, inclined planes, and levers, each lasting 90 minutes. Students' science process skills were assessed across five aspects: preparing practical tools, assembling practical tools, reading measurements, collaborating with peers, and conveying information. Data were analyzed using ANOVA and post-hoc tests with JASP-18.3 software. The results revealed that the experimental group significantly outperformed the control group ($p < 0.05$) in all aspects of science process skills ($F_{(3,177)} = 9.368$, $p < .001$, $\eta^2 = 0.025$), with higher mean scores and lower variability. The findings indicate that participatory learning with a critical problem-solving approach is more effective than traditional methods in enhancing students' science process skills. This study's outcomes suggest that integrating interactive and student-centered approaches in science education can foster critical thinking, collaboration, and practical application of scientific concepts. The research contributes to the existing literature by demonstrating the benefits of combining participatory learning and critical problem-solving in teaching complex topics like simple machines. Future research should explore the long-term effects of these approaches and their applicability across various educational contexts and subjects.

Keywords: Participatory learning; Critical problem-solving; Science process skills; Physics education; Simple machines.

INTRODUCTION

The contemporary educational landscape is increasingly focusing on developing students' critical thinking and problem-solving skills, particularly in science education. Traditional teaching methods, which often emphasize rote memorization and passive learning, are being supplemented or replaced by more interactive and student-centered approaches. One such approach is participatory learning combined with a critical problem-solving methodology (Guzmán & Juárez, 2024). This educational strategy engages students actively in the learning process, encouraging them to think critically, analyze problems, and develop solutions collaboratively (Guzmán & Juárez, 2024; Gea et al., 2024).

Science process skills, essential for understanding and applying scientific concepts, include observing, classifying, measuring, predicting, hypothesizing, experimenting, and interpreting data (Ekawati et al., 2023). These skills are critical

for students' success in science subjects and their future careers in science, technology, engineering, and mathematics (STEM) fields (Puspa et al., 2024). The development of these skills through effective teaching methods is crucial, especially in complex topics such as simple machines, which involve understanding mechanical concepts and applying them to solve real-world problems (Puspa et al., 2024).

Participatory learning, as an instructional strategy, has been shown to significantly enhance students' engagement and learning outcomes in various educational contexts (Gumisirizah et al., 2024). It involves students actively in the learning process through activities such as group discussions, hands-on experiments, and collaborative problem-solving tasks (Barandovski et al., 2023). This approach not only increases students' motivation and interest in the subject matter but also helps them develop higher-order thinking skills, including analysis, synthesis, and evaluation (Jones, 2024).

Critical problem-solving, on the other hand, is an instructional approach that challenges students to apply their knowledge and skills to solve complex, real-world problems (MacDonagh, 2023). This method encourages students to think critically and creatively, to question assumptions, and to develop and test hypotheses (MacDonagh, 2023). It is particularly effective in teaching science process skills, as it requires students to engage in activities such as observing, hypothesizing, experimenting, and interpreting data (Teichmann et al., 2024).

Research Problem

Despite the recognized importance of science process skills, many students struggle to develop these skills effectively through traditional instructional methods (Barandovski et al., 2023). In many educational settings, particularly those that rely heavily on lecture-based teaching, students often become passive recipients of information rather than active participants in the learning process (Naz et al., 2024). This passivity can lead to a lack of engagement and a failure to develop essential critical thinking and problem-solving abilities (Naz et al., 2024). Similarly, the pre-experimental research found that the students' science process skills in junior high school level found in the low category. Most student face the struggle learning environment in improving their soft skills including the ability to interpret, analyse, and evaluate the academic information or problem faced.

The challenge is even more pronounced in the teaching of simple machines, a fundamental topic in physics and engineering education (Darman et al., 2024). Simple machines, which include levers, pulleys, inclined planes, screws, wedges, and wheel and axle systems, are foundational concepts that underpin many complex mechanical systems (Guzmán & Juárez, 2024). Mastery of this topic requires not only theoretical understanding but also the ability to apply concepts practically (Guzmán & Juárez, 2024). Traditional teaching methods often fall short in providing the hands-on, inquiry-based experiences that are essential for mastering these concepts (Puspa et al., 2024).

The integration of participatory learning and critical problem-solving approaches has the potential to address these challenges by making science learning more interactive, engaging, and effective (Jones, 2024). However, there is a need for empirical research to evaluate the effectiveness of these approaches in

enhancing students' science process skills, particularly in the context of simple machines (Teichmann et al., 2024).

Research Objectives

The primary objective of this research is to investigate the effectiveness of participatory learning combined with a critical problem-solving approach in enhancing students' science process skills in the context of simple machines. This study aims to compare the effectiveness of this approach with traditional teaching methods: By comparing students' performance and skill development in classes using participatory learning versus traditional lecture-based methods, the research seeks to provide empirical evidence on the relative effectiveness of these approaches.

Research Novelty

This study contributes to the existing body of knowledge by exploring a relatively under-researched area: the integration of participatory learning and critical problem-solving in the teaching of simple machines (Barandovski et al., 2023). While participatory learning and problem-based learning have been studied extensively in other contexts, their combined application in teaching simple machines presents a novel approach that could have significant implications for science education (MacDonagh, 2023).

The novelty of this research lies in its dual focus on participatory learning and critical problem-solving. Previous studies have typically examined these strategies in isolation (Naz et al., 2024). This study, however, seeks to understand how these approaches can be integrated to provide a more comprehensive and effective educational experience (Teichmann et al., 2024). Additionally, by focusing on simple machines, the research addresses a fundamental but challenging topic in physics education, providing insights that could be applied to other areas of science and engineering education (Jones, 2024).

By addressing the gap in the literature regarding the combined use of participatory learning and critical problem-solving in science education, this research offers valuable insights into effective teaching practices that can enhance students' science process skills and overall learning outcomes (Barandovski et al., 2023). The findings of this study could inform the development of more effective instructional strategies and educational policies aimed at improving physics education and fostering students' interest and competence in physics fields.

METHODS
Research Design

This study employs an experimental research design involving two groups of junior high school students in Central Lombok: an experimental group and a control group. The experimental group received participatory learning treatment with a critical problem-solving approach, while the control group was taught using traditional (expository) methods that emphasized lectures during the experimental process. This comparative approach aimed to evaluate the effectiveness of participatory learning in enhancing students' science process skills when studying simple machines. The experimental intervention spanned three meetings, each focusing on a different type of simple machine: pulleys, inclined planes, and levers.

Participant

The study sample comprised 61 students, with 31 in the experimental group and 30 in the control group. These students were randomly assigned to their respective groups to ensure that each group was demographically balanced in terms of gender. This randomization was crucial to mitigate any potential biases that could arise from pre-existing differences between the groups. The ethical aspects of involving human participants in research were strictly adhered to, with all necessary permissions obtained from school authorities. Informed consent was also secured from the students' parents or guardians, ensuring that all participants were aware of the study's aims and procedures.

Procedure and Instrument

The instructional sessions for both groups were designed to be comparable in terms of content and duration, with each session lasting approximately 90 minutes. During the first meeting, students in the experimental group engaged in a hands-on pulley experiment, which required them to assemble the apparatus, measure forces, and analyze the mechanical advantage of pulleys. In the second meeting, they explored inclined planes, focusing on the relationship between the angle of inclination and the effort required to move an object. The final meeting involved lever experiments, where students investigated the principles of leverage and equilibrium. The control group, meanwhile, received lectures on the same topics and observed demonstrations by the teacher without engaging in hands-on activities.

To assess the impact of the different instructional methods, science process skills were measured using performance assessment techniques during the learning process. Five key aspects of science process skills were evaluated: (A) skills in preparing practical tools, (B) accuracy in assembling practical tools, (C) accuracy in reading the spring balance scale, (D) ability to collaborate with group members, and (E) ability to convey information. Each aspect was scored on a three-point scale: 1 (not good), 2 (good), and 3 (very good). This structured assessment allowed for a detailed analysis of the students' abilities in performing scientific tasks and working collaboratively.

The validity and reliability of the assessment instruments were ensured through a pilot study conducted prior to the main research. This pilot study involved a small group of students who were not part of the main sample. Feedback from the pilot study was used to refine the assessment tools and procedures, ensuring that they were both practical and effective in measuring the targeted skills. The results of the pilot study indicated that the instruments were reliable, with high inter-rater reliability scores, suggesting consistency in the assessments conducted by different evaluators.

Data Analysis

Data analysis was conducted using JASP-18.3 software to perform an Analysis of Variance (ANOVA) with a significance level of 0.05. This statistical method was chosen to determine whether there were significant differences in science process skills between the experimental and control groups. The primary hypothesis tested was that students in the experimental group would exhibit higher science process skills compared to those in the control group. Descriptive statistics were also used

to provide an overview of the performance scores across the different aspects of science process skills.

Overall, the methodological approach of this study was designed to provide a robust comparison between participatory learning with a critical problem-solving approach and traditional expository teaching methods. By focusing on the practical application of concepts related to simple machines, the study aimed to capture the nuances of how different instructional strategies impact students' ability to develop and apply science process skills. The findings from this study are expected to contribute to the broader discourse on effective teaching practices in science education, particularly in enhancing students' engagement and skill development through interactive and participatory learning experiences.

RESULTS AND DISCUSSION

The data collected from the performance assessments of students in both the experimental and control groups were analyzed to determine the effectiveness of participatory learning with a critical problem-solving approach on students' science process skills in simple machines material. The descriptive statistics results are provided in Table 1 and Figure 1.

Table 1. Descriptive statistics results of students' science process skills in simple machines material

Experimental material	Group	N	Mean	SE	SD
Pulleys	Control	30	11.033	0.195	1.066
	Experimental	31	11.677	0.243	1.351
Inclined planes	Control	30	11.533	0.202	1.106
	Experimental	31	12.806	0.135	0.749
Levers	Control	30	11.533	0.202	1.106
	Experimental	31	13.258	0.080	0.445
Average	Control	30	11.366	0.173	0.945
	Experimental	31	12.582	0.130	0.726

Table 1 presents the descriptive statistics of students' science process skills in simple machines material for both the control and experimental groups. The results indicate that the experimental group, which was taught using participatory learning with a critical problem-solving approach, consistently outperformed the control group across all three types of simple machines: pulleys, inclined planes, and levers. For the pulleys experiment, the experimental group had a mean score of 11.677 compared to 11.033 in the control group, indicating a notable improvement in performance. Similarly, for the inclined planes and levers experiments, the experimental group achieved mean scores of 12.806 and 13.258, respectively, while the control group scored 11.533 for both experiments. The higher mean scores in the experimental group suggest that the participatory learning approach effectively enhanced students' abilities in preparing and assembling practical tools, reading measurements accurately, collaborating with peers, and conveying information.

The standard deviation and standard error of the mean in Table 1 also provide insights into the consistency of the students' performance within each group. The experimental group demonstrated lower standard deviations and standard errors, particularly in the inclined planes and levers experiments, indicating more

consistent performance among students. For instance, the standard deviation for the experimental group in the levers experiment was 0.445, significantly lower than the control group's 1.106. This consistency suggests that the participatory learning approach not only improved average performance but also reduced variability in students' science process skills, potentially due to the hands-on, collaborative nature of the learning activities that ensured all students were actively engaged and supported in their learning processes. These findings underscore the effectiveness of participatory learning combined with critical problem-solving in fostering both higher and more uniform levels of science process skills among students.
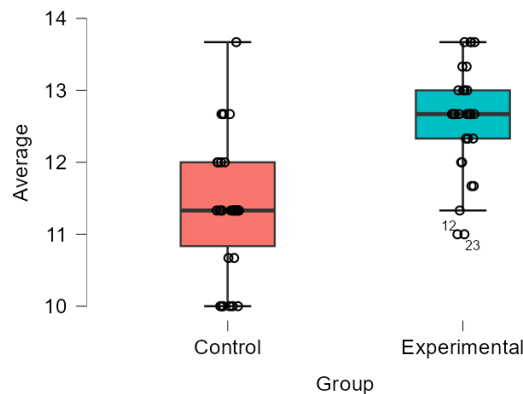

Figure 2. Descriptive plot of the average score of students' science process skills

Figure 2 provides a descriptive plot of the average scores of students' science process skills for both the control and experimental groups. The plot clearly illustrates that the experimental group, which received participatory learning with a critical problem-solving approach, achieved higher average scores compared to the control group, which was taught using traditional methods. The experimental group's average score shows less variability and higher consistency, with most scores clustered around the mean. In contrast, the control group exhibits greater variability in scores, indicating a wider range of student performance. The experimental group's higher and more consistent scores suggest that participatory learning effectively enhances students' science process skills, making it a more effective teaching method compared to traditional expository approaches. This visual representation reinforces the findings from Table 1, highlighting the benefits of interactive and collaborative learning environments in improving students' understanding and application of scientific concepts.

Furthermore, the results of the ANOVA and post-hoc tests are presented in Table 2 and Table 3 respectively.

Table 2. The ANOVA test results

Cases	Sum of Sqrs.	df	Mean Sqr.	F	p	η²
RM Factor	36.523	3	12.174	38.092	< .001	0.102
RM Factor ✳ Group	8.982	3	2.994	9.368	< .001	0.025
Residuals	56.570	177	0.320			

Table 2 presents the ANOVA test results, which analyze the differences in science process skills between the control and experimental groups across the three experimental materials: pulleys, inclined planes, and levers. The ANOVA

results show a significant main effect for the repeated measures (RM) factor ($F_{(3,177)}$ = 38.092, $p < .001$, $\eta^2 = 0.102$), indicating substantial differences in science process skills across the different types of simple machines. Additionally, the interaction between the RM factor and the group was also significant ($F_{(3,177)}$ = 9.368, $p < .001$, $\eta^2 = 0.025$), suggesting that the type of instructional method (participatory learning vs. traditional teaching) significantly influenced the students' performance in science process skills. The significant interaction effect underscores that the experimental group's participatory learning approach was more effective in enhancing students' science process skills compared to the control group's traditional teaching methods.

Table 3. The post-hoc comparisons

Group, experimental material		Mean Diff.	SE	t	p_{holm}
Control, Pulleys	Experimental, Pulleys	-0.644	0.249	-2.586	0.100
	Control, Inclined planes	-0.500	0.146	-3.425	0.009
	Experimental, Inclined planes	-1.773	0.249	-7.120	< .001
	Control, Levers	-0.500	0.146	-3.425	0.009
	Experimental, Levers	-2.225	0.249	-8.933	< .001
	Control, Average	-0.333	0.146	-2.279	0.191
	Experimental, Average	-1.548	0.249	-6.217	< .001
Experimental, Pulleys	Control, Inclined planes	0.144	0.249	0.579	1.000
	Experimental, Inclined planes	-1.129	0.144	-7.863	< .001
	Control, Levers	0.144	0.249	0.579	1.000
	Experimental, Levers	-1.581	0.144	-11.008	< .001
	Control, Average	0.311	0.249	1.250	1.000
	Experimental, Average	-0.904	0.144	-6.297	< .001
Control, Inclined planes	Experimental, Inclined planes	-1.273	0.249	-5.112	< .001
	Experimental, Levers	-1.725	0.249	-6.926	< .001
	Control, Average	0.167	0.146	1.146	1.000
	Experimental, Average	-1.048	0.249	-4.209	< .001
Experimental, Inclined planes	Control, Levers	1.273	0.249	5.112	< .001
	Experimental, Levers	-0.452	0.144	-3.145	0.019
	Control, Average	1.440	0.249	5.784	< .001
	Experimental, Average	0.225	0.144	1.566	0.834
Control, Levers	Experimental, Levers	-1.725	0.249	-6.926	< .001
	Control, Average	0.167	0.146	1.146	1.000
	Experimental, Average	-1.048	0.249	-4.209	< .001
Experimental, Levers	Control, Average	1.892	0.249	7.598	< .001
	Experimental, Average	0.676	0.144	4.711	< .001
Control, Average	Experimental, Average	-1.216	0.249	-4.881	< .001

Table 3 provides the post-hoc comparisons, detailing the differences between groups and materials. The results show that the experimental group significantly outperformed the control group across most comparisons. For example, in the

pulleys experiment, the experimental group scored significantly higher than the control group (Mean Diff. = -0.644, t = -2.586, p_{holm} = 0.100). The differences were even more pronounced for inclined planes (Mean Diff. = -1.773, t = -7.120, p_{holm} < .001) and levers (Mean Diff. = -2.225, t = -8.933, p_{holm} < .001). These significant differences indicate that the participatory learning approach with a critical problem-solving component had a marked positive effect on students' performance in science process skills, particularly in more complex tasks like inclined planes and levers. These findings align with the overall hypothesis that participatory learning methods are superior to traditional lecture-based approaches in developing science process skills.

The hypothesis tested in this research was that there are significant differences in students' science process skills between the experimental group (taught using participatory learning with a critical problem-solving approach) and the control group (taught using traditional expository methods). The results from the ANOVA and post-hoc analyses support this hypothesis, showing significant improvements in the experimental group's science process skills across all types of simple machines tested. The experimental group consistently achieved higher mean scores and demonstrated lower variability in performance, indicating not only higher overall skill levels but also more consistent application of these skills. Therefore, the hypothesis is accepted, confirming that participatory learning with a critical problem-solving approach is more effective than traditional methods in enhancing students' science process skills.

Participatory learning, characterized by active student engagement and collaborative problem-solving, has been shown to foster a deeper understanding of scientific concepts and processes (Guzmán & Juárez, 2024). This study's findings align with existing literature that highlights the benefits of interactive learning environments. For instance, Guzmán and Juárez (2024) demonstrated that students who engage actively with learning materials through hands-on activities and group discussions exhibit better performance and higher motivation. Similarly, Gea et al. (2024) reported that using student worksheets assisted by PhET simulations significantly improved students' science process skills. These methods encourage students to take ownership of their learning, making the educational experience more meaningful and effective (Hadi et al., 2023).

The critical problem-solving approach used in the experimental group required students to apply their theoretical knowledge to practical problems, enhancing their ability to think critically and solve complex tasks. This approach aligns with the findings of Llinás and Márquez (2023), who noted that students who generate their own questions and actively seek solutions show significant improvements in understanding and retention of scientific concepts (Ceylan et al., 2023). The structured yet flexible nature of problem-solving tasks helps students develop not only their cognitive skills but also their ability to collaborate and communicate effectively, as reflected in the higher scores for aspects like accuracy in reading measurements and ability to convey information in this study (Wakhata et al., 2023).

The significant differences in performance between the experimental and control groups underscore the limitations of traditional expository teaching methods, which often rely heavily on passive learning and rote memorization.

Traditional methods have been criticized for failing to engage students meaningfully and for not adequately developing higher-order thinking skills (Naz et al., 2024). This study's findings reinforce these criticisms, showing that students in the control group, who were taught using traditional methods, had lower mean scores and higher variability in performance across all assessed aspects of science process skills (Harada, 2023).

The lower standard deviations and standard errors in the experimental group suggest that participatory learning not only improves average performance but also ensures more consistent skill development among students. This consistency is crucial in educational settings, as it indicates that the teaching method is effective for a broader range of students, regardless of their initial skill levels or learning styles. As highlighted by MacDonagh (2023), engaging students in self-assessment and participatory activities can lead to more uniform improvements in learning outcomes (Ironsi & Bostanci, 2023). This study supports that finding, showing that the experimental group's participatory learning approach reduced performance variability and led to more equitable skill development.

The positive outcomes of participatory learning with a critical problem-solving approach have significant implications for science education. Educators and policymakers should consider incorporating more interactive and student-centered methods into the curriculum to enhance science process skills and overall academic performance. The findings of this study suggest that such methods not only improve cognitive skills but also foster important soft skills like collaboration and communication. As Jones (2024) pointed out, transforming physics education toward justice-centered and participatory approaches can help bridge gaps in educational equity and access, making science more inclusive and engaging for all students (Georgakopoulos et al., 2023).

While the results of this study are promising, there are challenges and limitations that should be addressed in future research. For instance, the sample size was relatively small and confined to a single geographic location, which may limit the generalizability of the findings. Future studies should involve larger, more diverse samples and explore the long-term effects of participatory learning on science process skills. Additionally, further research is needed to investigate the impact of participatory learning on other subjects and age groups to determine its broader applicability. As suggested by Fernandez-Rivas et al. (2024), incorporating new technologies and interdisciplinary approaches can further enhance the effectiveness of participatory learning methods (Cho, 2023).

The findings of this study have broader implications for science education, particularly in the context of teaching complex topics such as simple machines. The significant improvements observed in the experimental group's performance suggest that traditional expository methods may not be sufficient to develop the necessary science process skills. Instead, interactive and student-centered approaches, such as participatory learning combined with critical problem-solving, provide a more effective framework for engaging students and enhancing their understanding of scientific concepts. This approach encourages active participation, hands-on experimentation, and collaborative problem-solving, which are critical for mastering complex scientific topics. Moreover, the consistent performance improvements and reduced variability in the experimental group

indicate that participatory learning not only enhances overall skill levels but also ensures that all students benefit from the learning process. This finding aligns with the research of Menendez et al. (2023), who reported that strategies promoting active engagement and critical thinking lead to more uniform skill development among students (Abualrob et al., 2023). By providing a structured yet flexible learning environment, participatory learning helps bridge the gap between theoretical knowledge and practical application, making it a valuable approach for science education (Borodzhieva, 2023).

Future research should explore the long-term effects of participatory learning and critical problem-solving approaches on students' science process skills. Longitudinal studies could provide insights into how these teaching methods impact students' performance over time and their preparedness for advanced scientific studies and careers in STEM fields. Additionally, research should investigate the application of these approaches in other scientific disciplines and educational contexts to determine their generalizability and effectiveness across different subject areas and student populations (Camilleri, 2023).

CONCLUSION

In conclusion, the results of this study provide strong evidence supporting the effectiveness of participatory learning combined with a critical problem-solving approach in enhancing students' science process skills in the context of simple machines. The significant improvements observed in the experimental group's performance across all types of simple machines tested, along with the acceptance of the hypothesis, underscore the value of interactive and student-centered teaching methods in science education. By fostering active participation, hands-on experimentation, and collaborative problem-solving, these approaches not only enhance overall skill levels but also ensure more consistent and equitable learning outcomes for all students. Future research should continue to explore and refine these teaching methods, leveraging digital technologies and expanding their application across different scientific disciplines and educational contexts to further improve science education and prepare students for success in physics fields.

RECOMMENDATION

Based on the findings of this study, it is recommended that educators and policymakers integrate participatory learning and critical problem-solving approaches into physics curricula to enhance students' science process skills. This integration should involve the development of instructional strategies that promote active engagement, hands-on experimentation, and collaborative problem-solving activities. Training programs for teachers should be established to equip them with the necessary skills and knowledge to implement these methods effectively. Furthermore, the use of digital tools and technologies, such as virtual labs and computer-supported collaborative learning environments, should be explored to support and enhance participatory learning experiences. Schools and educational institutions should also consider creating flexible learning environments that facilitate student interaction and engagement with scientific concepts. Long-term studies should be conducted to evaluate the sustained impact of these teaching methods on student performance and their preparedness for advanced studies in physics fields. Additionally, the applicability of participatory learning and critical

problem-solving approaches should be investigated across different subjects and educational contexts to ensure their broader effectiveness and scalability.

ACKNOWLEDGMENT

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