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The Effect of Flipped Classroom Learning Assisted by Computer Simulation on Students' Comprehension of Simple Harmonic Motion

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Abstract: Innovation in science learning is highly recommended by various studies and education experts. Through this learning innovation, teachers create learning that facilitates students' curiosity by getting them involved in learning, which ultimately helps them understand science in depth. However, the current trend is that science classes "fail" to create innovative learning that can foster students' interest in science, so that many students do not understand science well. This research aims to determine the impact of flipped classroom learning on simple harmonic motion material assisted by computer simulations on students' conceptual understanding. A pre-experiment with a one-group pretest-posttest design was used in this research. Class X of the MIPA program was chosen as the experimental object in this research, and 30 students were used as samples. The test given is a multiple-choice test with explanations. The results showed that the average post-test score was better than the pre-test. The N-gain score is 0.79, which indicates that there is an increase in students' understanding in the high category. This shows that flipped classroom learning assisted by computer simulations can increase students' understanding of the concept of simple harmonic motion. By implementing computer simulation activities that are integrated into flipped classroom learning, learning alternatives can be enriched to help students understand science.

Keywords: Computer simulation; Flipped classroom; Harmonic motion; Physics learning

Introduction

Physics learning is an active process in which students observe occurrences, ask questions, gain information, explain natural phenomena, test their answers, and communicate their thoughts. Physical activity is insufficient; pupils must also get cognitive experience. This implies that learning physics encourages students to investigate and take action to obtain a better grasp of the natural world around them (Karamustafaoğlu et al., 2015; Marcelina et al., 2021; Ndoa et al., 2022).

According to studies, one of the most challenging courses for high school students to learn is physics. Aini et al. (2023) discovered that physics instruction tends to highlight the process of remembering formulae, which causes high school students to detest physics. Wahyudi et al. (2022) discovered that students believe that understanding physics equates to memorizing and applying several formulas. This conclusion is also

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consistent with research done by Sunardi et al. (2022), which discovered that physics instruction is overly mathematical with several formulas. According to the findings of a survey done by Erinosho (2013) and Lederman et al. (2014), students regard physics as a difficult, abstract, and boring topic that is only appropriate for highly skilled students. Following this, Sarabi et al. (2018) discovered that many secondary school pupils were disinterested in learning physics, citing the fact that it is extremely difficult. According to a survey done by Hartanto et al. (2015), 74% of students in multiple secondary schools in Palangka Raya find physics to be a difficult and boring subject, with the major cause being the excessive number of formulae. Students' learning results reflect the difficulty of physics subjects. Interviews with physics subject instructors at one of Palangka Raya's high schools revealed that student learning results were unsatisfactory; in other words, students continued to struggle with learning and understanding physics content.

Based on student observations at the school where the research was done, it also shows that pupils continue to lack freedom in their learning, relying mainly on what the instructor says in class. Students do not study and take notes on items they do not grasp at home before beginning the physics lesson material in class. Students only study alone if the teacher assigns homework relating to the content covered that day. This implies that student learning freedom is still unsatisfactory. Kaleka et al. (2023) argue that autonomous learning is critical for children to absorb what they are learning, seek references, solve issues independently, and develop a sense of responsibility.

In particular, based on talks with teachers about simple harmonic motion, learning is still expressed orally, and tasks are given by working on mathematical problems and formulae. Learning about simple harmonic motion continues to rely on formulae, such as solving quantitative problems with the equation for the period of a pendulum or the equation for the period of a spring swing. Due to limited equipment, the use of laboratories to help students understand concepts in depth (Lee et al., 2018) remains not possible, so teachers prefer to convey this harmonious motion material orally and provide questions and exercises. According to the reality in the area, instructors play the primary role in learning, while students are passive learners. According to Honey et al. (2011), even though students arrive to science classes with a lot of questions, science classes have trouble responding to them since class time is spent listening to teachers' explanations and remembering the content. This influences high school graduates who lack a strong knowledge of science (Şahin, 2009). Furthermore, the teacher supplied information that this simple harmonic motion content was a tough issue for students. Student learning results were still poor, which was a measure of students' problems on this topic.

Experts in education and learning suggest innovative ways to scientific learning (Karamustafaoğlu et al., 2015; Smetana et al., 2012). This innovative method to learning needs teachers increases students' interest in studying science by including them in the investigation process and assisting them in comprehending topics. Computer simulations offer enormous potential to accelerate this new learning paradigm. Computer simulations enable students to examine and interact with representations of natural events, which aids in the development of valid scientific interpretations for such occurrences. Computer simulations encourage students through challenges and immediate feedback (Smetana et al., 2012). Aside from that, computer simulation may overcome the limitations of real-world laboratory equipment, and computer simulation media are inexpensive to utilize (Abiasen et al., 2021).

Physics Education Technology (PhET) is a computer simulation that is commonly utilized nowadays. PhET Simulation makes it simple to conduct research-based and interactive simulations for mathematics and science learning. PhET simulations are interactive and user-friendly since they may be utilized both online and offline (Bello, 2022). In this study, PhET is extremely important and relevant to the material of simple harmonic motion. PhET offers two simulators on harmonic motion: "Mass and Springs," which simulates spring swings, and "Pendulum Lab," which simulates pendulum swings. PhET Simulation offers virtual laboratory equipment for carrying out and performing experiments on simple harmonic motion materials. For example, students can explore the swing of a pendulum as an ideal system, varying the mass and length of the string to discover how these factors affect the motion of the pendulum swing. Students can also use PhET simulations to study how gravity impacts the swing of a pendulum. Furthermore, bar graphs of kinetic energy, potential energy, and thermal energy are provided during the simulation to demonstrate energy changes in the pendulum system.

The combination of PhET with specific learning methods tends to make the learning process more interesting, implying that technology is used as a complement to create meaningful learning experiences (Hartanto et al., 2023; Sarabando et al., 2014; Smetana et al., 2012; Susilawati et al., 2022; Wieman et al., 2010). The flipped classroom paradigm is one learning approach that may be used with PhET. Researchers generally agree that the flipped classroom approach consists of two consecutive phases: pre-class preparation and in-class cooperation (Cheng et al., 2019), typical pre-class activities include reading given texts, watching videos, passing quizzes, and participating in asynchronous online discussions (Lai et al., 2016); Collaborative learning in groups and knowledge construction is the primary mode of instruction in the classroom (O'Flaherty et al., 2015). According to Walker et al. (2020) and Yilmaz et al. (2021), the flipped classroom requires students to discuss a topic at home (before class) through a short introductory video or other media that has been prepared by the teacher beforehand; then proceed with learning activities in class that deepen the topics studied and focus on various activities, such as projects, laboratory activities, discussions, and others. In other words, the flipped classroom shifts the focus of learning toward the student. According to Bergmann et al. (2012), the flipped classroom is an innovative student-centered learning paradigm that reverses the conventional classroom learning method implemented by teachers. The flipped classroom concept offers several advantages (Munir et al., 2018), such that students will have good attitudes, be receptive to new information, become more active, autonomous, and creative, and be more critical in addressing specific case issues.

This article aims to present an explanation of research findings on students' conceptual understanding of PhET-assisted flipped classroom learning at a public high school in Palangka Raya. The description of this research focused on simple harmonic motion, namely simple harmonic motion on a pendulum and motion on a spring.

Method

The present study utilized a pre-experimental quantitative approach with a one-group pretest-posttest design. This design was chosen for the reason that treatment was only given to a single group (one particular class) by first being given a pretest (initial test) and after being given treatment the sample was given a posttest (final test). The treatment outcomes may be determined by comparing the situations before and after treatment (Sudaryono, 2019).

Table 1. Flipped Classroom Learning Activities Assisted by PhET on the Topic of Simple Harmonic Motion in Pendulum Swings

Learning Activities	Description of Learning Activities
Study at home (pre-class)	Students first do the assignments given by the teacher. This task is done independently at each home. The teacher sends a link to the learning video and reading material about harmonious motion in pendulum swings. Students are asked to watch videos and read texts to help complete the assignments given by the teacher. The assignments given by the teacher include: What is meant by simple harmonic motion? What is a period? What is frequency? What is a pendulum? What is the restoring force on a swinging pendulum? Students are asked to answer these questions. These answers will later become the basis for learning activities in class. Students are asked to write their answers in writing as proof of having carried out the assignment. At this pre-class stage, students are reminded to prepare a PhET simulation that will be used in class meetings.
Study in class	Students present answers to assignments they have done at home in groups. Teachers help provide explanations when there are errors in students' homework results. Next, the teacher asks the question: What are the variables that influence the swing period of the pendulum? To answer this question, students in groups conducted experiments using the PhET "Pendulum Lab" simulation. In conducting experiments using PhET, students are guided by the Pendulum Swing Worksheet. There are four activities contained in the Pendulum Swing Worksheet. First activity: investigate the effect of string length on the swing period of the pendulum. Second activity: investigate the effect of gravitational acceleration on the swing period of the pendulum. Third activity: investigate the effect of mass on the swing period of the pendulum. Finally, students are guided to analyze the energy changes in the pendulum swing event. After the student groups have finished working on the experiment, the teacher asks each group to analyze and recheck the results of their work, then continue with a whole-class discussion. At the end of the lesson, the teacher gives a quiz (evaluation) to complete before leaving the class.

The research sampling approach applies a purposive sampling technique, which is a sample technique with specific concerns (Sudaryono, 2019). The researcher considers that the class chosen is the class that has the lowest learning outcomes compared to other classes. Using this selection strategy, just one set of students from class X in the Mathematics and Natural Sciences programs was chosen as a 30-person sample from one of Palangka Raya City's public high schools. This program focuses on simple harmonic motion topics using pendulum and spring swings. In addition, sampling was dependent on the school's class.

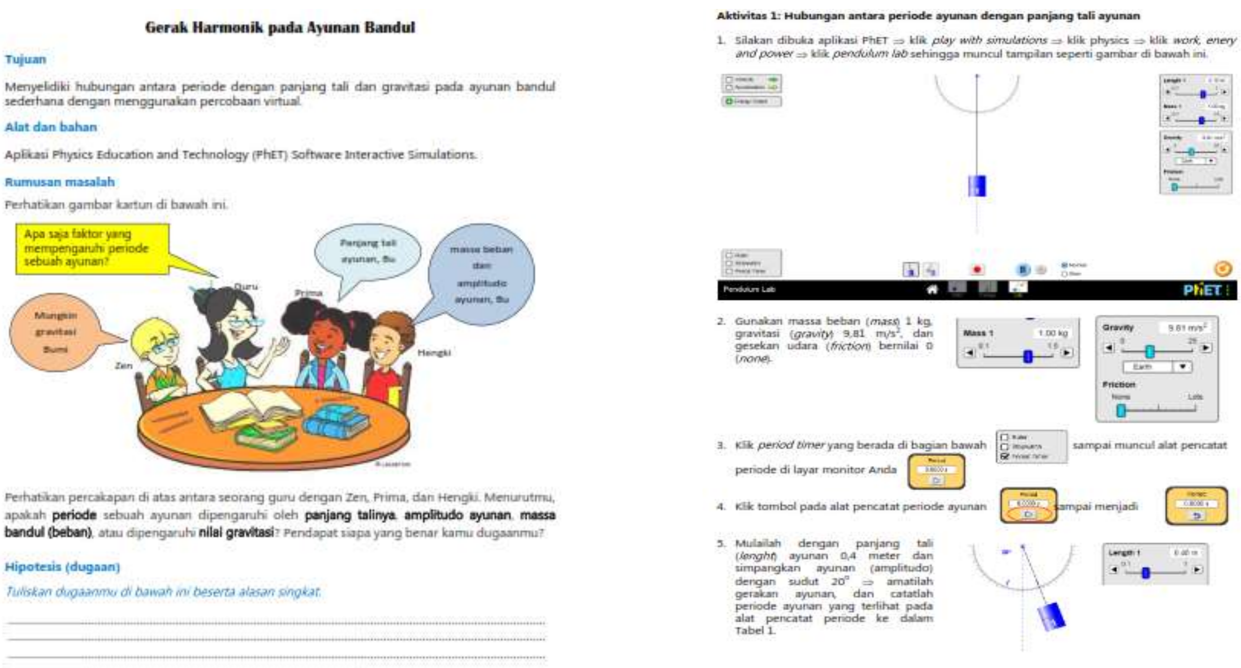
In this research, the treatment took the form of implementing flipped classroom learning. This flipped classroom learning was implemented in about four weeks. The study focused on harmonic motion in pendulum and spring swings. According to Petridou et al. (2022), the flipped classroom learning pattern is separated into two parts: (1) studying at home before class, and (2) learning activities in class. Table 1 provides an overview of the flipped classroom learning activities implemented in this study. This learning pattern was taken from the results of studies by Wei et al. (2020), Putri et al. (2019), Lo et al. (2018), and Husnaeni et al. (2019). To reduce difficulties with implementing learning, the teacher previously taught students what and how to use the PhET simulation media, ensuring that students did not encounter difficulties when utilizing the media.

The "Pendulum Lab" and "Mass & Spring" simulations are utilized in PhET learning. This simulation medium is believed to help students understand concepts and teachers explain information more clearly (Hartanto et al., 2023; Wijaya et al., 2021). During the class, students conduct PhET experimental tasks on computers or smartphones.

The PhET simulation used to assist flipped classroom learning activities has similarities to a real laboratory (Figure 1). Students can manipulate variables (for example, the mass of a load, length of rope, deviation) to determine the effect of these manipulations on other variables (for example, the swing period of a spring or the swing period of a pendulum). In Figure 1, variations can be made in the length of the rope (related to the first activity) and the mass of the pendulum (related to the third activity), assuming that the gravitational acceleration remains constant (Earth's gravitational acceleration) and that no friction occurs. The vibration period is shown in the box on the left. Students must pay close attention to the swing of the pendulum and calculate the value of the period of vibration correctly. Students also prove the effect of gravitational acceleration on the swing period of the pendulum (second activity). In addition, through PhET simulations, students can analyze energy transformations in a pendulum swing system.

Figure 1. Screenshot of PhET's interactive simulation for PhET's "Pendulum Lab" (http://phet.colorado.edu)

When class learning occurs, the teacher prepares worksheets to direct students through PhET activities. This worksheet provides a step-by-step tutorial to conduct simple harmonic motion experiments virtually using a smartphone or computer. Figure 2 shows a snapshot of the worksheet used in class.



Gerak Harmonik pada Ayunan Bandul

Tujuan

Menyelidiki hubungan antara periode dengan panjang tali dan gravitasi pada ayunan bandul sederhana dengan menggunakan percobaan virtual.

Alat dan bahan

Aplikasi Physics Education and Technology (PhET) Software Interactive Simulations.

Rumusan masalah

Perhatikan gambar kartun di bawah ini.

Perhatikan percakapan di atas antara seorang guru dengan Zen, Prima, dan Hengki. Menurutmu, apakah **periode** sebuah ayunan dipengaruhi oleh **panjang talinya**, **amplitudo ayunan**, **massa bandul (beban)**, atau dipengaruhi **nilai gravitasi**? Pendapat siapa yang benar kamu dugaanmu?

Hipotesis (dugaan)

Tuliskan dugaanmu di bawah ini beserta alasan singkat.

Aktivitas 1: Hubungan antara periode ayunan dengan panjang tali ayunan

1. Silakan dibuka aplikasi PhET ⇒ klik *play with simulations* ⇒ klik physics ⇒ klik *work, enery and power* ⇒ klik *pendulum lab* sehingga muncul tampilan seperti gambar di bawah ini.

2. Gunakan massa beban (*mass*) 1 kg, gravitasi (*gravity*) 9,81 m/s^2, dan gesekan udara (*friction*) bernilai 0 (*none*).

3. Klik *period timer* yang berada di bagian bawah sampai muncul alat pencatat periode di layar monitor Anda
4. Klik tombol pada alat pencatat periode ayunan sampai menjadi
5. Mulailah dengan panjang tali (*lenght*) ayunan 0,4 meter dan simpangkan ayunan (amplitudo) dengan sudut 20° ⇒ amatilah gerakan ayunan, dan catatlah periode ayunan yang terlihat pada alat pencatat periode ke dalam Tabel 1.

Figure 2. Example of a student worksheet on the topic of pendulum swings

The data was collected via test questions. Experts (a physics lecturer and a physics teacher) examined the test, which comprises of multiple-choice questions with explanations based on simple harmonic motion content. The initial test includes 30 questions. The test was generated and then checked and evaluated by an expert. The test was given to students in the tenth grade from a different school who had studied the topic after it had been changed by the expert's recommendations. The questions that required the most expertise were then sorted. Finally, the test includes the 12 questions showed in Table 2. The test is performed before and after the treatment.

Table 2. General Description of the Test Content

Sub Topic	Concepts	Questions
Harmonic oscillations in a pendulum swing.	The definition of harmonic oscillations	Number 1
	Factors influencing the period of the pendulum swing	Number 2
	Factors that do not influence the period of the pendulum swing	Number 3
	Period and frequency of a simple pendulum swing	Number 4
	Restoring force in a simple pendulum swing	Number 5
	The pendulum's speed and acceleration	Number 6
	Energy transformation on the pendulum swing	Number 7
Harmonic oscillations in a spring swing.	Factors Influencing the period of the Spring Swing period	Number 8
	Factors that do not influence the spring swing period	Number 9
	Period and frequency of simple spring swings	Number 10
	Restoring force on the spring swing	Number 11
	Energy transformation on the spring swing	Number 12

The collected data was then evaluated using Microsoft Excel for calculations and SPSS IBM version 24 for statistical analysis. The test results were analyzed using paired t-tests to evaluate whether there were significant changes in the study's treatment (Sudaryono, 2019). Before doing the paired t-test, the researcher performed a normality test to see whether the data was normally distributed. After computing the N-gain score to identify the category of improving the test score using the N-gain score test, the N-gain score is converted to the categories shown in Table 3. Table 3 shows the criteria used to assess the effectiveness of learning as established by Majdi et al. (2018). Finally, assuming the data is normally distributed and homogenous, a paired-sample t-test will be utilized. Meanwhile, if any of the data points were not normally distributed or homogenous, a non-parametric Wilcoxon signed-rank test would be used.

Table 3. Interpretation of Concept Understanding Based on N-Gain (Majdi et al., 2018)

N-gain	Conceptual Understanding Interpretation
<g> < 0.3	Poor
0.3 ≤ <g> ≤ 0.7	Medium
<g> > 0.7	High

Result and Discussion

In this study, the researcher administered a pre-test to the group that was receiving the treatment. The researcher subsequently implemented the treatment by implementing a flipped classroom with a PhET simulation. After completing the treatment, the researcher administered a post-test. The data was subsequently calculated and reviewed following the initial (pre-test) and final test (post-test). Figure 3 shows a comparison between pre-test and post-test average scores. The pre-test results revealed that the students' first average score was 20.28. The post-test resulted in 83.06 points, so we might suggest an improvement.

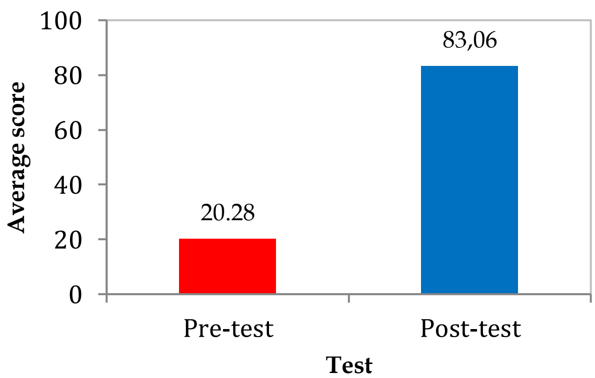


Figure 3. Pretest and posttest results

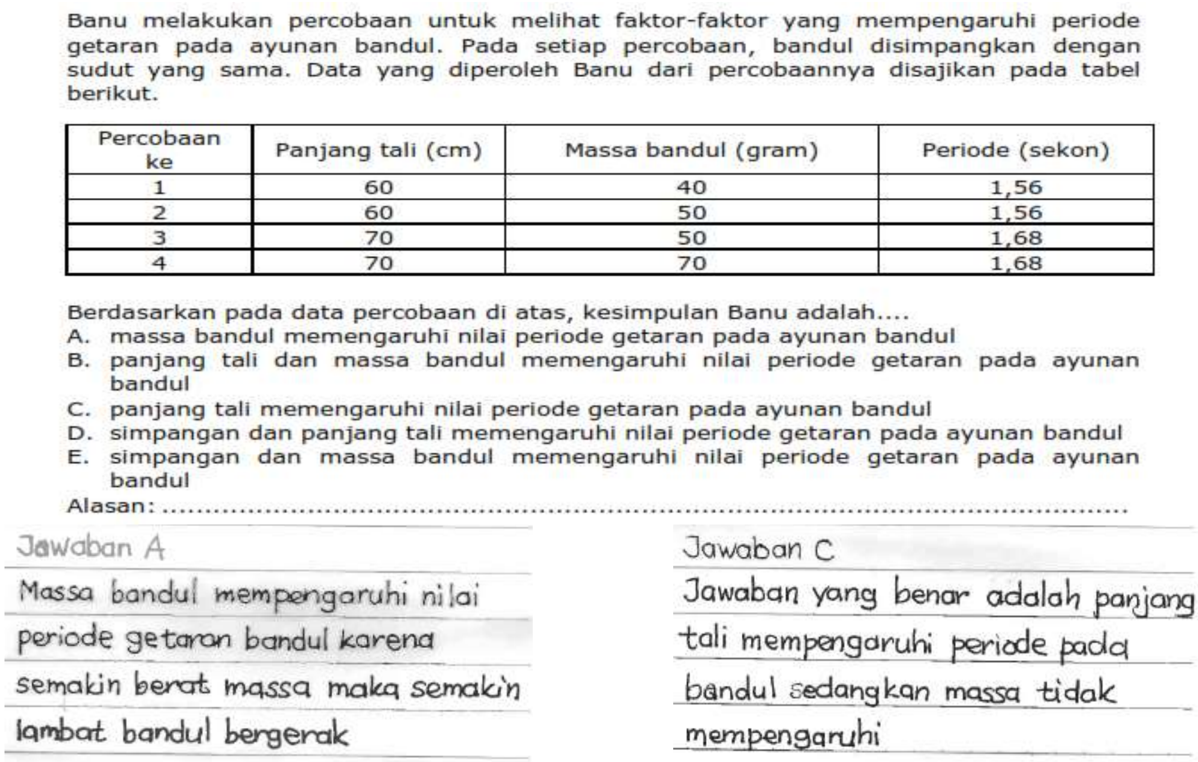
After calculating the average score, the normality test, N-Gain, and nonparametric Wilcoxon signed-rank test were performed to further explore the data using SPSS version 24. The final result is shown in Table 2. The normality examination, the pre-test, yields a significance level of 0.002, whereas the post-test yields 0.001. Since normally distributed data requires a sig. value < 0.05 (Neolaka, 2016), both the pre-test and post-test were not normally distributed. Despite this, a nonparametric test was conducted. The hypothesis test, the signed-rank test of Wilcoxon, was applied. The asymp. sig. (2-tailed) gained was 0.000, indicating that the student's comprehension significantly improved after applying the virtual lab activity (PhET) combined with flipped classroom learning.

The average N-Gain score was 0.79, indicating that it was highly effective in improving students' knowledge of science. The results of calculating the N-Gain score for each concept are shown in Table 4. Based on the results in Table 4, it appears that students understand the fundamental concepts of simple harmonic motion.

Table 4. Analysis of the N-Gain in each question

Concepts	Questions	Pretest	Posttest	Scores of N-Gain	Conceptual understanding interpretation
The definition of harmonic oscillations	Number 1	67	93	0.78	High
Factors influencing the period of the pendulum swing	Number 2	37	97	0.94	High
Factors that do not influence the period of the pendulum swing	Number 3	17	93	0.93	High
Period and frequency of a simple pendulum swing	Number 4	10	93	0.93	High
Restoring force in a simple pendulum swing	Number 5	10	90	0.88	High
The pendulum's speed and acceleration	Number 6	7	70	0.69	Medium
Energy transformation on the pendulum swing	Number 7	13	83	0.82	High
Factors Influencing the period of the Spring Swing period	Number 8	30	93	0.89	High
Factors that do not influence the spring swing period	Number 9	13	87	0.86	High
Period and frequency of simple spring swings	Number 10	23	97	0.95	High
Restoring force on the spring swing	Number 11	10	60	0.55	Medium
Energy transformation on the spring swing	Number 12	7	37	0.33	Medium

The quantitative analysis findings demonstrate that the pre-test and post-test results differ statistically significantly. Furthermore, the findings of this study show that calculating the N-Gain score has a significant impact on students' understanding of simple harmonic motion. Furthermore, students' written comments can be utilized to back up the findings from the quantitative data. Figure 4 shows one example of student comments.



Banu melakukan percobaan untuk melihat faktor-faktor yang mempengaruhi periode getaran pada ayunan bandul. Pada setiap percobaan, bandul disimpangkan dengan sudut yang sama. Data yang diperoleh Banu dari percobaannya disajikan pada tabel berikut.

Percobaan ke	Panjang tali (cm)	Massa bandul (gram)	Periode (sekon)
1	60	40	1,56
2	60	50	1,56
3	70	50	1,68
4	70	70	1,68

Berdasarkan pada data percobaan di atas, kesimpulan Banu adalah....

A. massa bandul memengaruhi nilai periode getaran pada ayunan bandul
B. panjang tali dan massa bandul memengaruhi nilai periode getaran pada ayunan bandul
C. panjang tali memengaruhi nilai periode getaran pada ayunan bandul
D. simpangan dan panjang tali memengaruhi nilai periode getaran pada ayunan bandul
E. simpangan dan massa bandul memengaruhi nilai periode getaran pada ayunan bandul

Alasan: ....

Jawaban A
Massa bandul mempengaruhi nilai periode getaran bandul karena semakin berat massa maka semakin lambat bandul bergerak

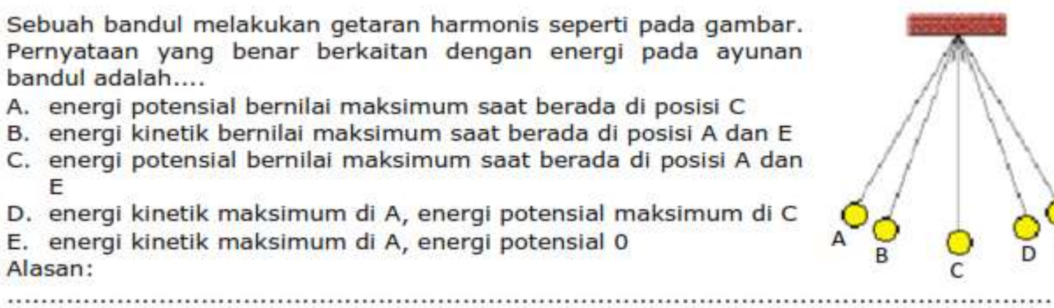
Jawaban C
Jawaban yang benar adalah panjang tali mempengaruhi periode pada bandul sedangkan massa tidak mempengaruhi

Students' answers on the pretest Students' answers on the post-test

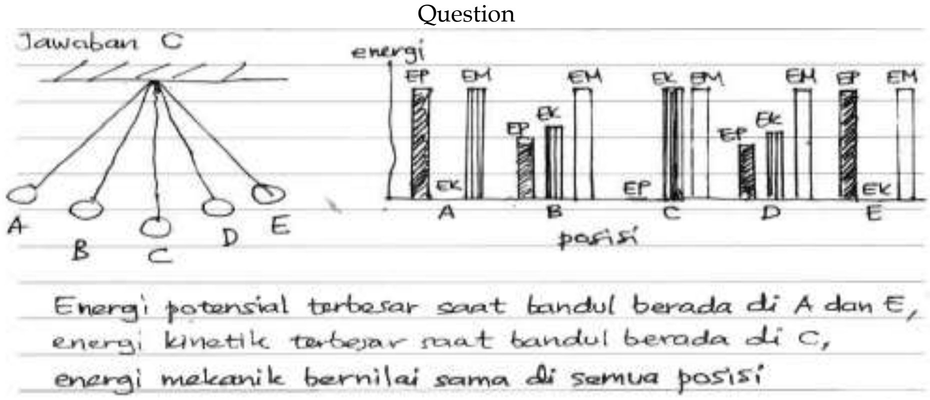
Figure 4. An Example of student answers

Students' comprehension has increased, as seen by their written responses above (Figure 4). In this case, students' written responses to the pre- and post-test show a decrease in incorrect comprehension. Figure 4 demonstrates that students' understanding of the factors influencing the period and frequency of pendulum swings was lacking during the pre-test. It is evident from the pretest responses that students "understood" that mass affects the pendulum swings' period. According to Andani et al. (2018) and Tumanggor et al. (2020), pupils first "understood" that mass had an impact on the pendulum's swing motion's period. Students' responses have "shifted" after realizing that the pendulum's swing period is determined by the length of the string rather than the mass. The pendulum's swing period is influenced by the length of the string; the longer the string, the longer the pendulum's period; conversely, the shorter the string utilized, the lower the period value. This indicates that students' responses on the post-test demonstrate an improved comprehension of the material. According to the findings of Wu et al. (2021), using a PhET simulation in conjunction with a flipped classroom increased students' conceptual knowledge. The learning process is improved and student comprehension is increased when flipped classrooms and PhET are combined (Aca et al., 2020; Banda et al., 2021; Kavitha et al., 2023). PhET and flipped classroom simulation work well together to improve science learning (Siu-Ping et al., 2020). The finding that flipped learning greatly increases student understanding than conventional instruction methods across several topic domains has been supported by numerous meta analyses of the well-researched flipped classroom (Ezeh et al., 2022; Gong et al., 2023).

However, if we examine the research findings, we can still find weaknesses in this study. Students still struggle with the concept of energy in spring swings, which is directly related to this weakness. The N-Gain calculation, which shows a gain of 0.32, illustrates this. The challenge lies in differentiating between elastic potential energy and gravitational potential energy in spring oscillations, according to the findings of the study of the students' responses. Elastic potential energy, gravitational potential energy, and kinetic energy make up a spring's mechanical energy when it swings. The key to understanding how energy changes during the motion of this system is for students to consider the three aspects that are changing: the mass's kinetic energy, its gravitational potential energy, and the energy contained in the spring (Quinn, 2014). It was discovered by Andani et al. (2018) and Tongnopparat et al. (2014) that a large number of pupils struggled to comprehend how mechanical energy is conserved in spring harmonic motion. This leads experts to believe that, in contrast to pendulum swings, the energy idea in spring swings is more complicated, making it harder for pupils to understand. According to Lucariello (2017), certain ideas become extremely challenging to comprehend when they are highly abstract and intricate.



Question



Post-test answer

Figure 5. The students' answers on the post-test about the concept of the energy on the pendulum

Students' written responses pertaining to the idea of energy in pendulum swings are displayed in Figure 5. Students' understanding of energy conservation is demonstrated by their answers in Figure 5, which show that when an object is in equilibrium (at position C), it moves with maximum kinetic energy and minimum potential energy; in contrast, objects in positions A and E have minimum kinetic energy and maximum potential energy. It's interesting to note that students included representations in various formats outside text, such as pictures and graphics. The researchers have a strong suspicion that the PhET simulation medium utilized in classroom instruction is what led to the observed findings. Similar findings were reported by Vegisari et al. (2020) and Hartanto et al. (2023), who discovered that students' multiple representation skills can be enhanced through learning with the aid of PhET simulations. Inayah et al (2021) state that the PhET simulation offering flexible access for various representation.

The flipped classroom learning pattern with PhET support is the primary variable in this research that positively affects learning, according to the findings and the discussion above. Effective learning can be achieved by combining technology and learning patterns (Widiyatmoko, 2018). In the first phase of the flipped classroom, known as the "home activities," students prepare and study the material that will be covered in class prior to the commencement of class (Robertson, 2022). Through this pre-class, the flipped classroom gives students more responsibility for their own learning. Pejuan et al. (2019) claimed that the flipped classroom influenced the growth of self-directed learning abilities. Novitri et al. (2022) agreed, saying that children can learn ethically and autonomously in flipped classrooms. Put differently, Walker et al. (2020) state that students who wish to engage in more in-depth class discussions and activities need to possess "initial investment" of knowledge. The effectiveness of learning in the classroom is significantly influenced by these pre-class activities (Lai et al., 2016). During the class phase, students use PhET simulations to assist in experimental activities, analyze experimental data, present their findings, and have in-depth conversations about the content. With the use of PhET simulations, students can reinforce the fundamentals of a subject during class discussions or activities. Teachers now serve as learning facilitators rather than as the exclusive source of knowledge thanks to this learning pattern. In their role as a facilitator, teachers respond to inquiries from the class, accompany and mentor them, offer constructive criticism, and oversee lesson plans (Robinson et al., 2020). Flipped classroom instruction is constructivist, meaning that students must actively participate in their learning as opposed to merely taking in information passively (Xu et al., 2018); the flipped classroom approach is found to increase student-centeredness in learning (Maxson et al., 2015).

Conclusion

Virtual lab activity (PhET) on simple harmonic oscillations was utilized together with flipped classroom learning for 30 Senior high school students in the tenth grade. After evaluating the data, it was discovered that students' comprehension had increased. The pre-test score was 20.28; the post-test score was 83.06. Furthermore, the N-Gain score of 0.79 indicated a significant improvement in student understanding. The pre-test and post-test scores differ statistically considerably, as seen by the analysis of mean scores. Overall, enhancing students' understanding through the use of the flipped classroom and virtual simulation PhET proved to be effective.

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Author Contributions

Conceptualization; T.J.H., S., B.S., Z.F.; methodology; T.J.H., S.; draft preparation; T.J.H., S., B.S., Z.F.; writing, review, and editing: T.J.H., S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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