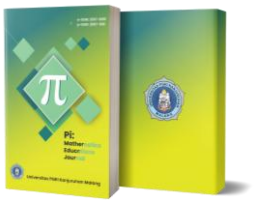
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The Effectiveness of Deep Learning Assisted by PhET Simulation on Students' Probabilistic Reasoning Skills

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ABSTRACT
This study aims to test the effectiveness of deep learning assisted by PhET simulation on students' probabilistic reasoning skills. This research design uses a one-group pretest-posttest design. This study took population of mathematics education students who took the probability theory course in the 2025/2026 academic year. The instrument in this study is a probabilistic reasoning test. Data were analyzed using a paired samples t-test, and Cohens' d effect size. The result of the paired samples t-test (t = -3.53; p = 0.002) show that the pretest and posttest have a significant difference. The effect size value of -0.680 is in the medium category, which shows that deep learning assisted by PhET simulation has a considerable impact on probabilistic reasoning skills. The results show that deep learning is able to encourage students to explore, reflect, and construct probability concepts.

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1. Introduction

Probability theory is an important topic to study because it helps build an understanding of the uncertainties that often occur in daily life. The value of the probability itself can appear before or after observation [1]. In mathematics learning, students are invited to use notation and symbols correctly [2]. Therefore, learning probability theory requires not only procedural calculations but also students' probabilistic reasoning skills [3], in which students must draw conclusions from existing premises [4].

The existence of probabilistic reasoning makes it easier for students to understand random events rather than just memorize the procedure for calculating probabilities. Students can identify opportunities and present them as graphs and other representations [5]. Therefore, to develop probabilistic reasoning skills, an appropriate learning approach is needed to teach probability material [6].

One learning approach that can be applied is deep learning. Through this learning, students can explore, reflect, and construct the concept of probability [7]. During the

exploration phase, students observe an experiment. Subsequently, in the reflection phase, they compare the experimental results with their initial hypotheses. Finally, they construct concepts based on the outcomes of the exploration and reflection. That way, learning is more meaningful and encourages students to analyze, evaluate, and think critically [8]. In addition, lecturers also need to design learning media based on interactive simulations, investigations, and reflective discussions [8], [9], [10]. This makes learning engaging and more effective [11], [12].

Lecturers can use PhET simulations for classroom instruction. In the PhET simulation, students can use many activities to visualize abstract probability concepts [13]. That way, the use of PhET simulation media motivates students to learn material concepts [14]. In the development of probabilistic reasoning, lecturers can apply deep learning integrated with PhET simulations. Through the PhET simulation, students can set and adjust variables [15]. That way, if integrated with deep learning, students can experiment virtually to construct a concept, solve a problem, practice critical thinking, and increase motivation to learn [9], [13], [16]-[21]

In learning probability theory, students need to understand the use of appropriate rules, notation, and procedures in the context of the problem [22]. Students also need to be able to reason to analyze, see the relationships between variables, and compile material concepts [4]. However, the learning of probability theory so far remains oriented towards calculating probabilities, leaving students' probabilistic reasoning skills underdeveloped.

As a result, students understand probability theory as a theory of calculation, without understanding the meaning of the events that occur. Some students find probability material difficult to understand. In addition, there are often misconceptions among students regarding the study of probability theory material [23]. At the university level, there are 42% terminology misconceptions, 44.7% conceptual misconceptions, 47.8% misconceptions of principles, 51% algorithmic misconceptions, and 52% [24].

This condition indicates the need for learning that makes students active in constructing mathematical concepts in depth and emphasizes probabilistic reasoning, rather than just learning procedures and formulas [25], [26]. On the other hand, probability reasoning develops relatively slowly; a proper and continuous learning strategy is needed [27]. Deep learning is considered relevant for classroom use, but many lecturers have not applied it consistently [28]. Thus, the application of deep learning to probability theory learning remains limited and has not been fully optimized.

The use of PhET simulations can be integrated with various learning approaches to facilitate the construction of material concepts[29]. Although PhET simulations are still relatively new, many studies recommend them [30]. However, the teaching of probability theory within the mathematics education study program at Universitas Muhammadiyah Purworejo has yet to utilize such media. Consequently, students encounter difficulties in constructing the concepts covered in the course material.

Whereas PhET simulations provide features that are easy to access and align with deep learning [31]. Students can foster creativity and critical thinking by exploring concepts through simulations in the PhET simulation [31]. However, there is still very limited research that uses deep learning assisted by PhET simulations to develop probabilistic reasoning abilities. The integration of deep learning and PhET Simulations is expected to provide students with opportunities to explore, reflect upon, and construct concepts independently. Therefore, this study focuses on examining the effectiveness of deep learning supported by PhET Simulations on students' reasoning abilities.

Problems in probability learning can be overcome by applying a deep learning approach integrated with PhET Simulations. Deep learning provides students with opportunities to explore, reflect, and construct their own concept of probability, making learning more meaningful. PhET Simulations provide interactive simulations that allow students to reason as they construct the concept of probability. The purpose of this study is to test the effectiveness of deep learning assisted by PhET Simulation on students' probabilistic reasoning skills.

2. Methods

This study employed a quantitative, one-group pretest-posttest design. This design was chosen because the researcher wanted to see changes in probabilistic reasoning abilities in one class. The researchers compared the initial and final conditions after the learning treatment. That way, researchers can describe the effectiveness of applied learning. Therefore, this study uses 1 experimental class, in which students are given pretest questions before treatment and posttest questions after deep learning treatment assisted by the PhET simulation. The effectiveness of deep learning assisted by PhET simulations is measured by comparing pre- and post-test scores.

This study examined the population of students in mathematics education who took the probability theory course in the 2025/2026 academic year. The sample in this study was obtained using saturated sampling, i.e., all members of the population. 27 students took the Theory of Probability course. Then, students received a deep-learning treatment assisted by a PhET simulation.

The research was conducted over five sessions, with each session involving in-depth instruction supported by PhET Simulation media. A pretest was administered prior to the first session. To facilitate learning, students used instructional modules provided by the lecturer. Deep learning, assisted by PhET simulations, is applied through stages of exploration, reflection, and concept construction. At the exploration stage, lecturers provide contextual problems related to the probability materials. Furthermore, students use PhET simulations to visualize and observe problems. In the reflection stage, students discuss the results of the observations obtained and relate them to the concept of probability. In the concept construction stage, students construct the concept of probability from observational results. This stage encourages students to understand the concept of probability in depth, think critically, and reason. A posttest was conducted during the final session.

The instrument used in this study was a probabilistic reasoning test consisting of 6 essay questions. The probabilistic reasoning test instrument was compiled based on probabilistic reasoning indicators. The probabilistic reasoning indicators used in this study are identifying random events, interpreting the meaning of probability, relating mathematical representations to the problem context, and compiling arguments against the results obtained. With these indicators, students are not only asked to perform mathematical calculations but also to explain the thinking process used to determine opportunities. Before being given to students, the probabilistic reasoning test questions were first validated by Prasetyo Budi Darmono, M. Pd., as a lecturer of the Mathematics Education Study Program. The validator checked the suitability of the instrument content with the probabilistic reasoning indicators. Besides that, it also checks the clarity of language and the accuracy of questions in measuring probabilistic reasoning abilities. The instrument validation results indicate that it is suitable and can be used for data collection. The reliability of the instrument was assessed using Cronbach's Alpha coefficient. The analysis yielded a Cronbach's Alpha value of 0.82, indicating that the instrument possesses good internal consistency and meets the reliability criteria employed in this study.

The scoring guidelines for the probabilistic reasoning test are compiled using assessment rubrics aligned with the probabilistic reasoning indicators. Each student's answer is judged not only by the accuracy of the final answer. Rather, a score is given based on the preparation of the sorting steps, the accuracy in applying the concept of opportunities, and the accuracy in providing arguments related to the answers. That way, the assessment not only focuses on the results of the calculation but also on students' reasoning as they work on the problem.

Once the data are obtained, they are analyzed using the Jamovi application. The first step of the descriptive statistical test is used to determine the average score and standard deviation of the pretest and posttest. The next step is to conduct a Shapiro-Wilk normality test to determine whether the data are normally distributed and to test the effectiveness of the treatment using a paired-samples t-test. The magnitude of the influence of deep learning assisted by PhET simulation was calculated using Cohen's d effect size. The significance level used in this study was 0.05, and the confidence interval was 95%.

3. Result and Discussion

The research was carried out in the odd semester of the 2025/2026 academic year in the Theory of Probability course. Deep learning, assisted by the PhET simulation, was conducted across 5 meetings. Before and after treatment, students were given probabilistic reasoning test questions, up to 6 descriptive questions. The descriptive statistics are shown in Table 1.

Table 1. Descriptive Statistics Results

	N	Mean	SD	SE
Pretest	27	60.2	20.7	3.99
Posttest	27	70.7	16.5	3.18

The data show an increase in the average score from the pretest to the posttest. This indicates an increase in students' probability reasoning after the implementation of deep learning assisted by PhET simulation.

Before testing effectiveness, the pretest and posttest data were tested for normality. This test was used to determine whether the pretest and posttest data were normally distributed. The result of the normality test is shown in Table 2.

Table 2. Normality Test Result

	different
N	27
Missing	0
Mean	10.6
Median	10
Standard deviation	-25
Minimum	45
Maximum	0.974
Shapiro-Wilk p	0.704

From the table above, we get that the pretest score was $p = 0.083$, and the posttest score was $p = 0.080$. Because $p > 0.05$ for both pretest and posttest scores, both can be considered normally distributed.

The next step is to conduct an effectiveness test using a paired-samples t-test. The test results are shown in Table 3.

Table 3. The result of the paired-samples t-test

		statistic	df	p
Pretest posttest	Student's t	-3.53	26.0	0.002

The effect size is shown in Table 4.

Table 4. Effect size test result

		95% Confidence Interval	
	Effect size	Lower	Upper
Cohen's d	-0.680	-1.09	-0.255

Based on the table above, an effectiveness test was carried out using a paired-samples t-test, yielding t = -3.53 and p = 0.002. Because p = 0.002 < 0.05, the pretest and posttest scores differ significantly. Cohen's d effect size was -0.680, which is in the medium category. In other words, students' probabilistic reasoning improved significantly after being given deep learning assistance using PhET simulations.

After deep learning, students can understand and explain the concept of probability, not just calculate the probability value of an event. Through deep learning, students are encouraged to interpret random events, relate mathematical representations to the problem context, and formulate arguments. Students are not only looking for the final answer, but must include reasons, assumptions, and the relationships between concepts. Thus, deep learning encourages students to understand material concepts carefully and develop probabilistic reasoning. With probabilistic reasoning, students better understand the uncertainty of an event, not just a definitive answer [32]

To develop probabilistic reasoning, deep learning proceeds through three stages: exploration, reflection, and concept construction. In the exploration stage, students are asked to study a probability problem and then identify it. In the reflection stage, students interpret the results of their thinking and then associate the concept with random events. At the concept construction stage, students are guided to find the concept of probability. These learning stages also align with the mathematics learning framework, which comprises 5E elements: Engage, Explore, Explain, Elaborate, and Evaluate [33]. So learning does not only focus on the use of procedures but rather on the development of probabilistic reasoning.

The use of PhET simulations helps students experiment virtually to explore the concept of probability; students are required to reason to determine the experiment's conclusion. One of the challenges in learning mathematics is constructing abstract mathematical concepts [34]. A PhET simulation helps students visualize the concept of probability, making it no longer abstract [35]. Students can also repeat the simulation until they understand the material's concept [36]. In other words, students can use the PhET simulation independently at home to conduct experiments repeatedly. Through the simulation, students can observe variations in results and the probability patterns that emerge, then interpret these observations and draw probabilistic conclusions. Through the observation process, students understand that probability does not only involve calculations but also how an event arises from the experiments carried out. In addition, students can change variable values and observe the resulting changes. That way, students can solve problems using their conceptual understanding and probabilistic reasoning [29], [37]-[40].

The findings indicate a statistically significant difference in students' probabilistic reasoning scores before and after the implementation of deep learning assisted by PhET simulations. Deep learning enables students to actively explore, reflect, and construct the concept of probability. Meanwhile, the PhET simulation helps students understand probability. With this simulation, students can conduct probability experiments independently or in groups, building understanding through observing random experiments rather than just learning counting procedures. Through this observation process, students are encouraged to think and reason to understand the concept of probability. The integration of the two encourages students to develop probabilistic reasoning skills, making learning more conceptually meaningful. These findings demonstrate that learning probability theory is more meaningful through virtual simulations than simply memorizing formulas. Students learn probability through patterns that emerge from repeated experiments, making it easier for them to grasp abstract probability concepts. Therefore, students' conceptual understanding and probabilistic reasoning can develop when PhET simulations assist deep learning.

The implications of this study indicate that deep learning can be applied to probability learning. Through this learning, students not only learn the procedure for calculating probability, but can also explore, reflect, and construct the concept of probability. With PhET simulation media, students can observe and construct concepts in depth. Therefore, deep learning integrated with PhET simulations can be used as an innovative approach to developing probability reasoning. This research can also serve as a reference for the development of the quality-of-learning theory of probability, which further develops reasoning skills and conceptual understanding.

This study has several limitations, including the absence of a control group, which means the findings cannot be broadly generalized. This research is also limited by the material on probability. So the effectiveness of learning may differ if applied to other materials. Another limitation is that it has not been analyzed in detail with respect to the development of probabilistic reasoning for each indicator. This study examines the development of probabilistic reasoning as a whole using pretest and posttest scores. For further research, it is recommended to use more classes, use other probability materials to develop probabilistic reasoning further, and examine the development of probabilistic reasoning in detail.

4. Conclusion

The results of this study indicate a significant difference between the pretest and posttest scores for students' probabilistic reasoning abilities following the implementation of deep learning supported by PhET Simulations. In deep learning assisted by PhET simulations, students explore, reflect, and construct concepts virtually, requiring them to reason to identify the concept of probability. This makes learning more meaningful rather than merely focusing on procedural calculations. These findings show that, in probability learning, it is necessary to design innovative learning experiences that develop probabilistic reasoning skills. Therefore, PhET simulation-assisted deep learning can be used as an innovative learning tool in the classroom to develop probabilistic reasoning skills.

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