Improving Learning Activity and Concept Mastery in Physics for 12th Grade Students Using a Virtual Lab (PhET Simulation)

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ABSTRACT

The Virtual Lab is one of the flagship products resulting from advances in information technology and laboratory development. By using a Virtual Lab, students can utilize laboratory equipment that cannot be physically presented and meet learning needs when teaching aids are unavailable. The use of the Virtual Lab is expected to enhance student learning activity and mastery of physics concepts for 12th-grade students during the odd semester at SMAN 1 Punduh Pedada. Following the implementation of learning activities using the Virtual Lab from one cycle to the next, the average student activity score increased from Cycle I to Cycle II. In Cycle I, the average student activity score was 84.08, categorized as active, while in Cycle II it rose to 89.34, also in the active category. Students' average concept mastery score also increased by 14.16 points, from an average of 66.62 in Cycle I to 80.78 in Cycle II. This improvement occurred because students found it easier to understand concepts explained by the teacher through the Virtual Lab. However, there were still some students whose concept mastery remained at a fair level, and only slight improvements were seen in several subtopics tested. This may be due to students' weaknesses in mathematical operations when solving test problems. Based on the average scores of student activity and concept mastery tests, it can be concluded that learning using the Virtual Lab can improve students' mastery of physics concepts.

Keywords
Virtual Lab; Activity; Concept Mastery; Physics; 12^{th} Grade Students

Introduction

Efforts to improve the quality of education in Indonesia are currently marked by the implementation of the *Merdeka Curriculum*. To achieve national education goals, Indonesia has introduced the *Merdeka Curriculum* as part of an educational reform aimed at producing a high-quality future generation (Putri and Nukman, 2024). Nationally, the positive effects of implementing the *Merdeka Curriculum* are evident in the increased literacy and numeracy learning outcomes in educational institutions applying this curriculum, compared to those still using the 2013 Curriculum (Aditomo, Badan Standar, and Asesmen Pendidikan, n.d.).

One of the improvements brought by the *Merdeka Curriculum* is the enhancement of students' literacy skills. Among these, digital literacy has become an essential competency, enabling students to optimize their abilities in the field of digital technology. Teachers are also expected to possess competent technological knowledge, as technology has become an integral part of modern education (Sri Athena Barus et al., n.d.). In this context, 21st-century learning is crucial, as students are not only expected to gain knowledge but also to develop critical thinking, collaboration, creativity, and communication skills. These 21st-century skills are imperative in today's educational landscape (Herlinawati et al., 2024).

Given this, Physics—being one of the subjects taught under the *Merdeka Curriculum*—requires teachers to fully utilize current technologies to help students better understand the subject. Physics often deals with abstract concepts that can be more easily grasped with the aid of technology. The learning process should also meet the demands of 21st-century skills by being student-centred, engaging, and technology-integrated. It should encourage students to be active participants, gaining empirical experience through observation or experimentation to achieve the learning objectives.

At SMAN 1 Punduh Pedada, physics learning is still largely teacher-centred. Students rarely express their opinions and often lack confidence in their knowledge. Their participation is low due to monotonous learning methods that fail to engage them. Student engagement in learning should focus on understanding problems and actively participating in the learning process (Pawarrangan, Aprilo, and Angriawan, 2024). Low student engagement often results in passivity during lessons. This condition stems from the limited availability of reading materials, information sources, and inadequate teaching aids and laboratory facilities. This aligns with research literature findings showing that more active learning generally yields better outcomes (Dancy et al., 2024).

Efforts to improve physics learning activities in the classroom have been made by teachers through the development of Physics Study Guide. This guide is expected to be the main reference that fosters student activeness in learning physics. In reality, students do follow the teacher's instructions, use the study guide, and do the exercises. However, data and observations show that these activities have not been effective in improving students' activity and conceptual mastery of physics.

The condition that arises is the low active participation of students in the learning process. Students tend to be passive, rarely ask questions, reluctant to express opinions, and minimal interaction during class discussions. This condition has a direct impact on learning outcomes. Based on the data of physics learning outcomes of class XII students at SMAN 1 Punduh Pedada, the average achievement for the learning objectives of describing and identifying the characteristics of light waves and their application in technology is only 56.6%. This figure is far below the Learning Objective Completion Criteria (KKTP) set at 70% according to the Merdeka Curriculum.

The results of interviews with students show that the main problems that arise are students find it difficult to understand physics phenomena explained abstractly by the teacher, and the material in the guidebook tends to be too theoretical and not contextualized, so students are reluctant to discuss and often experience confusion or misinterpretation. Ideally, the role of technology, particularly the PhET Virtual Lab, offers a promising solution. As a product of advancements in information and laboratory technology, Virtual Labs allow students to simulate laboratory experiences that cannot be provided in real life. This makes learning more engaging and enhances students' conceptual understanding. When students used the PhET simulation in class, they responded positively, finding the content more engaging and becoming more motivated to learn. Their comprehension and mastery of the material also improved (Puspitasari, Subiki, and Supriadi, 2022). This is further supported by Sasmita, Hartoyo, and Sutrisna (2023), who found that PhET interactive simulations positively affect students' understanding of physics concepts.

Based on the discussion above, utilizing the PhET Virtual Lab is considered an appropriate alternative to compensate for the lack of practical tools and to facilitate better understanding of abstract physics concepts. Using the PhET Virtual Lab in 12th-grade physics classes at SMAN 1 Punduh Pedada can improve students' learning activity and conceptual mastery.

Research Objectives: 1**)** To improve the learning activity in 12th-grade physics classes during the odd semester at SMAN 1 Punduh Pedada through the use of the PhET Virtual Lab; 2)To enhance students' conceptual understanding of physics in 12th-grade odd semester classes at SMAN 1 Punduh Pedada using the PhET Virtual Lab.

The results of this study are expected to serve as one of the solutions to the limitations in facilities, by replacing real tools with the PhET Virtual Lab simulations, ultimately improving students' engagement and concept mastery in physics learning.

Literature Review

PhET Simulations are one of the virtual laboratory options available online for students and professionals in the field of Physics. These simulations were developed by the University of Colorado Boulder and are widely used in educational settings around the world. PhET simulations offer a variety of interactive physics experiments that allow users to explore various concepts and principles in a virtual environment (Mashami et al., 2023). PhET facilitates more than 80 interactive simulations that meet science learning objectives in various countries, and most physics experiments can be conducted virtually (Durkaya, F., 2022).

A meta-analysis of 15 international studies showed that the use of virtual simulation (including PhET) significantly improved the physics learning achievement of secondary level students, with a large effect size (g = 0.941). This effectiveness is consistent across different regions of the world, not just Asia, but applies to different grade levels and implementation durations (Antonio, R., Castro, R.,2023).

Interactive PhET simulations play a crucial role in enhancing and developing conceptual understanding among students in physics (Banda and Nzabahimana, 2021). The implementation of PhET virtual simulations in schools can improve student learning outcomes. Moreover, learning management by teachers using the PhET Virtual Lab has also shown improvement, which positively impacts student activity and achievement (Halim et al., 2021). Another study conducted by Almadrones, R., Tadifa, F. (2024) showed that learning integrated PhET Simulation in physics learning can improve concept mastery and student performance on demonstrative physics applications. PhET is also recognized as an effective virtual laboratory to assess student performance.

Interpreting activity in learning refers to the involvement of students and lecturers/teachers during the learning process, such as participation in discussions, assignments, or practices. Measuring student activity through the percentage of activeness during PBM (Teaching and Learning Process), for example, the average student activity in PBM can reach 78.80% and is categorized as “good” to “very good” (Fitriani, 2024). Meanwhile, good mastery is defined as students' achievement of competencies or subject matter until they reach the predetermined completeness criteria. Good mastery is usually measured by the percentage of classical learning completeness, for example, learning completeness reaches 85.71% or even 100% after the intervention of certain methods (Winget & Persky, 2022).

Methods

This research was conducted at SMAN 1 Punduh Pedada. The research subjects were 37 12th-grade students (odd semester) in the 2024/2025 academic year, consisting of 17 female students and 20 male students. This study focused on a 12th-grade class with the following characteristics:1) Students’ learning activity in physics is relatively low. 2) Many students have not yet achieved the KKTP (Learning Objective Achievement Criteria).

The research procedure follows a classroom action research model, with steps adapted from the classroom action research design proposed by David Hopkins (1993) (classroom-research-hopkins, n.d.). In general, the steps of this research are illustrated in the diagram (not included here).

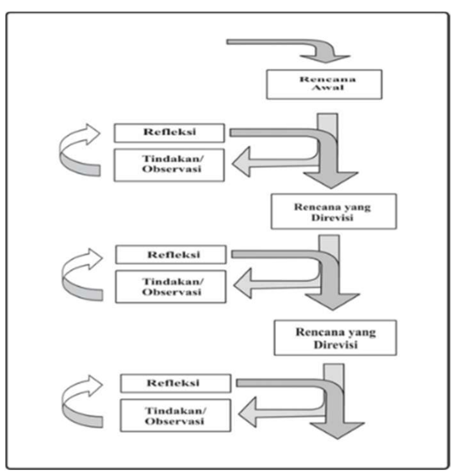

Figure 1. Action Research Cycle of Kemmis and Mc Taggart in David Hopkins (1993)

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The research method used in this study is Classroom Action Research by David Hopkins (1993), with the following general stages: 1) Field Orientation / Theoretical Study (fact-finding and analysis); 2) Learning Planning; 3) Implementation of Action; 4) Evaluation / Monitoring of Implementation and its Effects; 5) Reflective Evaluation / Identifying Constraints and Effects of Implementation; 6) Follow-up (return to stage 1 and repeat as needed).

Research Instruments

The instruments used in this research include: 1) Student activity observation sheets during the learning process; 2) Test sheets to assess students' mastery of the material (cognitive aspects); 3) Focused teacher observation sheets.

The data collected consists of qualitative data from the observation of the teacher-researcher during the learning process, and quantitative data in the form of students' cognitive learning outcomes taken at the end of each cycle.

Student learning activity data was collected at each meeting using observation sheets. Data was gathered by marking a checklist (√). The observed aspects included behaviours relevant to the learning activities, such as: 1) Student interaction in group learning activities, including discussions and working on worksheets; 2) Student confidence in asking questions and expressing opinions; 3) Participation in learning activities, including watching or performing demonstrations and consistently following teacher instructions; 4) Motivation and enthusiasm in completing individual assignments and actively solving problems using references; 5) Peer relationships during classroom discussions; 6) Student-teacher interaction during the learning process.

Data Analysis

The analysis process for student activity data was carried out using the guidelines for student activity categories according to Memes (2001: 36): student activity value 75.6 (active), if 59.4 student activity value < 75.6 (moderately active), student activity value < 59.4 (less active).

Data on students' concept mastery is obtained from the actual assessment, namely from the results of the final test in each cycle in the form of concept and application questions. If the student test results ≥ 66, then it is categorized as good, if 55 ≤ student scores ≥ 66, then it is categorized as good enough, and student scores < 55, then it is categorized as poor (Arikunto, 2008).

Results

Cycle I

Observation Results of Student Activities in Learning

Student activity during the learning process using the Virtual Lab was observed using a structured observation sheet prepared by the researcher. The data on student activity is presented in the table below:

Table 1. Distribution of Student Activity Scores – Cycle I

Activity Score (x)	Number of Students	Percentage	Criteria
$x \geq 75.6$	30 students	81.10%	Active
$59.4 \leq x < 75.6$	7 students	18.90%	Moderately Active
$x < 59.4$	0 students	0%	Less Active
Total	**37 students**	**100%**	-

Table 2. Description of Student Activity in Learning – Cycle I

Indicator	% Activity	Category
1. Student interaction in group-based learning activities (PBM)	93.69%	Active
2. Student confidence in asking questions and expressing opinions	77.47%	Active
3. Participation in PBM (observing/participating in demonstrations, following teacher instructions)	83.78%	Active
4. Motivation and enthusiasm in PBM (completing individual tasks, actively solving problems using references)	92.79%	Active
5. Peer interactions during PBM (class discussions)	80.18%	Active
6. Student-teacher interactions during PBM	76.57%	Active
Average student activity score	**84.08%**	**Active**

Based on the results in Table 1, out of 37 students observed in Cycle I, 30 students (81.10%) were categorized as active, 7 students (18.90%) as moderately active, and 0 students (0%) as less active. Table 2 shows that student activity in terms of group participation, motivation and enthusiasm, peer interaction, and general engagement in PBM was considered active.

However, confidence in asking questions and expressing opinions, as well as interactions with teachers, although still categorized as active, had the lowest percentages among all indicators. This may be due to students still feeling shy or hesitant during the learning process. Some students preferred to ask their peers within the group first or would ask a braver peer to raise the question on their behalf.

Overall, student activity in the learning process using the Virtual Lab in Cycle I was good, with an average activity score of 84.08%, which meets the "good" criteria.

Results of Concept Mastery Test

At the end of each cycle, students were given a concept mastery test. The goal of the test in Cycle I was to determine students' understanding of the learning target: *"applying magnetic induction and magnetic force in several technologies."* The results are presented in the following table:

Table 3. Distribution of Concept Mastery Test Results – Cycle I

Activity Score (x)	Number of Students	Percentage	Criteria
$x \geq 66$	20 students	54.06%	Good
$55 \leq x < 66$	8 students	21.62%	Fair
$x < 55$	9 students	24.32%	Poor
Average score	**37 students**	**66.62**	**Good**

Based on Table 3, 20 students (54.06%) had good concept mastery, 8 students (21.62%) were in the fair category, and 9 students (24.32%) were in the poor category. Some students still lacked conceptual understanding in certain sub-topics, likely due to difficulties with mathematical operations during the test.

The average score of 66.62, after using the Virtual Lab in Cycle I, is classified as "good" according to Suharsimi Arikunto's criteria.

Cycle II

Analysis of Student Learning Activities.

The data for student activity in Cycle II is shown in the Table 4 and 5.

Table 4. Distribution of Student Activity – Cycle II

Activity Score (x)	Number of Students	Percentage	Criteria
$x \geq 75.6$	34 students	91.90%	Active
$59.4 \leq x < 75.6$	3 students	8.10%	Moderately Active
$x < 59.4$	0 students	0%	Less Active
Total	**37 students**	**100%**	-

Table 5. Description of Student Learning Activity – Cycle II

Indicator	% Activity	Category
1. Student interaction in group-based learning activities (PBM)	95.49%	Active
2. Student confidence in asking questions and expressing opinions	79.27%	Active
3. Participation in PBM (observing/participating in demonstrations, following teacher instructions)	83.78%	Active
4. Motivation and enthusiasm in PBM (completing individual tasks, actively solving problems using references)	98.19%	Active
5. Peer interactions during PBM (class discussions)	91.89%	Active
6. Student-teacher interactions during PBM	87.39%	Active
Average student activity score	**89.34%**	**Active**

According to the data in Table 4 and Table 5, student activity in Cycle II showed improvements across all indicators: interaction in groups, participation, motivation and enthusiasm, peer and teacher interaction, and confidence in communication—all were categorized as active.

Student activity using the Virtual Lab in Cycle II generally improved, with an increase of 5.26% compared to Cycle I. This improvement is believed to be due to better classroom management by the teacher and students becoming more familiar with the Virtual Lab learning method. The average student activity score reached 89.34%, which falls under the "good" category.

Students' Concept Mastery Test Results

At the end of each cycle, students were given a concept mastery test. The purpose of the test in Cycle I was to determine the extent of students' understanding of the basic competency: "applying magnetic induction and magnetic force in various technologies," after implementing the learning process using a Virtual Lab. The data on students' physics concept mastery in Cycle II can be seen in Table 6.

Table 6. Distribution of Students' Concept Mastery Test Results in Cycle II

Activity Score (x)	Number of Students	Percentage	Criteria
x ≥ 66	30 students	81.08%	Good
55 ≤ x < 66	7 students	18.92%	Fair
x < 55	0 students	0%	Poor
Average Score	37 students	80.78	Good

Based on Table 5, it can be seen that out of 37 students who took the concept mastery test, 30 students or 81.08% had a good level of mastery, 7 students or 18.92% had a fair level of mastery, and 0 students or 0% had a poor level of mastery. Based on the analysis, most students struggled with questions related to Electromotive Force (EMF) induction where magnetic flux changes due to a change in the angle of the magnetic field entering the coil. Additionally, some students showed only a slight improvement in certain subtopics, likely due to difficulties with mathematical operations when solving test problems.

From the calculations, the average concept mastery score of students after the implementation of Virtual Lab-based learning in Cycle II was 80.78, which, according to Suharsimi Arikunto's criteria, is considered good.

Discussions

Learning activities encompass all physical and mental efforts of students that support their academic success. The more active students are, the better they are expected to understand and master the material delivered by the teacher.

The average student activity score in Cycle I was 84.04, which increased to 89.34 in Cycle II. According to Wayan Memes' activity criteria, student activity in both Cycle I and Cycle II was classified as active. Observational data showed that student activity increased across each cycle, including participation in learning activities, motivation and enthusiasm, interaction within groups, student-teacher relationships, courage to ask questions or express opinions, and peer interactions.

In Cycle I, students' average activity score using this method was 84.04, already categorized as active. However, in Cycle I, aspects such as students' courage to ask questions or express opinions and the student-teacher relationship showed the lowest percentages among all indicators. This was because many students still felt hesitant or shy to speak up during class. If something was unclear, they preferred to consult peers first or ask a braver friend to speak up.

In Cycle II, student activity increased by 5.30 points. This improvement was due to better classroom management by the teacher and students becoming more familiar with the Virtual Lab learning method. They began to ask questions confidently, express opinions without hesitation, and actively work on exercises and independent tasks at the end of each lesson. From these observations, it can be concluded that learning using Virtual Lab helps enhance students' learning activity.

The average concept mastery score increased from 66.62 in Cycle I to 80.78 in Cycle II. Based on Suharsimi Arikunto's classification, students' concept mastery in both cycles was categorized as good. The data showing student progress in concept mastery from one cycle to the next can be seen in the following graph.

Based on the analysis of Cycle I, some students still had poor mastery in specific subtopics due to weaknesses in mathematical operations needed to solve test problems. In Cycle II, the average concept mastery score improved by 14.16 points compared to Cycle I. This improvement was likely because students began to understand concepts more easily when delivered through the Virtual Lab. However, most students still struggled with problems related to EMF induction caused by changing magnetic flux angles, and there was only slight improvement in some subtopics due to students' general weakness in solving mathematical problems.

Conclusion

Based on the results of research that has been conducted in class XII IPA odd semester SMAN 1 Punduh Pedada, the use of PhET Virtual Lab proved effective in improving learning activities and mastery of physics concepts of students. The average value of student activity increased from 84.08 in cycle I to 89.34 in cycle II, both classified as active. Then, the average value of students' concept mastery increased from 66.62 in cycle I to 80.78 in cycle II, both classified as good.

The results of this increase are in line with previous research which shows that the use of technology-based learning media, such as PhET Virtual Lab, can improve students' physics activity and concept understanding. Other studies have also reported that PhET can facilitate interactive learning, increase motivation, and assist students in understanding abstract physics concepts more concretely through visual simulations and virtual experiments.

Limitations and Future Studies

There are still some students who have not mastered the concepts well, especially in subtopics that require better mathematics. Assessment of student activities and concept mastery was carried out using observation instruments and tests developed by the researchers themselves, so there is a possibility of subjectivity in the assessment process. Given these drawbacks, it is advised that future research create or incorporate specialized modules meant to improve students' mathematical abilities, especially for physics subtopics that call for a higher level of mathematical competence. Furthermore, to reduce subjectivity in assessing student actions and concept mastery, future research should make use of established and externally validated evaluation tools. To improve the review process's objectivity and accuracy, it is also advised to use technology-based assessment tools or involve numerous assessors.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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