Vol. 10, No. 2, 2024, pp. 769-778
DOI: https://doi.org/10.29210/020243846

Contents lists available at Journal IICET

JPPI (Jurnal Penelitian Pendidikan Indonesia)
ISSN: 2502-8103 (Print) ISSN: 2477-8524 (Electronic)

Journal homepage: https://jurnal.iicet.org/index.php/jppi

Exploring student learning outcomes in physics learning using a problem-based learning model with a differentiated learning approach

Jafriansen Damanik*), Novita Nabilla[2], Ridwan Abdullah Sani[2]
[1]Social Sience Education Department, Postgraduate Faculty, Universitas Indraprasta PGRI, Jakarta, Indonesia
[2]Physics Department, Universitas Negeri Medan, Medan, Indonesia

Article Info

Article history:

Received Mar 18th, 2024
Revised Jun 14th, 2024
Accepted Jun 21st, 2024

Keyword:

Problem-based learning model,
Differentiated learning approach,
Conventional learning,
Physics learning,
Student learning outcomes

ABSTRACT

The absence of structured teaching models and effective pedagogical approaches that are matched to the intricacies of the subject matter is frequently cited as the reason for low achievement levels in the field of physics education. This research aims to determine differences in student learning outcomes in physics learning by implementing a problem-based learning (PBL) model that uses a differentiation learning approach. This research is a type of experimental research in the form of Pre-Experimental Designs. The research design is One Group Pretest-Posttest Design. The participants in the research sample are 40 students from one class of XI PMIPA. The data analysis technique uses paired sample t-test. The results shows that there is a significant difference in physics learning results before and after PBL treatment with the differentiation learning approach. It can be stated that PBL with a differentiated learning approach has an effect on improving high school students' learning outcomes. The application of PBL with a differentiated learning approach makes students active, especially at the PBL stage, this is because it provides a real context for learning by introducing students to relevant and challenging physics problems. This makes learning more interesting and meaningful for students, because they can see direct applications of physics concepts in real-world situations.

Corresponding Author:

Jafriansen Damanik,
Universitas Indraprasta PGRI, Jakarta
Email: friansendamanik@gmail.com

Introduction

Research shows that students have difficulties learning Physics. For example, the research results by Azizah et al. (2015) indicated that Physics is a challenging subject for students and difficult to understand. Even students are inseparable from their difficulties in solving problems in learning physics. The difficulty of learning physics for students lies in several factors, among others, the lack of students' ability to understand mathematics as the language of physics (Wangchuk et al., 2023). This difficulty arises because physics involves multiple representations and concepts requiring mathematical comprehension (Ma, 2023). Additionally, the teaching methods used in schools may be less varied and innovative, further contributing to the students' struggles in understanding physics (Candido et al., 2023). To address these difficulties, teachers must enhance their ability to diagnose physics learning difficulties and improve their subject-teaching skills (Halmuniati et al., 2022). Furthermore, students can seek support and assistance, regulate negative emotions, and adopt effective learning

JPPI (Jurnal Penelitian Pendidikan Indonesia)
Vol. 10, No. 2, 2024, pp. 769-778

styles as coping mechanisms (Qotrunnada, 2022). By addressing these factors and implementing appropriate instructional support, students can overcome their difficulties in learning physics.

A study by Rivani et al. (2022) shows that students interested in physics will generally find it easy to understand physics lessons because the scientific attitude possessed by students can be said to be good, so fun and interest in learning physics emerge. This is because the learning process causes a direct relationship between the teacher and students, whose direction is to achieve a learning goal with the hope that students understand the material presented (Kurniawati, 2022). In line with that, the research results suggest that addressing students' leisure interests in physics classes can promote their situational interest and reduce their behavioral disengagement in physics (Brakhage et al., 2023). Additionally, using teacher-made video lessons in physics education is highly acceptable and positively influences students' performance and engagement (Tomkelski et al., 2022). Furthermore, the development of inquiry tasks in physics teaching has enhanced teachers' professional learning and promoted successful learning situations (Fauzan et al., 2022).

Moreover, the use of physics e-books with augmented reality in problem-based learning has been found to be effective in increasing student interest and engagement in physics (Basmayor, 2022). Therefore, it can be inferred that students with interest generally find it easier to understand physics lessons when their leisure interests are addressed, teacher-made video lessons are utilized, inquiry tasks are incorporated, and augmented reality is integrated into learning materials. Several problems in learning are caused by the teacher conveying the material without understanding the learning styles of their students during the learning process. There is a significant positive relationship between learning styles and physics learning outcomes (Asmar et al., 2023; Fatmawati et al., 2022; Karuru & Yulianti, 2023). Students at SMA Negeri 2 Kabanjahe also experience difficulties in learning physics. Meanwhile, school physics teachers do not yet know students' learning preferences. Based on observations made to students in class XI PMIPA 1, the results show diverse learning styles, so students' abilities to understand lesson material tend to vary. Hence, it is necessary to develop a strategy in order to be able to deal with real problems in the implementation of learning physics. Where the strategy is the steps used to achieve the goal, the strategy that can be applied is a learning model that can create student involvement and foster problem-solving abilities. Increasing this ability needs to be done, especially in learning physics, because studying physics means that students must be able to solve problems and evaluate how the event happened.

Currently, students are expected to be able to think critically and creatively in implementing learning. This is because students who have high critical thinking skills have knowledge and maturity in solving a problem (Tanty et al., 2022). Contemporary education aims to raise inquisitive individuals who can think critically and analytically, question and prove arguments, and build causal relationships between subjects (Sarigoz, 2023). The changing requirements of the 21st century, the ability to think critically and creatively, have led to a shift in the nature and functions of knowledge (Zheldibayeva, R. S., & Rimantas, 2023). Thinking critically is considered one of the high-level abilities in the 21st century that students need to be trained in through learning activities (Sudartik et al., 2023). Research has shown that students' critical thinking skills can be measured and evaluated and that these skills are a priority in education outcomes (Tengku, 2022). Physics subjects are often difficult for students, but there are ways to improve problem-solving skills in physics learning. Relevant learning models and media, such as Problem-Based Learning (PBL), PjBL, inquiry, and Discovery Learning, have been shown to be effective in improving problem-solving abilities (Qotrunnada, 2022). Props and practical mediums, like the Internet of Things (IoT), can make it easier for students to understand physics concepts, such as free-fall motion (Fauzan et al., 2022). Students may face difficulties solving physics problems with multiple representations, but using the "what is another way" method can help overcome these challenges (Jannah et al., 2023).

According to research results by Adawiyah et al. (2022), the learning model that can improve students' critical thinking skills is a Problem-Based Learning (PBL) model. Lespita et al. (2023) also claimed that the PBL model could improve physics students' high-order thinking skills (HOTS). The PBL model is effective for students. Applying the PBL model can improve students' critical thinking skills based on cooperation and the active role of teachers and students in achieving learning goals. PBL involves using student worksheets (LKS) that are designed to promote critical thinking skills (Safarati & Zuhra, 2023). Other studies also indicated that PBL positively impacts students' critical thinking skills (Azura & Selaras, 2023; Sartika et al., 2023). PBL in biology learning has been found to facilitate active student involvement, collaboration, and critical problem-solving (Marlina & Wiyono, 2023). It shows that PBL is an essential factor in improving students' critical skills in various subjects, including physics. Therefore, applying the PBL model can enhance students' critical thinking by providing engaging and interactive learning experiences.

The PBL model is a model that can bring up aspects of students' creative thinking skills because it creates new ideas or ideas for students (Elizabeth & Sigahitong, 2018). Suci et al. (2022) demonstrated that the PBL model can be used to improve students' abilities because it gives students real problems related to everyday life that require them to think critically to find solutions to problems. One of the uses of effective learning is a PBL model because, with it, students can be brought to collaborate in solving problems, so this learning provides an opportunity for students to hone their creative thinking skills (Handayani & Koeswanti, 2021). The PBL model positively impacts student learning outcomes and literacy skills. It can also improve students' learning outcomes in biology subjects (Azura & Selaras, 2023). The PBL model has been found to be effective in increasing students' environmental literacy skills in elementary science lessons (Ilma & Wulandari, 2023). Furthermore, applying the PBL model in physics learning has increased learning outcomes for high school students (Nurmahasih & Jumadi, 2023). Overall, the PBL model encourages active student participation, cooperation, and problem-solving, improving learning outcomes and critical thinking skills in various subjects.

Additonally, in the PBL model, students are encouraged to ask and answer questions to be active during learning, affecting their problem-solving skills (Wilujeng & Suliyanah, 2022). It can be seen that the PBL model is a learning model that can develop students' abilities. In addition to implementing learning models, it is necessary to apply other strategies that can increase student learning outcomes even though they have a variety of learning styles. The strategy that needs to be applied is the learning approach. The learning approach needs to be applied because the approach is our perspective on the learning process and the first step in forming an idea in an object of study that will determine the direction of implementing the idea. In learning, applying a differentiated approach can improve student learning outcomes (Wahyuni, 2022). Differentiation in teaching is a way of thinking about the classroom to maximize each student's capacity by assigning them to suitable groups. It focuses on each student's needs, abilities, and skills, allowing them to choose what and how they learn. Differentiation involves setting learning goals, connecting experiences to the learning process, and monitoring and analyzing achievements. It is based on meeting learners' diverse needs and exposing their unique capabilities and skills. Differentiated learning is a process or philosophy for effective teaching that provides a variety of ways for students to understand new information and learn effectively in a diverse classroom community. It accommodates all differences in students and provides the needs needed by each individual (Dapa & Undap, 2023; Daulay, 2023; Kancheli & Tchokhonelidze, 2023).

Differentiated learning approaches contribute to student success, active involvement, increased class awareness, and motivation (Demir, 2021). Differentiated learning aims to coordinate learning to focus on students' interests in learning, readiness, and preferences (Faiz et al., 2022). Based on the research results of (Wahyuni, 2022), a differentiated approach is able to accommodate students' learning needs by taking into account students' interests, profiles, learning styles, and learning readiness. Every student has the right to have the opportunity to learn in the way they want, so a teacher must ensure this is achieved (Wulandari, 2022). Several previous researchers have shown positive results from applying a differentiated learning approach, such as that differentiated learning can improve student learning outcomes and can be applied in all learning by accommodating student learning needs (Safarati & Zuhra, 2023). Teachers will know that students perform well by applying a differentiated learning approach. Differentiated learning can improve student learning outcomes by accommodating their diverse needs and characteristics (Jayantika & Santhika, 2023; Marantika et al., 2023). By differentiating the teaching approach to content and process, student learning outcomes in subjects like mathematics can be improved (Timbola & Odja, 2023). Implementing differentiated learning requires teachers to design learning activities that accommodate differences in student characteristics and backgrounds. Differentiated learning tools have been developed and found valid, practical, and effective in improving student learning outcomes. Overall, differentiated learning is a valuable approach that can be applied in all subjects to meet the diverse learning needs of students and enhance their learning outcomes.

The research gap at SMAN 2 Kabanjahe is due to the lack of a well-defined learning model and specialized teaching methodologies in the field of Physics. The deficiency is apparent in the insufficient attention given to students' learning preferences, which leads to subpar performance in Physics instruction. In the absence of a well defined pedagogical framework and customized methodologies, students may have difficulties in effectively interacting with Physics principles, resulting in obstacles in problem-solving and overall educational achievements. The lack of a differentiated learning method specifically emphasizes a substantial deficiency, as this strategy is recognized for addressing the unique requirements, preferences, and readiness levels of individual students. Failure to employ these procedures in the current teaching methods at SMAN 2 Kabanjahe may impede the students' capacity to comprehend intricate Physics topics and perform exceptionally well in problem-solving assignments, therefore not completely capitalizing on their potential. Thus, the existence of the gap highlights the urgent necessity to adopt a well-organized learning framework, such as the PBL model, and to apply a differentiated learning method that is specifically customized to the requirements of Physics education. This research aims to determine differences in student learning outcomes in physics learning by implementing a PBL model that uses a differentiation learning approach.

Method

Research Design

This research is a type of experimental research in the form of Pre-Experimental Designs. The research design is One Group Pretest-Posttest Design. In this design there is a pretest before treatment and a posttest after treatment. In this way, the results of the treatment can be known more accurately, because it can be compared with the situation before the treatment was given (Creswell, 2014).

Research Participants

This research was conducted at SMA Negeri 2 Kabanjahe in the even semester of the Academic Year 2022/2023. The participants in the research sample are 40 students from one class of XI PMIPA. These students will first take a pretest to assess their initial learning outcomes. Then, they will participate in the learning intervention using the Problem-Based Learning (PBL) model. After the intervention, the students will take a posttest to measure their learning outcomes again.

Research Procedure and Material

The research procedure involves a meticulous preparation phase outlining objectives, methodology, and participant selection from high school students of Class XI PMIPA at SMA Negeri 2 Kabanjahe. The study utilizes a one-group pretest-posttest design, implementing Problem-Based Learning (PBL) coupled with Differentiated Instruction across six material covering kinematics, dynamics, Newton's laws, work and energy, momentum and impulse, and dynamic fluids. Detailed research implementation guidelines can be seen in table 1.

Table 1. Guidelines for The Problem-based Learning (PBL) Model with A Differentiated Learning Approach

Material	Date (Time)	Location	Stages of Approach
Pretest	6 February 2023 (2 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Measure students' initial understanding of the material to be studied
Kinematics	13 February 2023 (4 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Problem identification related to kinematics, independent investigation, group discussion. ▪ Presentation of results, class discussion.
Dynamics	20 February 2023 (4 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Problem identification related to dynamics, independent investigation, group discussion. ▪ Presentation of results, class discussion.
Newton's Laws	27 February 2023 (4 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Problem identification related to Newton's Laws, independent investigation, group discussion. ▪ Presentation of results, class discussion.
Work and Energy	6 March 2023 (4 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Problem identification related to work and energy, independent investigation, group discussion. ▪ Presentation of results, class discussion.
Momentum and Impulse	13 March 2023 (4 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Problem identification related to momentum and impulse, independent investigation, group discussion. ▪ Presentation of results, class discussion.
Dynamic Fluids	20 March 2023 (4 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Problem identification related to dynamic fluids, independent investigation, group discussion. ▪ Presentation of results, class discussion.
Posttest	27 March 2023 (2 JP)	Class XI PMIPA, SMA Negeri 2 Kabanjahe	▪ Measuring students' understanding after implementing the PBL learning model.

JP = Lesson hours
*1 week 4 hours of lessons

Stages of the Problem Based Learning (PBL) Approach with Differentiated Learning (2 JP): (1) Giving problems: The teacher gives relevant and complex problems related to the physics material being studied. These problems should challenge and encourage students to think critically. (2) Independent Investigation: Students search for the information and data needed to understand the problem in depth. Students work independently or in small groups, adapting to their individual abilities. (3) Group Discussion: Students discuss in groups to analyze problems and formulate solutions. The teacher acts as a facilitator, providing guidance and feedback. 2 JP: (1) Presentation of Results: Each group presents their solutions and discussion results. These presentations provide an opportunity to share ideas and get feedback from teachers and classmates. (2) Class Discussion: Class discussion to discuss the solutions that have been presented, clarify concepts, and deepen understanding.

Differentiated Learning Approach: (1) Adjustment of Assignments: Assignments and activities are adapted to students' level of understanding and abilities. Students who understand the material more quickly can be given additional challenges, while students who need more time are given additional guidance. (2) Flexible Grouping: Students are grouped based on their learning needs, which can change according to the material and their learning progress. (3) Diverse Learning Strategies: Uses a variety of learning methods such as discussions, group work, projects, and use of technology to meet students' diverse learning styles. (4) Continuous Feedback and Evaluation: Provide students with specific and constructive feedback on an ongoing basis to help them understand their strengths and areas for improvement.

Data Analysis and Hypothesis

The data analysis technique uses descriptive analysis and paired difference tests (paired sample t-test) to see the differences before and after implementing the problem based learning (PBL) model with a differentiation learning approach to improve physics learning outcomes. Hypothesis testing was conducted to determine the difference in student learning outcomes in the sample group, both the experimental class and the control class. Hypothesis testing is determined using the t-test (Widodo, 2021). The hypothesis used in the one-tailed t-test is: Ho: There is no difference before and after implementing the problem based learning (PBL) model with a differentiated learning approach to improve physics learning outcomes. Ha: There are differences before and after implementing the problem based learning (PBL) model with a differentiated learning approach to improve physics learning outcomes.

Result and Discussion

Results

The measures of central tendency for the pretest and posttest data indicate significant enhancements in student performance. The average scores rose from 68.8 to 80.0, suggesting a substantial improvement in overall comprehension (Table 2). In a similar vein, the median and mean values also demonstrate this enhancement, exhibiting a tendency towards higher scores. Nevertheless, there is a little rise in variability, as indicated by the increase in standard deviation from 5.35 to 7.05, which implies that there is some dispersion in the posttest results. The range of scores expanded, indicating a wider range of student achievement. Furthermore, the skewness and kurtosis values, albeit being near zero, suggest a distribution that is generally symmetrical and less peaked, confirming that the intervention has successfully promoted more balanced learning outcomes within the student cohort.

Table 2. Descriptive results of pretest and posttest

Central Tendency	Pretest	Posttest
Mean	68.8	80.0
Std. error mean	0.846	1.12
Median	69.0	80.0
Mode	70.0	75.0
Standard deviation	5.35	7.05
Minimum	60	68
Maximum	78	95
Skewness	-0.0193	0.247
Kurtosis	-0.822	-0.744

Table 3. Results of paired sample t-test

Value	Paired Samples T-Test
	Sig. (2-tailed)
Pretest and Posttest	.001

Table 3 shows the physics learning results (sig = 0.001), this states that the p-value < 0.05 which shows that there is a significant difference in physics learning results before and after PBL treatment with the differentiation learning approach. It can be stated that PBL with a differentiated learning approach has an effect on improving high school students' learning outcomes. The application of PBL with a differentiated learning approach makes students active, especially at the PBL stage, this is because it provides a real context for learning by introducing students to relevant and challenging physics problems. This makes learning more interesting and meaningful for students, because they can see direct applications of physics concepts in real-world situations.

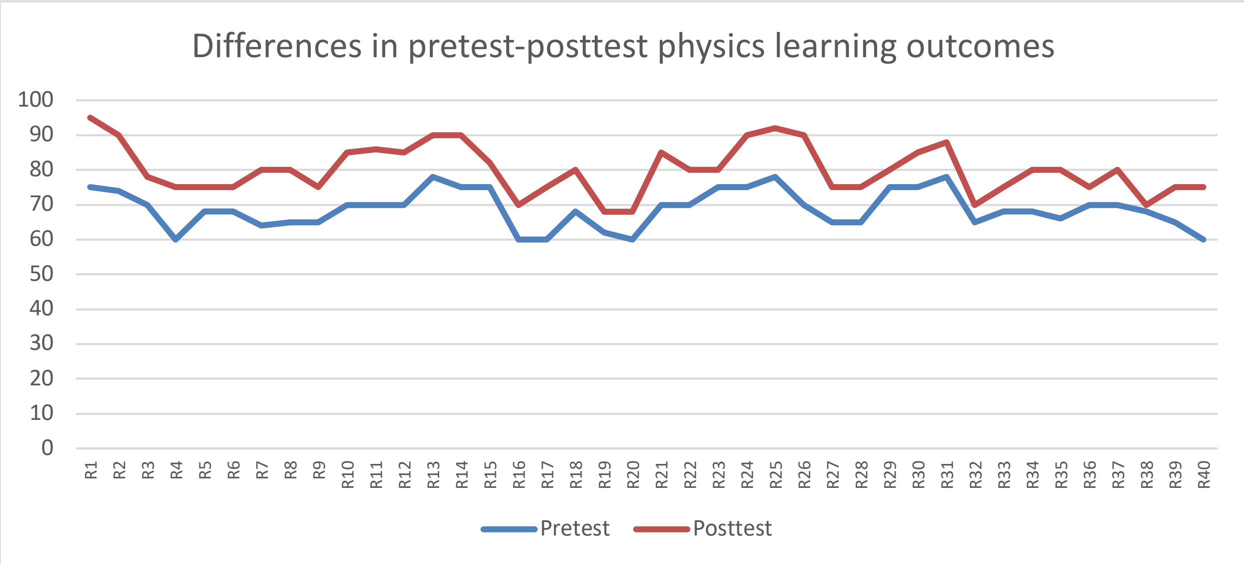

Figure 1. Difference in Results Before and After Treatment

Figure 1 provides a clear picture of changes in learning outcomes before and after treatment using the Problem Based Learning Model (PBL) with a differentiation approach. In this figure, we can see that every respondent, from R1 to R40, experienced a significant increase in their understanding and achievement in physics lessons. This increase reflects the effectiveness of PBL and the differentiation approach in facilitating a more effective and in-depth learning process. By using PBL, students are encouraged to actively engage in problem solving, critical thinking, and collaboration with others. The differentiation approach allows for the delivery of material tailored to each student's needs and abilities, so that they can learn in the way that is most effective for them. The results shown in Figure 1 confirm that the combination of PBL with a differentiation approach can have a real positive impact on students' physics learning outcomes. This includes not only improvement in mastery of the material, but also the development of critical, collaborative, and problem-solving skills that are essential for future success.

This research highlights the potential of problem-based learning (PBL) with a differentiated learning approach as an effective pedagogical tool in physics education. Project-Based Learning (PBL) involves the incorporation of practical problems and tailored educational activities to actively engage students in the process of investigation and analytical reasoning. This approach promotes a more profound comprehension and lasting memory of physics principles. This strategy not only improves academic achievement but also fosters crucial abilities such as problem-solving, cooperation, and self-directed learning, which are extremely beneficial for students' future academic and professional pursuits.

Furthermore, the beneficial effects of incorporating PBL with a diversified instructional method go beyond immediate academic advancements. It fosters a dynamic and captivating learning atmosphere that encourages students to actively investigate, test, and utilize their information in real-life situations. Engaging in physics not only enhances students understanding of fundamental principles but also fosters curiosity, inventiveness, and self-assurance in their capacity to address intricate problems both within and beyond the educational setting. The PBL model encourages students to improve learning outcomes. PBL model alternative learning makes students more effective because, within this model, students can discuss and exchange opinions with friends, ask the teacher, answer questions, and express what is known with as much as possible (Asdar et al., 2020). A study conducted by Rahayu et al. (2017), at Public Senior High School 1 Mukomuko found that the problem-based learning paradigm has the potential to enhance student engagement, motivation, and academic performance. The results of this study follow Ali et al. (2023) research, which found that the PBL model has the advantage of having students get used to dealing with and solving problems skillfully and can stimulate and develop creative and comprehensive thinking skills in the learning process. This research also aligns with prior studies that differentiated teaching practices according to learning styles are more effective for students' motivation toward science learning than traditional teaching models and that teaching-oriented student views support differentiated teaching practices (Demir, 2021; Hadi et al., 2022).

Furthermore, recent studies have demonstrated that the incorporation of diverse technologies into PBL approaches can facilitate and enhance the learning process by enabling students to construct meaningful solutions to real-world issues (Jin & Bridges, 2014; Sadlo, 2014). Technology-based PBL has been suggested by several researchers to have a more substantial impact on cognitive and affective abilities when compared to traditional or in-person PBL (Chanprasitchai & Khlaisang, 2016; Jin & Bridges, 2014; Phungsuk et al., 2017). Similar to other academic disciplines, science education can experience a decline in learning productivity if instructional technology advancements are not implemented effectively or if they are not incorporated into learning environments. The utilization of technology in science education facilitates the presentation of difficult-to-access materials, the concretization of learning, the execution of experiments with greater ease, and the customization of the learning environment to accommodate the unique characteristics of each student (Doğru & Kıyıcı, 2005). Scholars have examined several obstacles associated with the teaching of scientific subdisciplines, including physics: complex and abstract topics, costly experimental materials, equipment shortages, inaccessible objects, and misconceptions (Argaw et al., 2017). According to the results of a study conducted by Tuncel & Fidan (2018) in Turkey using a large sample size, middle and junior high school students encounter greater challenges when it comes to physics topics including force, motion, and pressure in their science curriculum.

The growing implementation of PBL frameworks, which incorporate a differentiated learning strategy, among physics instructors represents a favourable transition in the direction of enhancing students' academic achievements. This phenomenon highlights the critical role that educational administrators play in cultivating an environment that promotes the incorporation of PBL and differentiated instruction in every subject, not just physics. The provision of support, resources, and opportunities for professional development by principals is crucial in enabling teachers to effectively implement these innovative teaching methods. In addition, although this article focuses on physics education, the effectiveness of PBL in conjunction with a differentiated learning strategy is not limited to this field. It is amenable to investigation and experimentation in numerous mathematical and natural science fields, including biology, chemistry, and mathematics. Moreover, these methods have the potential to be utilized in a wide range of domains beyond STEM disciplines, providing opportunities for experimentation and integration in various sectors beyond science and mathematics. Hence, this progressive pedagogical methodology offers academic establishments a chance to adopt a comprehensive pedagogical paradigm that fosters student engagement, problem-solving abilities, and critical thinking across a broad range of disciplines and subjects.

Conclusion

The results shows that there is a significant difference in physics learning results before and after PBL treatment with the differentiation learning approach. It can be stated that PBL with a differentiated learning approach has an effect on improving high school students' learning outcomes. The application of PBL with a differentiated learning approach makes students active, especially at the PBL stage, this is because it provides a real context for learning by introducing students to relevant and challenging physics problems. This makes learning more interesting and meaningful for students, because they can see direct applications of physics concepts in real-world situations. It means that implementing the PBL model based on a differentiated learning approach can improve student learning outcomes. Thus, this research suggests that the PBL model uses a differentiated learning approach that can be relied upon to improve student learning outcomes, so teachers need to use the PBL model more intensively based on a differentiated learning approach to encourage increased student learning outcomes in physics. Additionally, this study also suggests further research, i.e., teachers who want to apply the same learning are expected to carry out socialization and simulation related to the syntax of the learning model first, and the availability of supporting learning facilities such as digital devices, internet access, and projectors greatly influences the implementation of learning.

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