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Implementation of a PBL Model Based on a Process Differentiation Approach to Improve High School Students' Problem-Solving Skills in the Topic of Static Fluids

Karimah Fajriani*, Lina Aviyanti, Winny Liliawati

Department of Physics Education, Faculty of Mathematics and Natural Sciences Education, Indonesia University of Education, Bandung, Indonesia
*e-mail: karimahfajriani21@gmail.com

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Abstract: Problem-solving skills are considered essential competencies in 21st-century physics education, yet many students experience difficulties in solving physics problems effectively. This study aimed to examine the effectiveness of applying a Problem-Based Learning (PBL) model integrated with a process differentiation approach in enhancing senior high school students' problem-solving skills on the topic of static fluids. The study employed a quantitative quasi-experimental design with a nonequivalent control group format. Participants consisted of 68 eleventh-grade students from a public senior high school in Bandung, divided into an experimental group and a control group. In the experimental class, process differentiation was implemented through varied learning activities tailored to students' learning-style characteristics. Data were gathered through essay-based tests designed to measure problem-solving skills and were analyzed using N-Gain and Mann–Whitney tests. The findings revealed that students in the experimental class showed greater improvement, with an average N-Gain score of 0.51, compared to 0.31 in the control class. In addition, the calculated Cohen's d value of 1.1 indicated a strong practical effect of the treatment. The results suggest that integrating process differentiation into the PBL model effectively improves students' problem-solving skills in learning about static fluids. The findings contribute to the growing body of evidence supporting the integration of differentiated instruction with Problem-Based Learning as an effective pedagogical approach for physics education.

Keywords: Learning Styles; Problem-Based Learning; Problem-Solving Skills; Process Differentiation; Static Fluid.

Introduction

In the 21st century, education systems are confronted with increasingly complex global demands that require students to master higher-order thinking skills. Among the competencies considered essential are the 4C skills: critical thinking and problem-solving, creativity and innovation, communication, and collaboration. These competencies are regarded as important provisions for younger generations in responding to the challenges of the Society 5.0 era [1]. Consequently, problem-solving ability is not only recognized as a global educational demand but has also become an important concern within national education systems.

To address these challenges, the Indonesian government introduced the Merdeka Curriculum to enhance educational quality by strengthening Higher Order Thinking Skills (HOTS). This curriculum gives teachers greater flexibility to organize learning activities according to students' characteristics and learning needs, while also promoting a graduate profile that emphasizes critical reasoning as one of its key dimensions [2]. This policy indicates that developing problem-solving competence is a strategic national priority.

Nevertheless, classroom realities show that many students still experience difficulties, especially when planning solution strategies and evaluating the results they obtain [3]. This condition is often associated with learning practices that remain teacher-centered and focus more on procedural completion rather than analytical reasoning [4]. Previous studies have also reported that senior high school students' problem-solving skills are generally still categorized as low or insufficient [5], [6].

The findings of a preliminary study conducted at a senior high school in Bandung further support this condition. The indicators of understanding the problem and describing the problem using physics concepts obtained the highest average scores, namely 57.76 and 53.88, respectively. In contrast, the achievement of other indicators remained relatively low, including planning solutions (31.61), executing solutions (11.49), and evaluating results, which had the lowest score at 8.62. These findings suggest that students still encounter difficulties in formulating strategies, implementing solutions, and reflecting on the outcomes. This condition may be related to limited variation and innovation in instructional learning models.

One instructional model considered relevant to overcome these challenges is Problem-Based Learning (PBL). This model emphasizes student-centered learning by engaging learners in authentic problem-solving situations, allowing them to construct knowledge actively [7], [8]. PBL has been shown to improve students' problem-solving skills and learning achievement compared with conventional teaching approaches [9], [4]. PBL also promotes students' critical thinking abilities in various physics topics, including energy, waves, and heat [10], [11].

In addition, the diversity of students' needs, interests, and learning styles should be considered to create more

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meaningful learning experiences. One approach that can accommodate these differences is differentiated instruction, which emphasizes adjusting learning based on students' readiness levels, learning profiles, as well as their interests and talents [12], [13], [14]. Within the Merdeka Curriculum, differentiated instruction promoted by the Ministry of Education, Culture, Research, and Technology (Kemendikbudristek) is intended to optimize learning through three principal strategies, namely content differentiation, process differentiation, and product differentiation. Content differentiation is achieved by modifying learning materials to meet students' needs. Process differentiation involves providing varied learning activities that match students' characteristics, while product differentiation focuses on adjusting the forms of learning outcomes based on students' abilities [15].

The implementation of differentiated instruction should also consider students' learning styles, since this can help them understand concepts through methods that are most suitable for their individual characteristics [15]. De Porter and Hernacki classify learning styles into three major categories: visual, auditory, and kinesthetic [16]. Visual learners tend to absorb information more effectively through seeing activities such as reading, observing, or viewing representations. Auditory learners generally learn better through listening activities, whereas kinesthetic learners understand concepts more effectively through movement, hands-on experiences, and physical interaction. Therefore, understanding the variety of learning styles enables teachers to design more effective and responsive instruction according to students' needs [17].

Based on data from the preliminary study, students demonstrated diverse learning style preferences. The largest proportion belonged to the Kinesthetic–Visual (KV) category at 29.03%, followed by Auditory–Visual (AV) at 25.81% and Kinesthetic–Auditory (KA) at 19.35%. Furthermore, 16.13% of students were categorized as Kinesthetic (K), 9.68% as Visual (V), while no students were identified in the Auditory (A) category. These data were collected through a learning-style assessment conducted using the AkuPintar.id application. The results indicate that most students tend to have blended learning styles, defined as combinations of two or more learning modalities. Students' learning preferences commonly involve more than one modality [18].

The variation in students' learning styles further highlights the importance of implementing differentiated instruction, particularly process differentiation, so that learning activities can be adjusted to students' characteristics. Several empirical studies have also confirmed the effectiveness of this approach in improving problem-solving skills. Problem-based differentiated learning has been reported to significantly enhance students' problem-solving abilities [19]. In addition, the application of differentiation in collaborative science and technology learning activities can increase both student engagement and problem-solving competence [20]. Likewise, adapting learning processes to students' learning styles has been shown to contribute positively to the development of critical thinking and problem-solving skills [21]. Previous studies have demonstrated that both Problem-Based Learning and differentiated instruction are effective in enhancing students' problem-solving abilities. However, most of these studies focused primarily on a single dominant learning style, such as visual, auditory, or kinesthetic. Research investigating the implementation of process differentiation based on combinations of learning styles within the PBL model, particularly in physics learning, remains limited. Therefore, this study aims to examine the effectiveness of implementing a process-differentiated Problem-Based Learning (PBL) model, based on combinations of students' learning styles, in improving senior high school students' problem-solving skills in learning static fluids. The implementation of this model is also expected to create a learning environment that is more responsive to students' individual abilities and learning style characteristics.

Research Methods

This study employed a quantitative research approach, which is intended to describe phenomena and test predetermined hypotheses [22]. The research design was a quasi-experimental nonequivalent control group design. The structure of this design is presented in Table 1.

Table 1. Research Design: Nonequivalent Control Group Design

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

The population of this research consisted of eleventh-grade students from a public senior high school in Bandung who had not previously studied the material on static fluids. The sample included two eleventh-grade classes from the same school. A non-probability sampling technique, namely purposive sampling, was used to select the participants. Sugiyono defines purposive sampling as a sampling technique based on specific considerations or criteria [22]. In total, 68 students participated in this study: 36 in the experimental class, who received instruction through a Problem-Based Learning (PBL) model integrated with a process differentiation approach, and 32 in the control class, who were taught using the PBL model only.

The learning process in the experimental class was conducted over three meetings, covering the main topics of static fluids: hydrostatic pressure, Pascal's principle, and Archimedes' Principle. Process differentiation was implemented through learning-style-based worksheets (LKPD) designed in accordance with the syntax of Problem-Based Learning (PBL) and the principles of process differentiation. In each meeting, students were provided with different types of LKPD based on combinations of learning styles, including Kinesthetic–Visual, Kinesthetic–Auditory, and Auditory–Visual.

The instrument used to measure students' problem-solving skills was an essay test administered before the treatment (pretest) and after the treatment (posttest). The test consisted of three main questions, each divided into five sub-questions developed according to the problem-solving indicators proposed by Heller et al. (1992, as cited in Rosidah) [23]. Prior to implementation, the instrument was evaluated for content validity, construct validity, reliability, and item difficulty. Content validity was assessed by five experts, yielding an Aiken's V coefficient of 0.87, indicating a high level of validity ($V > 0.8$). Construct validity was examined using the Rasch model. The results showed that among the 15 sub-items tested, seven met three fit criteria, five met two, and three met one. Overall, all sub-items were considered valid and appropriate for use.

The reliability analysis produced a person reliability value of 0.72, which was categorized as adequate, indicating satisfactory consistency in students' responses. The item reliability coefficient reached 0.97, classified as very good, reflecting high item quality. In addition, the Cronbach's Alpha (KR-20) coefficient was 0.77, which falls within the good range, indicating that the instrument was reliable for research purposes. Based on item difficulty, the instrument consisted of three very easy items, three easy items, six difficult items, and three very difficult items. This distribution suggests that the test items were sufficiently balanced and capable of measuring students' problem-solving skills across different ability levels.

Prior to the implementation of the treatment, both groups were given a validated instrument. The pretest was administered to measure students' initial problem-solving skills before the learning intervention began. During the treatment stage, the experimental class received instruction through a process-differentiated Problem-Based Learning (PBL) model for three meetings on static fluid material, whereas the control class was taught using the PBL model without differentiation. The pretest and posttest data were analyzed descriptively to determine the improvement in students' problem-solving scores using the Normalized Gain (N-Gain) formula. The interpretation of the N-Gain score refers to the criteria proposed by Hake [24]. The N-Gain criteria are presented in Table 2.

Table 2. N-Gain Scoring Criteria

N-Gain value	Category
$g \geq 0.7$	High
$0.7 > g \geq 0.3$	Moderate
$g < 0.3$	Low

In addition, a Mann–Whitney test was conducted in SPSS to examine whether a significant difference existed between students taught using the process-differentiated PBL model and those taught using the regular PBL model.

The data analysis was conducted through several stages. First, the N-Gain score was calculated to identify the level of improvement in students' problem-solving abilities. Next, prerequisite tests were performed, consisting of a normality test using Shapiro–Wilk and a homogeneity test using Levene's test. Because the data did not meet the assumptions of parametric analysis, the nonparametric Mann–Whitney test was selected. This test was initially applied to the pretest scores of both groups to determine the equivalence of their initial abilities. Subsequently, the Mann–Whitney test was conducted on the posttest scores to compare the final performance of the experimental and control groups. Lastly, an effect size analysis was performed to measure the magnitude of the treatment effect on students' problem-solving skills.

Prior to the study's implementation, permission to conduct the research was obtained from the school, and all research activities were carried out in accordance with applicable educational procedures and regulations.

Results and Discussion

Improving the Problem-Solving Skills of High School Students

The improvement of students' problem-solving skills has become a major concern in many educational studies, given the important role these skills play in addressing the demands of the 21st century. Problem solving is regarded as a fundamental learning process, particularly in science and mathematics [25]. A task categorized as problem solving generally involves challenges that cannot be completed solely through previously known procedures or routine methods possessed by the learner [26].

Teachers need to make optimal efforts to support the development of students' problem-solving abilities throughout the learning process [27]. These skills can be fostered through appropriate learning models, strategies, methods, approaches, and classroom techniques. In the present study, the improvement in students' problem-solving skills was assessed quantitatively using pretest and posttest scores, with overall N-Gain and N-Gain scores for each problem-solving indicator.

N-Gain Test

Data on students' problem-solving skills were collected through 15 essay-based test items. The scores obtained from the pretest and posttest were then analyzed using the N-Gain formula. This analysis was conducted to measure the extent of students' improvement in problem-solving ability by comparing their scores before and after the learning intervention. A summary of the N-Gain results for students' problem-solving skills is presented in Table 3.

Table 3. N-Gain Calculation Results

Class	N	Pretest	Posttest	Average N-Gain	Category
E	36	30.94	66.28	0.51	Moderate
C	32	25.35	48.52	0.31	Moderate

Table 2 shows that both the experimental and control classes improved their problem-solving skills after the learning intervention. However, the experimental class demonstrated greater improvement, achieving an average N-Gain score in the moderate category, exceeding the control class's gain. This finding indicates that implementing a Problem-Based Learning (PBL) model integrated with a process differentiation approach was more effective at improving students' problem-solving skills than using the conventional PBL model alone.

Among the 36 students in the experimental class and the 32 in the control class, differences in the level of improvement after the intervention are also evident in the distribution of N-Gain categories in each group, as presented in Table 4. Table 4 shows a clear difference in the distribution of N-Gain categories between the experimental and control classes. Most students in the experimental class improved to the moderate and high categories, whereas the control class was still dominated by students in the low category. This finding indicates that implementing a Problem-Based Learning (PBL) model integrated with a process differentiation approach was more effective at improving students' problem-solving skills than the conventional PBL model alone in learning about static fluids. The higher proportion of students achieving moderate and high improvement categories in the experimental class also suggests that learning activities designed based on students' combinations of learning styles supported them more effectively during the problem-solving process.

Table 4. Distribution of the N-Gain Category

Category N-Gain	Experiment (n=36)	%	Control (n=32)	%
High	7	19.4	1	3.1
Moderate	24	66.7	13	40.6
Low	5	13.9	18	56.3
Total	36	100%	32	100%

The results of this study are in agreement with previous relevant findings. Fadila [28] reported that the application of a differentiated Problem-Based Learning (PBL) model in vibration and wave topics improved students' learning outcomes, as indicated by an N-Gain score of 0.70, which is categorized as high. Similarly, Agustiana and Untarti [29] found that a process-differentiated PBL model effectively enhanced students' problem-solving abilities.

Improvement in Each Problem-Solving Ability Indicator in the Experimental Class

The improvement in students' problem-solving skills for each indicator was analyzed based on the pretest and posttest scores. The assessment instrument consisted of three open-ended questions, each divided into five sub-questions representing the indicators of problem-solving skills proposed by Heller et al. (1992), as cited in previous studies. These indicators include: (a) understanding the problem, (b) describing the problem using physics concepts, (c) planning solutions, (d) executing solutions, and (e) evaluating results. The summary of the average pretest, posttest, and N-Gain values for each indicator is presented in Figure 1.

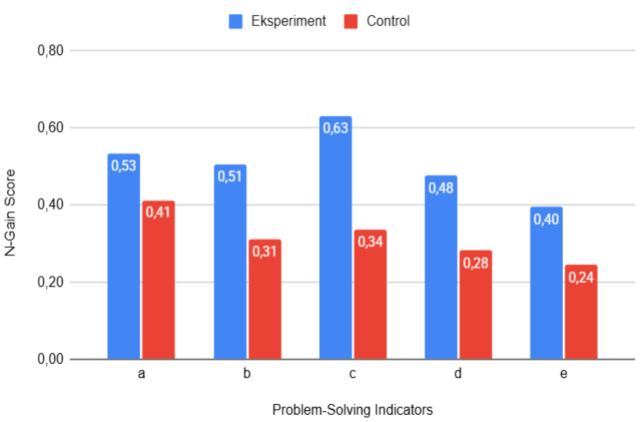

Figure 1. N-Gain Diagram for Each Problem-Solving Skill Indicator

Figure 1 shows that the experimental class consistently achieved higher N-Gain scores across all problem-solving indicators compared with the control class. The highest improvement in the experimental class was observed in the planning solutions indicator, while the lowest improvement occurred in the evaluating results indicator. A similar pattern was also found in the control class. These findings indicate that students were generally more capable of understanding problems and planning appropriate solution strategies than evaluating the correctness and effectiveness of the final answers.

The relatively low achievement on the "executing solutions" and "evaluating results" indicators suggests that students still had difficulty applying solution strategies systematically and critically reviewing the results obtained. In contrast, the higher improvement in the planning solutions indicator indicates that the implementation of the process-differentiated PBL model was able to support students in organizing and developing problem-solving strategies more effectively. Learning activities tailored to students' combinations of learning styles may have helped them engage more actively during discussions and problem-analysis activities. These findings are consistent with Walidain et al. [30], who reported that students in differentiated physics learning tended to demonstrate better performance in understanding problems, describing physics concepts, and planning solutions, while difficulties remained in executing and evaluating solutions. The higher improvement in the planning solutions indicator may be associated with the structured scaffolding and guided learning activities provided through process differentiation. Through differentiated learning activities, students were encouraged to analyse problems, organise information, and construct solution strategies more systematically, aligned with their learning characteristics. In addition, Singh et al [31] explained that the early stages of problem solving, such as conceptual analysis and solution planning, are generally easier to develop through active learning environments, whereas evaluating results requires more advanced metacognitive abilities, including reflection, monitoring, and self-regulation.

These findings are also supported by previous studies reporting that the stages of understanding problems and planning solutions tend to be easier for students, whereas executing solutions and evaluating outcomes are generally more complex and produce lower levels of achievement in problem-solving skills [32], [33], [34].

Improving Problem-Solving Skills Based on Learning Styles

Based on the diagram in Figure 2, students' problem-solving skills across all learning-style combinations showed moderate improvement across all indicators. This finding suggests that implementing a Problem-Based Learning (PBL) model integrated with process differentiation can support the development of students' problem-solving abilities in line with their learning style characteristics. These results are consistent with the study by Syarqia et al. [35], which reported that differentiated learning through the PBL model improved problem-solving skills across various learning styles within the moderate category. To obtain a more comprehensive understanding of these improvements, further analysis was conducted for each problem-solving ability indicator. The results of this analysis are presented in Figure 3.

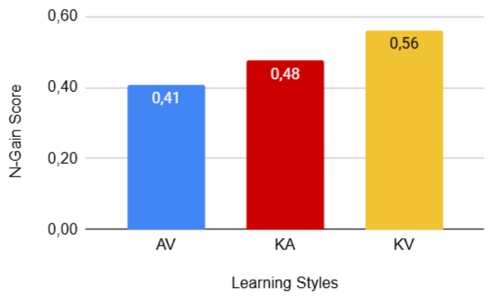

Figure 2. N-Gain Diagram Based on Learning Styles

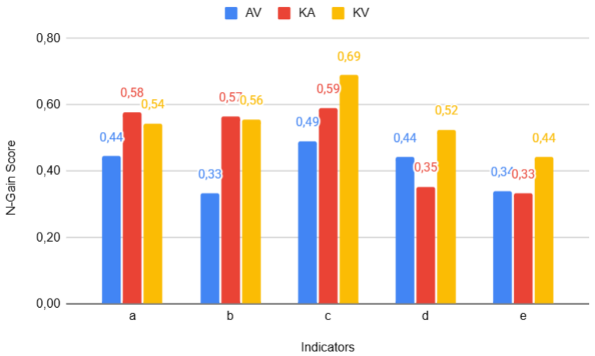

Figure 3. N-Gain Diagram: An Indicator of Problem-Solving Ability Based on Learning Styles

Figure 3 shows differences in the achievement of problem-solving skills among the various combinations of learning styles. Overall, students with the kinesthetic–visual (KV) combination demonstrated higher achievement across most indicators compared with the other groups, whereas the auditory–visual (AV) combination generally produced lower scores. The highest improvement among all groups was found in the planning solutions indicator, particularly in the KV group, while the lowest achievement was observed in the evaluating results indicator across all learning style combinations. These findings suggest that learning style combinations involving kinesthetic elements tend to provide stronger support for students during the problem-solving process than combinations dominated by auditory characteristics. Learning activities involving direct engagement, active participation, and visual representation may help students analyze problems and develop solution strategies more effectively. In contrast, the relatively lower achievement of the auditory–visual group indicates that hands-on learning experiences remain important for supporting students' understanding and problem-solving performance in physics. Therefore, students' problem-solving abilities appear to be influenced not only by a single learning style but also by the interaction among multiple learning style combinations [36], [37].

The Effectiveness of a Problem-Based Learning Model Based on a Process-Differentiation Approach on Students' Problem-Solving Skills

The effectiveness of the Problem-Based Learning (PBL) model, integrated with a process differentiation approach, in improving students' problem-solving skills was examined through several stages of data analysis, including statistical hypothesis testing and effect size estimation. Before conducting the main statistical analysis, prerequisite tests consisting of normality and homogeneity tests were first carried out to determine whether the data satisfied the assumptions required for further testing.

Normality Test

A normality test was conducted to assess whether the data were normally distributed, which informed the selection of the appropriate statistical procedure for hypothesis testing. When the data meet the assumption of normality, parametric tests can be applied; otherwise, non-parametric tests are more appropriate. In this study, normality testing was performed using IBM SPSS Statistics 27 software through the Shapiro–Wilk method. The results of the normality test are presented in Table 5.

Table 5. Results of the Normality Test

		Shapiro-Wilk		
		Statistic	df	Sig.
Problem-solving skills	Pretest (C)	0.915	32	0.015
	Posttest (C)	0.948	32	0.124
	Pretest (E)	0.977	36	0.638
	Posttest (E)	0.979	36	0.709

Table 5 shows that the pretest scores of the control class produced a significance value (Sig.) lower than 0.05, indicating that the data were not normally distributed. Since the normality assumption was not fully satisfied, further analysis was conducted using the non-parametric Mann–Whitney test.

Hypothesis Testing

Hypothesis testing was conducted to examine the equivalence of students' initial abilities before the treatment and to determine the effectiveness of the intervention, namely the process-differentiated Problem-Based Learning (PBL) model. The hypotheses formulated in this study were as follows.

H_0 = There is no difference in problem-solving ability between students who learn through the process-differentiation-based PBL model and those who learn through the PBL model without process differentiation on static fluid material.

H_a = There is a difference in problem-solving ability between students who learn through the process-differentiation-based PBL model and those who learn through the PBL model without process differentiation on static fluid material.

The hypothesis-testing procedure employed the nonparametric Mann–Whitney test in SPSS. The results of the pretest analysis are presented in Table 6.

Table 6. Results of the Mann-Whitney U Test on the Pretest

	Logit Scores for the Experimental and Control Groups
Mann-Whitney U	455.000
Wilcoxon W	983.000
Z	-1.491
Asymp. Sig. (2-tailed)	0.136

Table 6 shows that the Asymp. Sig. (2-tailed) value obtained from the Mann–Whitney U test was 0.136, which is greater than 0.05. Therefore, there was no significant difference in the initial problem-solving abilities of students in the experimental and control groups. This finding indicates that both groups had equivalent baseline abilities before the treatment was implemented. Following the completion of the intervention, a posttest was administered to measure students' final problem-solving performance. The results of the posttest analysis are presented in Table 7.

Table 7. Results of the Mann-Whitney U Test on the Posttest

	Logit Scores for the Experimental and Control Groups
Mann-Whitney U	252.500
Wilcoxon W	780.500
Z	-3.984
Asymp. Sig. (2-tailed)	< 0.001

Based on Table 7, the Asymp. Sig. (2-tailed) value obtained from the Mann–Whitney U test was < 0.001, which is lower than 0.05. Therefore, H_a was accepted, indicating a significant difference in students' problem-solving abilities between those who learned through the process-differentiation-based Problem-Based Learning (PBL) model and those who learned through the standard PBL model on static fluid material. This result suggests that implementing the PBL model, integrated with a process differentiation approach, made a meaningful contribution to improving learning outcomes, particularly students' problem-solving skills. To obtain a more detailed interpretation, further analysis was conducted for each problem-solving ability indicator. The results of this analysis are presented in Table 8.

Table 8. Results of the Mann-Whitney U Test on the Problem-Solving Ability Indicator

Problem-Solving Skills Indicator	Asymp. Sig. (2-tailed)	Interpretation
Understanding the problem	0.045	Significant Difference
Describing the problem using physics concepts	0.002	Significant Difference
Planning solutions	0.000	Significant Difference
Executing solutions	0.002	Significant Difference
Evaluating results	0.007	Significant Difference

Based on Table 8, all indicators of problem-solving ability obtained significance values below 0.05, indicating that there were significant differences between the experimental and control classes for every measured indicator. These results strengthen the evidence that the Problem-Based Learning (PBL) model, integrated with a process differentiation approach, had a positive effect on students' problem-solving skills, both overall and for each specific indicator. Moreover, this analysis highlights that the process-differentiation-based PBL model made a meaningful contribution to the development of students' problem-solving abilities in a more comprehensive and systematic manner.

Effect Size

After significant differences were identified between the experimental and control groups, the next stage of the analysis was to determine the magnitude of the effect of implementing the Process Differentiation-Based Problem-Based Learning (PBL) model. The Cohen's d value presented in Table 8 reflects the overall effect size of this instructional model on students' problem-solving skills. This coefficient describes the practical influence of the treatment, rather than only indicating statistical significance.

Table 9. Results of Cohen's d

Cohen's d	
$\dfrac{\bar{x}_t - \bar{x}_c}{s_{pooled}}$	1.1

Based on the analysis presented in Table 9, a Cohen's d value of 1.1 was obtained, which falls into the high category [38]. This indicates that implementing the Problem-Based Learning (PBL) model, integrated with a process differentiation approach, had a strong practical effect in improving students' problem-solving skills. In addition, effect size analysis using Cohen's d was also conducted for each indicator of problem-solving ability. The detailed results of these calculations are presented in Table 10.

Table 10. Cohen's d Values for the Problem-Solving Ability Indicator

Problem-Solving Skills Indicator	Cohen's d	Interpretation
Understanding the problem	0.49	Low
Describing the problem using physics concepts	0.88	High
Planning solutions	1.00	High
Executing solutions	0.75	Moderate
Evaluating results	0.63	Moderate

The analysis results presented in Table 10 indicate that the indicators of describing problems using physics concepts and planning solutions were categorized in the high effect size category. Meanwhile, the indicators of executing solutions and evaluating results were classified in the moderate category, whereas the understanding of the problem remained in the low category. These findings suggest that implementing a Problem-Based Learning (PBL) model integrated with a process differentiation approach had a substantial impact on students' problem-solving skills, particularly in conceptual understanding and solution planning.

These results are consistent with the findings of Lestari et al. [39], who employed problem-solving indicators based on Heller's framework and reported significant improvement in students' problem-solving abilities. In addition, Nursa'ada [13], using the Mann-Whitney test, obtained a p-value of 0.001, indicating that implementing this model significantly enhanced students' critical thinking skills. Similar conclusions were also reported by Agato et al. [40], who found that the application of differentiated learning strategies through the PBL model was highly effective in improving students' learning outcomes on the topic of work and energy.

Despite the positive findings, this study has several limitations. First, the sample size was relatively small and comprised students from only one senior high school, which may limit the generalizability of the findings. Second, the intervention was conducted in only three meetings, so the long-term effects of the process-differentiated PBL model on students' problem-solving skills could not be fully examined. Third, this study was limited to static fluids and focused on several combinations of learning styles, which may not capture all student characteristics. Therefore, future studies are recommended to involve larger, more diverse samples, use longer intervention periods, and examine the implementation of process differentiation in other physics topics and educational contexts.

Conclusion

This study demonstrated that implementing a Problem-Based Learning (PBL) model integrated with a process differentiation approach effectively improved senior high school students' problem-solving skills in static fluids. The effectiveness of the instructional model was reflected in the higher average N-Gain score achieved by the experimental class (0.51) compared with the control class (0.31), as well as in the Mann–Whitney test results, which indicated a significant difference between the two groups ($p < 0.05$). In addition, the obtained Cohen's d value of 1.1 showed that the treatment had a strong practical effect on students' problem-solving performance. Improvements were observed across all indicators of problem-solving skills, particularly in understanding problems, describing problems using physics concepts, and planning solutions, although lower achievement was still identified in executing and evaluating solutions. The findings also revealed that the process-differentiated PBL model was able to accommodate students' diverse learning styles, with students in the kinesthetic–visual category demonstrating the highest improvement. Overall, integrating process differentiation into the PBL model contributed to creating a more adaptive and student-centered learning environment while supporting the development of higher-order thinking and problem-solving skills in physics learning.

Author's Contribution

K. Fajriani: responsible for formulating the research concept and design, developing the research instruments, collecting and analyzing the data, and drafting the main manuscript. L. Aviyanti and W. Liliawati: contributed to supervising the research methodology, reviewing the scientific content, and editing and refining the manuscript. All authors were involved in discussing the results, drawing conclusions, and approving the final version of the manuscript for publication

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