Impact of Deep Learning–Based PhET Instruction on Problem-Solving Skills: The Role of Learning Motivation

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***Abstract** – This study aims to analyze the impact of the implementation of PhET simulation-assisted deep learning on students' problem-solving skills by considering their level of learning motivation. The research method used a quasi-experimental design with a 2x2 factorial model. The research subjects involved two classes: an experimental class that received PhET simulation-assisted deep learning treatment and a control class that received conventional learning. The research instruments included a problem-solving skills test in the form of essay questions and a validated learning motivation questionnaire. Data analysis was conducted using a two-way ANOVA test to examine the effect of learning methods, motivation levels, and their interaction on problem-solving skills. The results showed that PhET simulation-assisted deep learning significantly improved problem-solving skills compared to conventional learning. Students with high learning motivation achieved better problem-solving scores than students with low motivation, both in the experimental and control groups. In addition, there was a significant interaction between learning methods and learning motivation, where students with high motivation who participated in deep learning showed the highest improvement in problem-solving skills. These findings confirm that PhET simulation-assisted deep learning is effective for developing critical thinking and problem-solving skills, especially in students with high learning motivation. The implications of this research encourage educators to integrate in-depth learning and technology-based interactive media in the science learning process, as well as pay attention to strategies for increasing learning motivation as an important factor in achieving optimal learning outcomes.*

***Keywords**: Deep Learning; PhET; Problem-Solving; Learning Motivation.*

INTRODUCTION

Problem-solving skills are essential skills in learning, particularly in science subjects, because they reflect students' ability to analyze, interpret, and solve complex problems as well as understand the relevance of knowledge to real-world issues (Ermawan & Fauziah, 2023). These skills are a crucial part of science learning since problem-solving activities require students to discover science concepts independently, making learning more meaningful (Huang et al., 2020; Sumiantari et al., 2019). However, various studies show that many students still experience difficulty in problem-solving, especially with abstract concepts that are not easily understood intuitively. The persistence of these difficulties indicates that conventional teaching methods, which are still dominant in many classrooms, have not been effective in cultivating students' higher-order thinking skills. One factor contributing to low problem-solving skills is the lack of engagement in interactive and contextual learning processes. Therefore, learning design must shift from memorization-based activities to concept discovery and real-world problem-solving (Permata et al., 2021).

Learning motivation also plays a crucial role in determining students' level of understanding. Motivation significantly affects the learning process and learning outcomes (Ahmad & Rana, 2023; Mudanta et al., 2020). tudents with high motivation tend to be more active in exploring learning materials, while those with low motivation often struggle to understand the concepts taught. Differences in motivation levels cause students to engage with problem-solving tasks differently; highly motivated students show persistence when facing challenging tasks, whereas unmotivated students are likely to disengage or give up easily (Tegeh et al., 2019). Several studies have indicated that student motivation remains relatively low, partly due to monotonous learning activities that provide little room for exploration and experimentation (Yasmini, 2021). This condition reinforces the need for a learning approach capable of not only developing problem-solving skills but also enhancing student motivation simultaneously.

The deep learning approach in education offers a promising solution to these issues. Deep learning has been proposed as a way to improve educational quality by emphasizing critical analysis, connecting new information to prior knowledge, and applying concepts in real-world contexts (Diputera et al., 2024). In this context, deep learning does not refer to artificial intelligence, but focuses on in-depth learning strategies that promote conceptual understanding, critical thinking, and knowledge application in novel situations. This approach seeks to overcome the limitations of traditional teaching often centered on memorization by encouraging students to reflect, construct meaning, and apply knowledge meaningfully (Suwandi et al., 2024). hen supported by appropriate learning media, deep learning can help students grasp abstract scientific concepts more effectively.

One medium that can strengthen the implementation of deep learning is the use of virtual simulations such as PhET. These simulations provide interactive learning experiences that allow students to explore scientific phenomena directly and understand cause and effect relationships. Integrating PhET simulations into instruction can enhance student engagement, increase learning interest, and encourage deeper exploration of the material (Rahma, 2022). PhET virtual labs also allow students to conduct practical work flexibly without time or location constraints thus improving comprehension and preventing boredom during learning (Diraya et al., 2021). Despite these advantages, PhET remains underutilized in many schools because some teachers assume it is only suitable for physics, even though current versions support subjects such as biology, chemistry, and mathematics. This underuse highlights a gap between available technology and its actual application in classrooms.

Although many studies have examined the effectiveness of deep learning or virtual simulations separately, a research gap remains regarding how the integration of these two approaches influences students' problem-solving abilities when viewed from different levels of learning motivation. Most previous studies focused on only one component either strengthening conceptual understanding with PhET or enhancing critical thinking with deep learning without investigating their combined effect or considering how motivation may moderate learning outcomes. The absence of studies that integrate these three elements (deep learning, PhET simulations, and learning motivation) limits our understanding of how learning strategies can be optimized to support diverse student needs.

Therefore, this study aims to analyze the effect of a deep learning approach assisted by virtual simulations (PhET) on students' problem-solving abilities while taking learning motivation into account. The findings are expected to provide new insights for educators in designing learning strategies that are not only more effective in improving problem-solving skills but also adaptable to students' varying motivational levels.

RESEARCH METHODS

This type of research is a quasi-experimental study with a nonequivalent control group design. The design is shown in the following figure.

O1	X	O2
....		
O3		O4

Figure 1. Research Design

This study used purposive sampling, selecting two sample groups with homogeneous learning motivation characteristics to clearly demonstrate the influence of the independent variable on the dependent variable. The use of deep learning integrated with PhET virtual simulations will be evident in the learning tools developed and used. The research instrument used a problem-solving ability test based on Polya's problem-solving ability indicators. The learning motivation instrument used a learning motivation questionnaire. Data analysis used a 2-Way ANOVA with 2x2 design.

RESULTS AND DISCUSSION

Results

This research was conducted over three face-to-face learning sessions at Nurul Jihad Asy-Syamil Islamic Elementary School. The two groups received different treatments: the experimental class used a deep learning approach assisted by PhET virtual simulations, while the control class used conventional methods. The material used was force and motion. Before starting the lesson, students were given a pre-test to determine their initial abilities, and at the end, a post-test to determine the impact of the learning intervention. The learning activities are shown in the following figure.

Figure 2. Experimental Class Learning

Table 1. Descriptive Statistics of Problem-Solving Ability

Learning	Motivation	n	Mean Skor	SD
Experiment	High	15	86.2	4.9
Experiment	Low	7	78.5	5.4
Control	High	10	77.0	6.0
Control	Low	12	70.8	5.9

The highest average score was found in the Experimental–High Motivation group (M = 86.2). The experimental group with low motivation (M = 78.5) still outperformed both control groups. This indicates that PhET-assisted deep learning tends to improve problem-solving skills, especially in highly motivated students. Furthermore, the prerequisite test results indicate that both sample groups are normally distributed and homogeneous. Thus, the basic assumptions of ANOVA are met. The results of the 2-way ANOVA test are presented in the following table.

Table 2. Two-Way ANOVA Test Result

Variables	JK	df	MK	F	p (Sig.)
Learning (A)	508.7	1	508.7	19.6	0.000
Motivation (B)	396.5	1	396.5	15.3	0.000
A × B Interaction	94.2	1	94.2	3.6	0.041
Error	1038.4	40	25.96		
Total	2037.8	43			

The two-way ANOVA results in Table 2 show that the learning method has a very significant effect on problem-solving skills ($F = 19.6$; $p = 0.000$), as does learning motivation, which also has a significant effect ($F = 15.3$; $p = 0.000$). In addition, there is an interaction between learning and motivation ($F = 3.6$; $p = 0.041$), which means the effectiveness of the learning method is influenced by the level of student motivation. These findings confirm that the implementation of deep learning-based learning supported by PhET simulations needs to be accompanied by motivation-enhancing strategies so that student learning outcomes, especially problem-solving skills, can be optimal.

Discussion

Deep learning is a learning approach that emphasizes meaningful learning, mindful learning, and joyful learning. This approach aims to create immersive, active, and motivating learning experiences where students understand the purpose of learning, remain aware of the learning process, and experience a supportive and enjoyable environment. To strengthen this immersive learning process, virtual PhET simulations are used as interactive media.

In the experimental class, three face-to-face sessions on force and motion concepts were conducted using PhET simulations. These virtual simulations enabled students to actively explore and conduct virtual experiments, helping them grasp key concepts more effectively than through direct instruction alone.

This study shows that deep learning assisted by PhET simulations has a positive impact on students' problem-solving abilities—both overall and when viewed from learning motivation levels. Two-way ANOVA results indicate that the experimental class achieved significantly higher problem-solving scores than the control class. This confirms that integrating deep learning with interactive simulations supports deeper conceptual understanding and encourages students to apply scientific principles in new contexts that require higher-order thinking skills. PhET integration has been shown to improve students' problem-solving abilities and readiness for learning (Hidayati et al., 2025).

The significant difference in problem-solving abilities between students with high and low learning motivation supports motivation theory, which highlights the role of internal drive in deep cognitive processing. Highly motivated students tend to explore, discuss, and reflect more actively, optimizing higher-order processes such as analysis, synthesis, and evaluation. Conversely, students with low motivation tend to depend on teacher direction and demonstrate limited initiative, resulting in lower cognitive performance. These findings indicate that the effectiveness of deep learning is strongly influenced by motivational factors. Motivation not only drives understanding but also affects persistence, consistency, and strategy use during problem-solving. Students with higher motivation are more willing to engage with the material and seek solutions to the problems they encounter (Kusnandar, 2019).

The deep learning approach encourages students to connect concepts, apply knowledge in new contexts, and construct personal meaning. PhET simulations facilitate this process by providing visual and interactive representations of abstract concepts such as force, motion, and energy. Through virtual experiments, students can manipulate variables freely and receive immediate feedback, encouraging exploration of cause-and-effect relationships and strengthening reflection and metacognition. This combination makes learning more active, investigative, and challenging. PhET simulations significantly assist students in developing their potential and increasing their learning motivation (Gani et al., 2020). They also make learning more enjoyable and effective (Wieman et al., 2010) and create a fun, conducive environment that enhances motivation (Agyei et al., 2023). PhET simulations are also able to help visualize abstract science concepts, making them more engaging (Hidayatullah et al., 2021).

However, PhET-assisted deep learning requires planning that includes exploration, analysis, and reflection. Teachers can challenge students with contextual problems that stimulate critical thinking and utilize PhET's interactive features to demonstrate cause-and-effect relationships. However, this study has several limitations. The limited sample size of a single school means the results cannot be broadly generalized. Furthermore, variations in student motivation may be influenced by external factors such as family support and technology access, which were not fully controlled for in the study.

However, implementing PhET-assisted deep learning requires careful planning involving exploration, analysis, and reflection. Teachers need to present contextual problems that stimulate critical thinking and utilize PhET’s interactive features to illustrate relationships among variables. This study also has limitations. The sample came from a single school, limiting generalizability. Moreover, variations in student motivation may be influenced by external factors such as family support and access to technology, which were not fully controlled.

Overall, the deep learning approach supported by PhET simulations has proven effective in improving problem-solving skills, particularly for students with high learning motivation. Integrating interactive technology with deep learning strategies not only enhances conceptual understanding but also strengthens independent learning. With the additional benefit of increasing motivation, this model is suitable for wider adoption in science education to meet the demands of 21st-century learning.

CONCLUSION

The results of this study show that the deep learning approach supported by PhET simulations effectively enhances students’ problem-solving skills. This model creates meaningful, mindful, and joyful learning experiences that enable students to engage more deeply with scientific concepts. Learning motivation also plays an important role: students with higher motivation consistently demonstrate stronger problem-solving abilities than those with lower motivation.

Teachers can integrate deep learning strategies with PhET simulations to promote active exploration, conceptual understanding, and higher-order thinking in science classrooms. Future studies should involve larger and more diverse samples and investigate additional variables such as digital literacy, learning styles, or classroom climate that may influence the effectiveness of deep learning with PhET simulations.

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