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How did problem-based learning with the TPACK approach (PBL-TPACK) enhance physics learning outcomes?

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Abstract
This study aimed to determine the average score category of students' physics learning outcomes and the effect of the PBL-TPACK on students' physics learning outcomes. This research is a type of quantitative research with a comparative approach. The research design used was a randomized pretest-posttest design. The sample was randomly selected, and two class groups were chosen as the research sample. The data collection technique was carried out using a test technique. The data collection instrument was a test instrument with multiple choice questions of 30 test items with five alternative answers. The results showed that the average score of students' physics learning outcomes taught by the PBL-TPACK was included in the high category. In contrast, the DI-TPACK was included in the low sort, and there is a significant difference in average physics learning outcomes between students taught through the PBL-TPACK and those taught through the DI-TPACK. The PBL-TPACK has a positive effect on students' physics learning outcomes.

Keywords: Problem-based learning, Direct instruction, TPACK, Physics learning outcomes

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I. Introduction

Education in Indonesia is increasingly developing in line with developments in the current era [1]. The government issued various policies to increase the quantity and quality of existing education. The government has attempted multiple methods to improve the quality of education in Indonesia. Some of the efforts that have been made include changes to the education curriculum, renewal of the learning system, and provision of educational facilities.

One goal of improving education quality in Indonesia is to achieve a successful school learning process. A quality learning process can be performed by choosing a suitable learning model. This is supported by an opinion that states that achieving success in the learning process at school is influenced by several essential components, one of which is the application of learning models [2]. By implementing appropriate and effective learning strategies or models in the classroom, the possibility of achieving success in the learning process can be realized by obtaining high learning outcomes. An effective learning model can also stimulate students to participate more actively in classroom learning [3], including physics learning.

Physics is an exact science that contains knowledge and some skills or abilities. This requires students to explore their skills during the learning process. This is strengthened by the opinion that the most essential aspect of learning physics is that students are active when studying [4]. This activity is needed to solve problems in physics. Because physics is an exact science, you must carry out an experiment or experiment using the scientific method to prove the theory. The experimental results show the relationship between variables expressed as a mathematical equation. These mathematical equations are considered problematic for some students, making them less interested in physics. Apart from that, difficulties in understanding physics material are also a problem that causes low student learning outcomes.

The lack of optimal achievement of student learning outcomes can be caused by students still needing to be actively involved in the problem-solving process in physics learning. Apart from that, the learning model teachers use does not require student activity.

Thus, a learning model is needed to liven up the classroom atmosphere. One learning model that can be implemented is problem-based, or what is better known as Problem-Based Learning (PBL), supported by [5], which states that the PBL model can involve students actively participating in learning. Through the PBL model, starting from the initial learning activities, students are faced with a problem. Then, they must actively seek information and alternative solutions to the problem by discussing or collaborating in groups or individually. Thus, this PBL model will involve students thinking more critically and participating actively in every learning process. The learning outcomes are hoped to be more memorable and meaningful for students. The PBL model can also provide active learning conditions for students, which allows students to be actively involved in the problem-solving process during the learning process [6]. In this way, students can gain knowledge and skills to solve physics problems to improve learning outcomes.

A professional teacher must have four competencies: professional competence, pedagogical competence, personality competence, and social competence. Professional competence is related to teachers' mastery of learning material more broadly and in-depth. Pedagogical competency is related to the teacher's ability to understand students, plan and implement learning, develop students, and evaluate student learning outcomes to actualize their potential. According to Mishra & Koehler, these two competencies are also called "pedagogical knowledge" and "content knowledge" [7].

The development of technology and communication requires physics teachers not only to be able to master the material and how to teach students but also to use technology to understand students. By integrating the role of technology in physics learning, professional teacher competence will become a complete competence, which is in the future referred to as "technological pedagogical and content knowledge," abbreviated as TPACK. Technological Pedagogical Content And Knowledge (TPACK), namely knowledge which is a combination of each field of knowledge (content knowledge, pedagogical knowledge, technological knowledge, pedagogical and content knowledge, and technological and content knowledge) by focusing on the use of technology to teach content and achieve pedagogical goals [8]–[10].

Information and communication technology development has significantly influenced the 21st-century learning process and has encouraged teachers to know information and communication technology. Facing technological developments in 21st-century learning today, teachers must have technological pedagogical and content knowledge (TPACK) to integrate technology into learning. TPACK is a type of new knowledge that teachers must master to be able to integrate technology well into learning [7]. TPACK transforms knowledge (content and pedagogy knowledge) into different knowledge types to develop and implement learning strategies [11]. TPACK is knowledge about how various types of technology can be used for learning, which can change how teachers teach [12]. Teachers must have the necessary competencies to integrate technology appropriately and effectively in learning [13]. TPACK integrates knowledge about technology, pedagogy, and content that influence each other in the learning process [14].

Technology integration in teacher learning is the main factor in the TPACK approach [15]. TPACK is a framework used to analyze the integration of technology in teacher learning [16]. Based on this description, TPACK is a framework for integrating technology mastery with pedagogical abilities and content knowledge, which teachers must master. Thus, TPACK is teachers' knowledge about when and how to use technology to learn specific material. Therefore, teachers must be able to use appropriate technology in appropriate pedagogy for specific content.

The Problem-Based Learning (PBL) model with the TPACK approach is an innovative learning model where each learning step is integrated with the use of technology such as PowerPoint, Macromedia Flash animation, canvas, Random List, Padlet, Kahoot, Google Form, Quizizz, PhET simulations, social media, etc. Empirical research shows that the PBL model with the TPACK approach can improve students' abilities in problem-solving [17], [18]. In this research, the problem-solving ability measured was mathematical problem-solving ability. In this research, the problem-solving ability measured is the physics problem-solving ability from students' physics learning outcomes.

Problem-Based Learning (PBL) syntax integrated with the TPACK (Technological Pedagogical Content Knowledge) approach involves a structured process and framework for designing and implementing this instructional method. Below is a step-by-step description of the syntax in Table 1.

Table 1. The Syntax of PBL-TPACK

Number	Syntax	Description
1	Identify Learning Objectives	Begin by identifying specific learning objectives or educational goals you want students to achieve. These objectives should align with the curriculum and the content knowledge (CK) students must acquire.
2	Select a Real-World Problem	Choose a real-world problem or scenario relevant to the learning objectives and content. This problem should be complex enough to require critical thinking and problem-solving but not so complex that it overwhelms students.
3	Integrate Technology (Technological Knowledge - TK)	Identify appropriate technology tools and resources to enhance the learning experience and help students address the problem. Consider how technology can be used for research, data analysis, simulations, or presentations.
4	Design the Problem Scenario	Create a detailed problem scenario or case study introducing the problem to students. Include background information, relevant data, and any constraints or limitations they must consider. Ensure the scenario engages and encourages students to explore the problem further.
5	Form Student Groups	Organize students into small groups. Collaborative learning is a key element of PBL, and group dynamics play a crucial role in problem-solving.
6	Provide Resources and Support	Offer students access to various resources, including textbooks, articles, online databases, and technological tools. Ensure they have the necessary support and guidance from the teacher or facilitator throughout the process.
7	Facilitate Group Discussions (Pedagogical Knowledge - PK)	Encourage students to engage in group discussions and brainstorming sessions. The teacher should act as a facilitator, guiding discussions, asking probing questions, and ensuring students stay on track.
8	Problem Analysis and Hypothesis Generation	In their groups, students should analyze the problem, identify key issues, and generate hypotheses or potential solutions. They should consider the content knowledge (CK) they've learned and how it applies to the problem.
9	Research and Data Collection (Technological Knowledge - TK)	Use technology to gather relevant data, research, and validate their hypotheses. This may involve using digital resources, conducting online surveys, or utilizing software for data analysis.
10	Solution Development	Encourage students to develop and refine their solutions or strategies for addressing the problem. They should consider the technological tools and methods they've learned to optimize their solutions.
11	Presentation & Communication Skills	Have each group present their findings and proposed solutions to the class. This promotes communication skills and allows students to share their insights with their peers.
12	Reflection and Evaluation	After presentations, engage students in a reflective discussion about the problem-solving process, what they learned, and how they can apply their newly acquired knowledge and skills in different contexts.
13	Assessment and Feedback	Assess students' problem-solving abilities, content knowledge application, and their use of technology. Provide constructive feedback to help them improve.
14	Iterate and Repeat	Use PBL integrated with TPACK for multiple problems or scenarios throughout the course to reinforce learning and continually develop students' problem-solving skills.

By following this syntax in Table 1, teachers can effectively implement Problem-Based Learning with the TPACK approach, providing students with a structured and engaging learning experience that enhances their problem-solving skills while integrating technology, pedagogy, and content knowledge.

Based on the background of the problem, the researchers then conducted research with the aim of (1) finding out the categories of physics learning outcomes for students taught using the PBL-TPACK model, (2) knowing the categories of physics learning outcomes of students who are taught using the direct instruction (DI) model integrated with the TPACK (DI-TPACK), and (3) determine the effect of the PBL-TPACK model on students' physics learning outcomes.

II. Methods

This research is quantitative with a quasi-experimental model, while the research design used is a randomized pretest-posttest design (Table 2). The research sample was randomly selected by class. After randomizing the classes, 32 students were chosen as the experimental group and 32 as the control group.

Table 2. Research Design

Group	Pretest	Treatment	Posttest
Experiment	Y_1	X_1	Y_2
Control	Y_1	X_2	Y_2

The data collection technique used in this research is the test technique. The research instrument was a multiple-choice test question sheet with five alternative answers. The test questions developed were 30 test items. Data analysis techniques for testing test instruments use validity tests and reliability tests. The item validity test was carried out using the product moment correlation equation (1) [19]–[24]:

$$r_{XY} = \frac{N\sum XY - \left(\sum X\right)\left(\sum Y\right)}{\sqrt{\left\{N\sum X^2 - \left(\sum X\right)^2\right\}\left\{N\sum Y^2 - \left(\sum Y\right)^2\right\}}} \quad (1)$$

Based on data analysis using the product-moment correlation equation (r_{XY}), the results obtained were that of the 30 test items tested, it turned out that 6 test items did not meet the valid criteria, so they were declared invalid. In comparison, 24 test items were declared good or valid so they could be used to collect data on physics learning outcomes—students in two sample groups.

Valid test items are then analyzed using the KR 20 technique to determine their reliability value using the equation (2) [25]–[27]:

$$r_i = \frac{k}{(k-1)}\left\{\frac{s_t^{\,2} - \sum p_i q_i}{s_t^{\,2}}\right\} \quad (2)$$

The reliability test results of 24 valid test items with the help of SPSS 25 for Windows software obtained a reliability coefficient value $r_i = 0.739$.

The students' physics learning outcomes were categorized in each sample group using descriptive statistics [28]. The categorization was carried out by following the criteria in Table 3.

Table 3. Criteria for Student Physics Learning Outcome Scores

Score	Criteria
$20.00 \le \bar{X} \le 24.00$	Very High
$15.00 \le \bar{X} \le 19.00$	High
$10.00 \le \bar{X} \le 14.00$	Moderate
$5.00 \le \bar{X} \le 9.00$	Low
$0.00 \le \bar{X} \le 4.00$	Very Low

Before the mean difference test, the students' physics learning outcomes data is subjected to analysis prerequisite tests, including the normality and homogeneity tests. The normality test is carried out to determine whether the data obtained from each sample group is normally distributed. The data normality test was carried out using the Chi-Square equation (3) [29]:

$$\chi^2 = \sum \frac{(f_0 - fh)^2}{fh} \quad (3)$$

With the help of the SPSS 25 for Windows software application, the results were obtained in Table 4.

Table 4. Normality Test

Group	Df	χ^2	P	Normality
PBL-TPACK	14	12.062	0.601	Normal
DI-TPACK	14	14.875	0.387	Normal

The variance homogeneity test was carried out to analyze whether the variances of the two sample groups were homogeneous. The homogeneity test is carried out using the F test (equation (4)) [30]:

$$F = \frac{\text{Big Varians}}{\text{Small Varians}} \tag{4}$$

The homogeneity test was conducted using SPSS 25 for Windows software, with results as in Table 5.

Table 5. Homogeneity of Variance Test

Group	N	Variance	F_{test}	P	Conclusion
PBL-TPACK	32	359.210	37.156	0.519	Homogenous
DI-TPACK	32	392.609			

After the analysis prerequisite tests are fulfilled, a hypothesis test is carried out using the mean difference test for the two sample groups, namely the t-test (equation (5)) [30]:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \tag{5}$$

H_0: $\mu_1 = \mu_2$ (There is no difference in the average physics learning outcomes between students taught through the PBL-TPACK model and students led through the DI-TPACK model).

H_1: $\mu_1 \neq \mu_2$ (There is a difference in the average physics learning outcomes between students taught through the PBL-TPACK model and students taught through the DI-TPACK model).

Test decision: if the t_{count} is more significant than the t table, then H_0 is rejected, or if the p-value <0.05, then H_0 is left, so the conclusion is that there is a difference in the average physics learning outcomes between students taught through the PBL-TPACK model and students taught through the DI-TPACK model.

III. Results and discussion

Physics learning outcomes for the PBL-TPACK group

Descriptive data on students' physics learning outcomes taught using the PBL-TPACK model in the experimental group are presented in Table 6.

Table 6. Descriptive Data of the Experimental Group

Data	Results
Highest Score	22.00
Lowest Score	4.00
Average Score	15.84
Standard Deviation	4.54

Suppose the average score of students' physics learning outcomes taught using the PBL-TPACK model in Table 6 is confirmed by Table 3. In that case, the average score of students' physics learning outcomes is included in the high category.

Physics learning outcomes for the DI-TPACK group

Descriptive data on the physics learning outcomes of students taught using the DI-TPACK model in the control group are presented in Table 7.

Table 7. Descriptive Data of Control Group

Data	Results
Highest Score	17.00
Lowest Score	1.00
Average Score	8.78
Standard Deviation	4.73

Suppose the average score of students' physics learning outcomes taught using the DI-TPACK model in Table 7 is confirmed by Table 3. In that case, the average score of students' physics learning outcomes is included in the low category.

Learning outcomes of the PBL-TPACK and DI-TPACK model

One of the aims of this research is to determine the effect of the PBL-TPACK model on students' physics learning outcomes. To answer the research objectives, inferential statistical tests were carried out on data on students' physics learning outcomes in the two sample groups after being given treatment. The inferential statistical test used to analyze the differences in students' average physics learning outcomes from the two sample groups is the t_{test}.

The analysis results using the t_{test} are presented in Table 8.

Table 8. Summary of t_{test}

Group	N	Average	SD	t_{test}	*p*	Conclusion
Experiment	32	15.84	4.54	6.096	0.000	Very Significant
Control	32	8.78	4.73			

Based on Table 8, the p-value from the results of data analysis using the independent sample t-test obtained a p-value = 0.000. The p-value is less than 0.05 ($p < 0.05$). Thus, the decision from the analysis results using the t-test is that H_0 is rejected. This decision shows a significant difference in the average physics learning outcomes between students taught through the PBL-TPACK model and those taught through the DI-TPACK model.

This significant difference is because learning with the PBL-TPACK model can emphasize daily problem-solving activities related to the concepts of physics material being taught to increase students' understanding. During the problem-solving discussion process with the group, students are encouraged to ask questions, discuss and solve problems together, and dare to express their opinions. With activeness, students will enjoy learning activities and feel enthusiastic and motivated in the learning process because students are involved in solving the problems they face. In this way, the material presented will be well received so that physics learning outcomes can improve.

The results of this research show that the PBL-TPACK model can positively influence students, where students are directly involved in mastering physics concepts through the problem-solving process provided by the teacher. PBL-TPACK can make students more active, not passive observers, and allow students to be responsible for their learning. When using PBL-TPACK, students are more motivated to be involved in learning, as evidenced by students who know how to interact, think together, examine each other, and express opinions in their groups. This finding is supported by relevant research conducted by Paradina et al., which states that PBL-TPACK can encourage students to learn to think critically and analytically and collaborate with their groups [5]. Students acquire concepts through problem-solving so that the ideas obtained are not easily lost from memory, ultimately increasing success in learning physics.

The results of this research are also supported by a theory in line with this research, namely Piaget's theory of cognitive development. Piaget's theory of cognitive development explains that children are always curious and try to understand the world around them. Likewise, a student facing new experiences manipulates things, asks questions, and looks for answers. That way, students can be actively involved in obtaining information and will automatically build their knowledge [31]. Supporting factors for implementing the PBL-TPACK model include two-way and not monotonous learning, high student motivation, and high awareness and responsibility of teachers and students. Based on this description, if the PBL-TPACK concept is implemented well, the impact can be felt in the learning process and student learning outcomes.

This is different from students who are taught using the DI-TPACK model. When learning through the DI-TPACK model, the teacher presents learning material only using the direct lecture method and taking notes on the blackboard. Therefore, students tend to be more passive and less motivated to answer the topics presented by the teacher. In principle, the DI-TPACK model needs to receive full attention from students from the beginning of the learning process. However, because learning only takes place in one direction, students get bored quickly and usually don't pay attention to the teacher. This means the material taught is less acceptable, and student learning outcomes could be more optimal.

This shows that the DI-TPACK model is less effective in improving students' physics learning outcomes because communication in the learning process tends to be one-way. This one-way communication needs to be improved for more interaction between teachers and students. Apart from that, during learning, students only listen to what the teacher says, and students also show a passive attitude because they are not interested in learning. After all, they are bored. Students also do not focus on the learning material provided by the teacher. With the DI-TPACK model, the teacher only gives instructions, explaining certain things using available books to increase students' knowledge. If this learning continues, it will cause problems faced by students and teachers, namely, students becoming less active and not interested in participating in learning, either by listening or taking notes, ultimately resulting in low student learning outcomes in physics subjects.

This is very relevant to research results, which state that using the PBL-TPACK model can provide better results than conventional learning models, including the DI-TPACK model [32]. This is reflected in the average physics learning outcomes of students who use the PBL-TPACK model, which is higher than those of students who use the conventional model, DI-TPACK. Thus, the PBL-TPACK model positively affects the physics learning outcomes of students in the odd semester of the 2022/2023 academic year. The following description is a comparison between PBL-TPACK and DI-TPACK in Table 9.

Table 9. Comparison between PBL-TPACK and DI-TPACK

Number	Aspect	PBL-TPACK	DI-TPACK
1	Learning Orientation	It is oriented to solving problems by utilizing the role of existing technology. Students are given assignments or problems that require critical thinking and problem-solving using technology.	Focuses on direct instruction with the help of existing technology. Teachers provide information directly to students and guide learning strictly with the help of technology.
2	Role of Teachers and Students	The teacher acts as a facilitator who guides students through the problem-solving process by utilizing the role of technology in the problem-solving process. Students are active in exploration and independent learning through existing technology.	The teacher acts as the primary transmitter of information, providing direct instruction to students with the help of technology. Students receive information and instructions from the teacher.
3	Technology Integration	Technology is used as a tool to investigate and solve problems. Students learn to use technology to achieve learning goals.	Technology is used to convey instructions—for example, multimedia presentations, learning videos, or digital learning resources. Integrating technology with a good understanding of how to use technology effectively in learning contexts is essential.

PBL-TPACK has a positive effect on student learning outcomes. Several advantages of PBL-TPACK, including support this: (1) *More Meaningful Learning Experience*: PBL-TPACK allows students to face real challenges and solve problems, providing a more meaningful learning experience than in-person learning. (2) *Development of Critical Thinking Skills*: PBL-TPACK encourages the development of critical thinking skills, as students must design solutions to complex problems and apply their knowledge contextually. (3) *Effective Integration of Technology*: TPACK emphasizes integrating technology with pedagogy and content. By using PBL as a learning model, teachers can more easily integrate technology effectively in the context of problem-solving. (4) *Collaborative Skills Development*: PBL-TPACK encourages group work and collaboration, helping students develop social and collaborative skills that are important for the real world. (5) *Differentiated Learning Experiences*: PBL can be tailored to students' needs and ability levels, allowing for more significant instructional differentiation than teacher-centered DI models. (6) *Encourages Intrinsic Motivation*: PBL-TPACK can increase students' intrinsic motivation because they are involved in solving problems that have real relevance in their lives.

The Problem-Based Learning (PBL) model with the TPACK (Technological, Pedagogical, and Content Knowledge) approach can effectively improve students' problem-solving abilities. This happens because PBL-TPACK combines content knowledge with an appropriate pedagogical approach (Pedagogical Knowledge) and utilizes technology wisely (Technological Knowledge). The following describes how PBL with the TPACK approach can improve problem-solving abilities: (1) *TPACK Integration*: The TPACK approach combines three essential elements in learning: Technology, Pedagogy, and Content Knowledge. In the PBL-TPACK context, teachers must deeply understand these three elements. They must know how to integrate appropriate technology with learning content and use effective pedagogical strategies to guide students in solving problems. (2) *Problem-Based Learning Context*: In PBL-TPACK, students are given real problems or tasks that require solving. This problem is usually related to the learning content being studied. For example, in physics, students can be asked to design solutions to the current issue of global warming. (3) *Development of Critical Thinking Skills*: PBL-TPACK encourages students to think critically and analytically as they seek solutions to problems. They must identify relevant information from various sources, decompose problems into smaller components, and design effective problem-solving strategies. (4) *Collaboration*: PBL-TPACK often involves cooperation between students. They work in teams to find the best solution to a given problem. This develops their ability to collaborate, share ideas, and discuss solutions. This collaboration also reflects the importance of technology in connecting students and enabling them to work together online when necessary. (5) *Supportive Use of Technology*: In the TPACK approach, teachers use technology to support learning. They can integrate software, online resources, or other relevant digital tools into the learning content. Technology can also be used to collect data, visualize information, or support problem-solving processes. (6) *Reflection and Feedback*: PBL-TPACK promotes reflection on the learning process. Students are invited to think about how they approached the problem, what they have learned, and how they can improve their problem-solving. Teachers also provide constructive feedback that helps students develop their abilities further. By combining PBL and the TPACK approach, students learn about learning content and develop problem-solving skills that are invaluable in real life. They can connect their knowledge with relevant technologies and use appropriate pedagogical strategies to solve their problems, making them better prepared to face the challenges of an ever-evolving world with technology.

IV. Conclusions

The conclusions of this research include: the average physics learning score of students taught using the PBL-TPACK model is in the high category; the average physics learning score for students taught using the DI-TPACK model is in the low category; and there is a significant difference in the average physics learning outcomes between students taught through the PBL-TPACK model and those taught through the DI-TPACK model. The PBL-TPACK model has a positive impact on students' physics learning outcomes.

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