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Improving Students' Critical Thinking Through Problem-Based Learning in Physics: A Quasi-Experimental Study at *SMA Negeri* 7 Surakarta

Jihan Fadhilasari, Daru Wahyuningsih
Physics Education Study Program, Faculty of Teacher Training and Education, Sebelas Maret University
Ir. Sutami Street No.36, Jebres, Surakarta, 57126, Indonesia
*Corresponding Author Email: *jihanfadhilasari@student.uns.ac.id* and *daruwahyuningsih@staff.uns.ac.id*

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Abstract. During the Industrial Revolution era, education faced the challenge of equipping students with 21st-century skills, one of which is the ability to think critically. The core of the problem raised is the low critical thinking ability of students and the development of effective learning models to develop them, especially in Physics learning. As a solution, research is carried out to explore the implementation of learning models, primarily Problem-Based Learning. The purpose of this research is to investigate the application of the Problem-Based Learning model on students' critical thinking skills, assess its effectiveness, and identify both the advantages and disadvantages of the learning model, particularly in dynamic fluid materials. The research was conducted at *SMA Negeri* 7 Surakarta using a quasi-experimental design involving two groups: an experimental class that implemented the Problem-Based Learning (PBL) model and a control class that employed conventional learning methods. The result of this study shows that the Problem-Based Learning model effectively improves students' critical thinking skills in dynamic fluid physics materials. This study also confirmed a significant rise in students' critical thinking skills after the application of the Problem-Based Learning model. In conclusion, the Problem-Based Learning model is an effective and pedagogically valuable strategy for enhancing students' critical thinking skills in Physics.

Keywords: Critical Thinking, Learning Model, Problem Based Learning, Physics, Dynamic Fluid

INTRODUCTION

Education is essentially an effort that is carried out with awareness and planning to create a learning situation and teaching with learning activities so that students can actively build the abilities contained in them, have the potential for religious faith, self-control, and the ability that they must have for themselves, the environment, and their country. One of the competencies written in the *Peraturan Menteri Pendidikan dan Kebudayaan Nomor 20 Tahun 2016* It is critical thinking skills. Critical thinking skills encompass the ability to trace a fact, expose and articulate thoughts, seek opinions, make comparisons, develop conclusions, weigh evidence, and solve problems. The purpose of critical thinking is to enhance and deepen students' understanding of the lessons they learn. Critical thinking skills can be continually developed because the human brain is constantly striving to make sense of its experiences.

The Program for International Student Assessment (PISA), conducted in 2018, ranked Indonesia 72nd out of 78 countries in terms of critical thinking skills. (Pratama, 2023). This incident arose due to problems in the teaching and learning process, which resulted in students in Indonesia having critical thinking skills below average, without exception, in science subjects. Science subjects are essential at all stages of education, from primary to secondary.

According to Johnson at Nantara (2021) Students can evaluate evidence, logic, conjectures, and language to assess the viewpoints of others through the systematic process of critical thinking. Everyone can learn to think critically because the human brain consistently tries to understand and gain understanding from its knowledge (Nantara, 2021). According to Adinda in Fauziah & Kuntoro (2022) A person who can think critically is someone who can draw conclusions based on their knowledge, understand how to approach a problem, and identify various appropriate information sources to support their understanding of the problem.

Analytical skills in science subjects, especially Physics, require students to continue being creative and skilled when thinking to devise a precise and accurate strategy to solve a problem (Widana, 2017) . Physics is one of the many sciences that has a significant role in technological progress. (Handriani et al., 2015) . Learning physics is a way for students to maximize their critical thinking skills, also solve problems in real life (Aripin et al., 2021).

So this is of interest to researchers, where special attention is needed for teachers in overcoming students' low critical thinking skills, and the need for a new design for teachers when choosing a learning model (Meilasari et al., 2020) . The learning model describes systematic steps to organize students' learning experiences to attain predetermined learning objectives, as well as function as a guideline for educators when planning and implementing learning activities (Siregar, 2021) . It is necessary to have a name, systematics of curriculum preparation, materials, how to manage student activities, guidelines for teachers, guidelines for learning settings, how to build a supportive learning environment, how to achieve expected goals, and how to evaluate it, which consists of measuring, assessing, and providing feedback (Asyafah, 2019).

Problem-Based Learning is a learning model that conveys directions for the participation of students to design understanding from the students themselves, develop advanced-level skills, exploratory skills in investigations, and increase self-confidence (Veronika Tiara et al., 2024) . Therefore, it is not just a concept that follows the problem that is used as the core of learning, but also the understanding of learning, the ability to use scientific methods in problem-solving activities, and giving rise to a critical thinking pattern (Fristadi & Bharata, 2015). Dynamic Fluid material is divided into several sub-materials, which contain fluid discharge, continuity principle, Torricelli's Principle, Bernoulli Principle on venturimeters, airplanes, pitot tubes, and viscosity. The material is taught to students who are studying in class XI (eleven), the second semester (Zai et al., 2020).

The aim of this experiment is to analyze the implementation of the Problem-Based Learning model to students' critical thinking skills in dynamic fluid materials. To find out the impact of the application of the Problem-Based Learning model on students' critical thinking skills. As well as knowing what the advantages and disadvantages of the application of the Problem-Based Learning model are to students' critical thinking skills in dynamic, fluid materials.

METHOD

The research employs quasi-experimental research methods, complemented by a quantitative approach. In this study, a control class was established; however, it did not fully function to provide control over external variables that could influence the experiment's implementation (Sugiyono, 2023). The research design that the researcher will employ in this study is the Nonequivalent Control Group Design (Sugiyono, 2023) . This design is nearly similar to the design og the pretest and posttest control group. The Nonequivalent Control Group Design is a research design comprising two groups: the experimental group and the control group. In this study, Class XI-A serves as the experimental class, receiving a Problem-Based Learning model. In contrast, Class XI-C serves as the control class, receiving a conventional learning model. The pretest is conducted to determine the initial level of ability of students before the treatment is implemented, both in the experimental class and the control class. In addition, the results of the pretest were used as a basis for comparison between the performance of the experimental class and the control class, both before and after the treatment was administered. The implementation of the pretest will take place on February 19, 2025, in the control class and on February 17, 2025, in the experimental class.

The instruments employed in this study include both test and non-test instruments. The test instrument applied in the study was a test of students' critical thinking skills. The test given is in the form of a description test consisting of 10 questions, including Dynamic Fluid questions. The description test is chosen so that students can provide answers to their problems using descriptions, explanations, and reasons, and discuss the questions based on their knowledge. Test questions were given during the pretest and posttest for two sample groups. Each question is made from indicators of critical thinking skills. Meanwhile, for the non-test instruments, they are in the form of interviews, questionnaires, and documentation. The questionnaire was conducted to gather information that supports the outcomes of the interviews conducted by the researchers. Documentation was carried out throughout the research to support its progress. Documentation is also carried out to provide evidence that the study has been conducted.

The research procedure is conducted in three stages: pre-experiment, experiment, also post-experiment. In the pre-experiment stage, the research sample was determined, and the pretest and questionnaire were provided. If the pretest result meets the prerequisite test in the form of normally and homogeneously distributed data, then the research can continue to the experimental stage. During the experimental stage, different learning models were applied to both research samples, with the experimental class receiving the Problem-Based Learning model. In contrast, the control class received the conventional learning model. After the treatment is completed, it is followed by a post-experiment in the form of a posttest and questionnaire. The data is then analyzed to prove the hypothesis and draw conclusions. This study hypothesizes that the critical thinking ability of students who employ the Problem-Based Learning model is higher than that of students who employ the conventional learning model.

RESULT AND DISCUSSION

This study is an experimental research that aims to ascertain the effectiveness of the Problem-Based Learning model on students' critical thinking skills in learning the physics of dynamic fluid materials. The primary competency being researched is the analysis of fluid principles in daily life and their applications in technology. The data from this study's results are test scores obtained from the pretest and posttest. This test is administered to students in both the experimental as well as control classes, with the same shape and number. The questions in the pretest and posttest consisted of 10 questions in the form of descriptions that measured critical thinking skills based on indicators prepared, including dynamic fluid materials such as discharge, the principle of continuity, and the principle of Bernoulli. These questions have been validated and arranged according to the critical thinking indicators, as outlined by Ennis, which include the ability to provide simple elaborations, build basic skills, draw conclusions, deliver more complex explanations, as well as design strategies and tactics. Because of this, the questions in this test are designed to gauge students' critical thinking skills as a whole. The following is a descriptive analysis of the pretest and posttest results data provided to students in the experimental and control classes.

Applications of the Problem-Based Learning Model to Students' Critical Thinking Skills in Dynamic Fluid Materials

This research is an experimental study that aims to ascertain the effectiveness of the Problem-Based Learning model in enhancing students' critical thinking skills when learning the physics of dynamic fluid materials. The primary competency being researched is the analysis of fluid principles in daily life and their applications in technology. The data from this study's results are test scores obtained from the pretest and posttest. This test is administered to students in both the experimental as well as control classes, with the same shape and number. The questions in the pretest and posttest consisted of 10 questions in the form of descriptions that measured critical thinking skills based on indicators prepared, including dynamic fluid materials such as discharge, the principle of continuity, and the principle of Bernoulli. These questions have been validated and arranged according to the critical thinking indicators, as outlined by Ennis, which include the ability to provide simple elaborations, build basic skills, draw conclusions, offer further explanations, and design strategies and tactics. Because of this, the questions in this test are designed to measure students' critical thinking skills as a whole. The following is a descriptive analysis of the pretest and posttest results data provided to students in the experimental and control classes.

The application of the Problem-Based Learning model in this study demonstrates a substantial contribution to improving students' critical thinking skills, particularly in dynamic and fluid materials. This is evidenced by the outcomes of a comparison between experimental classes that utilize the Problem-Based Learning model and control classes that employ conventional learning models, as measured by pretest and posttest scores. Quantitatively, students in the experimental class showed a sharper increase in scores, as well as a higher proportion of students reaching the high category. This difference suggests that the Problem-Based Learning model approach can effectively stimulate students' critical thinking skills, particularly in the context of scientific problem-solving, which requires analytical and evaluative skills.

The pretest outcomes obtained serve as the basis for comparing the effectiveness of the Problem-Based Learning model in the experimental class and the conventional model in the control class in enhancing students' critical thinking skills. The posttest in this study is conducted as the final stage, following the completion of the learning process in both the experimental and control classes. The purpose of the posttest is to assess students' knowledge of how they have improved their critical thinking skills after various learning treatments. The experimental class was taught with the Problem-Based Learning model, while the control class was taught with the conventional model. The posttest implementation was carried out on February 26th in the experimental class and on March 7th in the control class.

The outcomes of this posttest are used to provide insight into the extent to which students' critical thinking skills are improved after receiving different learning treatments in each class. The experimental class has adopted a Problem-Based Learning approach, while the control class follows the conventional learning model. The comparison of post-test results between the two classes is the primary basis for evaluating the effectiveness of each learning model in mastering dynamic fluid materials.

The Problem-Based Learning model begins with real, contextual problems, which force students to gather information, discuss, and find solutions based on their reasoning. In dynamic fluid materials, for example, students are faced with problems such as water flow in pipes, liquid pressure, and the application of Torricelli's theorem in daily life, which not only requires conceptual understanding but also a high level of critical thinking skills (Fristadi & Bharata, 2015)

Various previous studies also support the effectiveness of the Problem-Based Learning model in enhancing critical thinking skills. Windari & Yanti (2021) Found that the application of the Problem-Based Learning model in physics learning not only helps enhance analytical skills but also encourages students to formulate solutions based on information synthesis and argument evaluation. Meanwhile, Dewi (2020) In the context of economics lessons, it was also found that the Problem-Based Learning model encourages students to be more active, reflective, and participate in teaching and learning activities, which is a characteristic of critical thinking.

Furthermore, Agnesa & Rahmadana (2022) emphasized that the flexibility of Problem-Based Learning allows this model to be combined with various learning media and technologies, creating a more interactive and contextual learning environment. In this study, the context of dynamic fluids provides an opportunity to relate physics theories to real life, such as the drainage system or the application of the pressure principle in household appliances.

The Effect of the Application of the Problem-Based Learning Model on Students' Critical Thinking Skills in Dynamic Fluid Materials

The application of the Problem-Based Learning model demonstrated a substantial influence on improving students' critical thinking skills in relation to dynamic, fluid materials. Based on the outcomes of the descriptive statistical test, the experimental class that received the Problem-Based Learning model recorded an average posttest score of 9.23, which was higher than the control class, which received the conventional learning model with an average score of 8.67. The most considerable difference, 0.55583, although seemingly minor, has important implications in the context of science learning, such as physics, where conceptual understanding and critical thinking skills are essential.

The Problem-Based Learning model, which emphasizes solving real problems, directly trains students to think critically through problem identification, information exploration, and solution formulation. This is in accordance with the opinion of Zakiah & Lestari (2019) The Problem-Based Learning model is not only effective in transferring knowledge but also in honing the metacognitive dimension of students as a whole.

The validity of the result was strengthened by the Independent Samples Test, which yielded a significance value of 0.040, indicating that the difference between the experimental and control classes was not a mere coincidence. A t-value of 2.092 confirms the statistical significance of the difference. This suggests that the use of the Problem-Based Learning model makes a substantial contribution to the process of internalizing the concept of dynamic fluids. Given that this concept requires mathematical understanding, as well as the application of physical laws in a dynamic context, learning approaches that position students as active actors in the discovery and construction of knowledge, such as Problem-Based Learning, become highly relevant (Windari & Yanti, 2021).

Furthermore, when examined through the framework of critical thinking skill indicators, as outlined by Ennis, the positive impact of the Problem-Based Learning model is evident in all aspects of critical thinking skills. This model has been proven to enhance students' ability to provide simple explanations, formulate logical arguments, draw evidence-based conclusions, and design systematic problem-solving strategies. The problem-based learning model encourages students to examine issues in depth, think analytically, and evaluate arguments and solution choices. This result reflects the essence of critical thinking as explained by Ennis, namely, the ability to make reflective and rational judgments in the face of the complexity of problems, which is actual practice in the context of problem-based learning Zakiah & Lestari (2019).

The experimental class in this study is Class XI-A, comprising a total of 36 students. This class received treatment in the form of the application of the Problem-Based Learning model to the learning of dynamic fluid materials. The aim of this treatment is to help develop students' critical thinking skills through a contextual problem-solving approach.

The control class in this study is Class XI-C with a total of 36 students. This class is taught using a conventional learning model, rather than the Problem-Based Learning model employed in the experimental class. The traditional model is used as a standard treatment that is commonly employed in the learning process to determine the difference in effectiveness on students' critical thinking skills.

Table 1. Pretest scores for the experimental class

Range	Grade	Student
91–100	A	0
81–90	A-	6
71–80	B+	5
61–70	B	7
51–60	B-	1
41–50	C+	3
31–40	C	6
21–30	C-	5
11–20	D+	3
0–10	D	0

Based on the results of the pretest shown in Table 1, it is known that students in the experimental class on dynamic fluid materials show a fairly varied distribution. A total of 7 students received a score in the range of 61–70 with the predicate B, six students received a score in the range of 31–40 with the predicate C, and 81–90 with the predicate A-. Furthermore, each of the five students received a score in the range of 21–30 with a C-predicate and 71–80 with a B+ predicate. Scores in the range of 11–20 with the predicate D+ and 41–50 with the predicate C+ were obtained by three students each. Additionally, one student received a score in the range of 51–60 with a grade of B-, and there were no students who received a score in the range of 0–10 with a grade of D, nor in the range of 91–100 with a grade of A.

Table 2. Pretest scores for the control class

Range	Grade	Student
91–100	A	1
81–90	A-	3
71–80	B+	5
61–70	B	1
51–60	B-	3
41–50	C+	9
31–40	C	7
21–30	C-	0
11–20	D+	3
0–10	D	0

According to the pretest results shown in Table 2, students in the control class on dynamic fluid materials exhibited a fairly widespread distribution. Most of the students received scores in the range of 41–50, corresponding to a grade of C+, with nine students achieving this score. Additionally, seven students achieved a score range of 31–40, earning a C grade, and five students fell within the B+ range, with a score range of 71–80. A total of 3 students each obtained the A-predicate with a score range of 81 – 90, the B-predicate with a score range of 51 – 60, and the D+ predicate with a score range of 11-20. Meanwhile, the predicates A and B, with score ranges of 91–100 and 61–70, were obtained by one student each. There are no students who receive scores in the range of 0–10 with the grade of D.

The outcome of the pretest showed that both classes had relatively equal initial levels of critical thinking skills. Students in the experimental class were distributed in category C (61 – 70), while the control class tended to be distributed in category C+ (41 – 50). However, there were slight differences in the distribution of scores. The difference was not statistically significant, indicating that the improvement in posttest results was more attributable to the effectiveness of the learning model used, rather than to differences in students' initial abilities.

Table 3. Posttest scores for the experiment class

Range	Grade	Student
91–100	A	27
71–80	B+	3
61–70	B	3
51–60	B-	1
0–50	D–C+	0

From the posttest results shown in Table 3, it can be seen that the majority of students in the experimental class achieved scores in the range of 91–100, with the predicate A, which is 27 out of a total of 36 students. This demonstrates a substantial improvement in students' critical thinking skills following participation in learning using the Problem-Based Learning model. On the other hand, the number of students who got a score in the range of 51 – 60 with the predicate of B- was only one student, while three students in the score range of 61 – 70 with the predicate of B, as well as in the score range of 71 – 80 with the predicate of B+. No student scored less than 51.

Table 4. Posttest scores for the control class

Range	Grade	Student
91–100	A	16
81–90	A-	11
71–80	B+	5
61–70	B	4
51–60	B-	2
0–50	D–C+	0

From the test results shown in Table 4, it can be seen that the majority of students in the control class achieved scores in the range of 91–100, with the predicate A, which is 16 students. In addition, there were 11 students in the score range of 81–90 with the predicate A-, and five students in the score range of 71–80 with the predicate B+. Although most students managed to achieve the high score category, there were still four students with results below the range of 71, namely two students in category B with a score range of 61–70 and two students in category B- with a score range of 51–60. There were no students who scored less than 51.

Following the implementation of the Problem-Based Learning model, the experimental class showed a significant improvement in post-test results. It was recorded that as many as 27 students achieved a category A score (91–100), but none of the students received a score lower than category B. These results corroborate the results of Darwati & Purana (2021) Research indicates that Problem-Based Learning encourages students' cognitive activity through contextual explorations, thereby enhancing their overall critical thinking skills. Activities such as problem analysis, group discussions, as well as personal reflection in the Problem-Based Learning model have been shown to enhance students' mental involvement more intensively than conventional methods.

In contrast, the control classes, which follow the conventional learning model, also showed improvement, although not as significantly as the experimental classes. Only 16 students achieved A's, and there were still some students in the B and B– categories, indicating that while conventional learning models allow students to explore independently, this approach is less systematic in stimulating specific critical thinking skills.

In the early stages before implementing the Problem-Based Learning model, students' critical thinking skills in the experimental class are still at medium to low levels. In the pretest, the indicators with the highest total scores were "setting strategies and tactics," followed by "concluding" and "providing further explanations."Meanwhile, the indicators with the lowest scores were 'building basic skills' and 'providing simple explanations', indicating that before the implementation of the Problem-Based Learning model, students were still not sufficiently capable in the aspects of explaining and basic skills.

Following the application of the Problem-Based Learning model in the posttest, all indicators showed a substantial increase, as shown in the table above. 'Setting strategies and tactics' remains the highest scoring indicator, showing that the Problem-Based Learning model is successful in developing students' abilities when designing solutions and thinking strategically. The largest declines were also observed in the indicators of "providing simple explanations" and "building basic skills." Meanwhile, the indicator with the lowest posttest score is 'provide further explanation. Overall, these data confirm that the application of the Problem-Based Learning model is practical in enhancing students' critical thinking skills across all indicators, with the most notable improvements in fundamental aspects and conceptual explanations.

Meanwhile, in the control class with the conventional learning model during the pretest, the indicator with the highest score was 'setting strategies and tactics', followed by 'giving further explanations' and 'concluding'. Meanwhile, the lowest-scoring indicator was 'building basic skills', indicating that, before treatment, students' abilities in each aspect of basic skills were relatively weak. This highlights the limitations of traditional teaching methods, which focus solely on the verbal transfer of information without allowing for intellectual exploration. As stated by Agnesa &

Rahmadana (2022) Conventional approaches are practical in forming an initial understanding, but they do not sufficiently motivate the development of critical thinking skills, which require simultaneous engagement of emotions, cognition, and social interaction.

In the posttest, 'setting strategies and tactics' remains the highest indicator, reinforcing that this aspect has indeed been the main strength of students from the beginning. 'Concluding' also shows a significant improvement. Meanwhile, the indicator with the smallest increase is 'provide a simple explanation'. When compared to the experimental group, the improvement in the control group tended to be more moderate and less significant, indicating that the conventional learning model did not have the same impact on improving critical thinking skills as the Problem-Based Learning model.

Therefore, it can be concluded that Problem-Based Learning significantly enhances students' critical thinking skills in dynamic fluid learning. Not only does it demonstrate its effectiveness in improving learning outcomes statistically, but it also reveals a more profound pedagogical impact through the enhancement of each critical thinking indicator. This result reinforces the position of the Problem-Based Learning model as a learning approach that is not necessarily relevant, but is indispensable in the context of science education, which requires 21st-century skills such as problem-solving, critical thinking, as well as cooperation. Therefore, the integration of the Problem-Based Learning model in physics learning is not necessarily a methodological alternative, but a strategic need in preparing a generation that can think reflexively and act solutively in facing the complex challenges.

Advantages and Disadvantages of the Application of the Problem-Based Learning Model on Students' Critical Thinking Skills in Dynamic Fluid Materials

The dynamic fluid learning that took place at *SMA Negeri 7* Surakarta took place in a reasonably active and practice-based atmosphere. Teachers are accustomed to using website-based experimental and simulation approaches, such as PhET (Physics Education Technology) Colorado, to help students understand concepts in concrete terms. Practicum is an integral part of delivering this material because it allows students to interact directly with physical phenomena, such as Torricelli's theorem. The teacher assessed that the practical method was able to foster students' enthusiasm and active learning involvement through group discussions and direct observation.

The Problem-Based Learning model creates a substantial effect on the development of students' critical thinking skills. Based on the interview, students are invited to begin learning by exploring real-life experiences, which are then linked to relevant scientific theories and concepts. Students at *SMA Negeri 7* Surakarta felt helped in understanding dynamic fluid materials because they were invited to connect experimental variables with theoretical concepts, make observations, and write systematic analyses. Even students acknowledge that they are 'more informed because of the *practice,*' which reinforces the effectiveness of the active learning approach.

However, the Problem-Based Learning model also has shortcomings in its implementation. The teacher mentioned that this method takes longer because it requires group division, classroom conditioning, and complex activity management. This can be a challenge in a school system that has limited learning time in its classrooms. Additionally, students reported that they sometimes experience confusion when learning begins without sufficient theoretical explanations. A balance between free exploration and teacher guidance must be maintained to ensure the effective implementation of the Problem-Based Learning model.

CONCLUSION

The implementation of the Problem-Based Learning (PBL) model on dynamic fluid materials at SMA Negeri 7 Surakarta integrates hands-on activities, group discussions, and contextual problem analysis. This approach fosters an active learning environment that encourages students to analyze, evaluate, and apply dynamic, fluid concepts to real-life situations. Statistical analysis shows that PBL is significantly more effective than conventional learning, evidenced by the higher average score of the experimental class (9.23) compared to the control class (8.67). The interview results further support that students become more enthusiastic, gain a deeper conceptual understanding, and are better able to relate theory to practice. PBL offers several advantages, including increased student engagement, enhanced conceptual understanding, and the natural development of critical thinking skills through meaningful experiences. However, it also presents challenges such as longer time requirements, classroom management demands, and the need for sufficient student readiness to avoid confusion. Theoretically, this study strengthens evidence of PBL's effectiveness in developing critical thinking skills within the context of dynamic fluids. Practically, the findings offer guidance for physics teachers to employ PBL as an effective strategy for promoting active involvement and deep understanding. Teachers are encouraged to prepare problem scenarios, manage time effectively, assign student roles, and conduct comprehensive evaluations. Students, in turn, are expected to actively participate in discussions and problem-solving. Future researchers are advised to expand the scope to different materials or educational levels, consider additional variables, and explore other activity-based learning models that may further enhance critical thinking skills

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