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DETERMINATION OF EARTH'S GRAVITATIONAL ACCELERATION USING PHET SIMULATION MEDIA WITH A WEIGHTED AVERAGE TECHNIQUE

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Abstract :
The value of gravitational acceleration (g) varies across different locations depending on the distance from the surface to the Earth's center of mass. Additionally, the value of ggg is influenced by the data processing method employed. This study aims to determine the Earth's gravitational acceleration in the Banten region using a pendulum assisted by the Phet pendulum-lab simulation. The experiment was conducted using two methods: the average technique and the weighted average technique. For the average technique, the period was measured 10 times for a string length of 80 cm. For the weighted average technique, the period of the pendulum swing was measured at varying string lengths from 80 to 100 cm, with five variations, each measured 10 times. The results of the study showed that the gravitational acceleration determined using the average technique was 9.72 ± 0.28 m/s², while the weighted average technique yielded 9.78 ± 0.08 m/s². With the reference value of gravitational acceleration being 9.80 m/s², the weighted average technique successfully corrected the relative error from 0.82% to none. Moreover, the determination of gravitational acceleration using the weighted average technique produced more accurate results compared to the average technique. This study also confirms that the PhET simulation is an effective and reliable tool for measuring gravitational acceleration, particularly when physical experimental conditions are less than ideal. The weighted average technique significantly contributes to improving measurement precision, making it valuable for both physics research and education.

Keywords: Average Technique, Gravitational Acceleration, Pendulum, Phet Simulation, Weighted Average Technique.

INTRODUCTION

Gravitational acceleration is one of the most fundamental physical constants, connected to various natural phenomena and technological applications. Generally, gravitational acceleration, symbolized by the letter 'g,' varies at different points on the Earth's surface and depends on several factors, including altitude and geological conditions (Serway & Jewett, 2018). In this context, understanding and measuring gravitational acceleration is central to the study of physics, particularly in the analysis of the motion of objects(Halliday et al., 2013).

The value of Earth's gravitational acceleration varies across different locations. Besides altitude, this difference may also occur due to uncertainties in gravity measurement (Khairul Sabri et al., 2024). Earth's gravitational acceleration is not uniform at every location on the Earth's surface, as it depends on the height at which the object is located. Since changes in altitude affect the magnitude of the Earth's central gravitational force acting on the object, the gravitational acceleration also varies (Pratiwi, 2024). Additionally, differences in the region's coordinates relative to the Earth's equator and altitude above sea level can influence the value of Earth's gravity(Medellu et al., 2023).

Earth's gravitational acceleration can be measured using various experimental methods, one of which is a mathematical pendulum consisting of a single mass point m suspended by a string, with negligible mass, where the upper end of the string is fixed to a stationary wall (Aisiyah et al., 2022). Factors affecting the pendulum's swing include period, frequency, gravitational force, and the length of the pendulum's string. When an object is released from a certain height, it falls and moves toward the Earth's center. The acceleration experienced by the falling object is caused by Earth's gravitational force. In a simple pendulum system, the object's motion along the axis is influenced only by Earth's gravity, and the pendulum's period can be calculated using Equation 1 (Giancoli, 2014).

One of the main challenges in this research is minimizing experimental errors and improving measurement accuracy, particularly in measurements highly sensitive to variables such as string length and swing angle. The use of a weighted average technique in data analysis is one approach designed to address this issue, allowing for the integration of varying measurement results to produce more accurate and reliable values. This approach not only compensates for minor variations in data but also reduces the influence of data with greater uncertainty, helping to achieve more consistent conclusions

With technological advancements, digital simulations have become a highly useful tool in teaching and research. Information and Communication Technology (ICT) is necessary to support today's students, who may find traditional teaching methods tedious, in learning complex scientific concepts. Computer simulations have great potential to enhance students' conceptual understanding and help bring abstract concepts into everyday teaching (Rehman et al., 2021). Simulation-based learning has also proven more effective in improving student achievement compared to conventional physics teaching methods (Najib et al., 2022). Virtual laboratories have the advantage of replicating more scenarios than are typically analyzed in theoretical and practical classes. Additionally, these laboratories are an excellent complement for verifying answers in problem-solving (Chiodi et al., 2021).

PhET simulations, as an interactive learning tool, have proven effective in enhancing students' understanding of physics concepts, including gravitational acceleration. The use of this simulation allows students to conduct virtual experiments that demonstrate the laws of gravity and free fall, thereby providing a more immersive learning experience (Rizaldi et al., 2020; Verdian et al., 2021; Prastika et al., 2020). One well-known medium in this context is PhET Interactive Simulations, a platform that offers interactive simulations for various physics concepts. PhET serves as an important bridge between classroom learning and laboratory experience in Physics Education courses (Saudelli et al., 2021). The use of PhET in pendulum experiments allows students and researchers to conduct experiments virtually, minimizing experimental errors and enriching conceptual understanding through in-depth visualization. The discovery learning model supported by PhET simulations can enhance physics learning strategies and is effective in improving student activity and learning outcomes. Therefore, this approach is recommended for application in physics teaching, especially for simple harmonic motion material (Kristantiniati & Ishafit, 2022). The integration of technology through the use of PhET creates an engaging learning experience, enhances student motivation, facilitates concept understanding, and encourages active engagement in the learning process. Therefore, the application of PhET is recommended in learning activities(Pranata et al., 2024).

Previous studies have highlighted the variability of Earth's gravitational acceleration across different locations, influenced by factors such as altitude, geological conditions, and coordinates relative to the equator (Serway & Jewett, 2018; Medellu et al., 2023). Traditional methods, such as using a mathematical pendulum, have been employed to measure gravitational acceleration; however, minimizing experimental errors and improving measurement accuracy remain significant challenges, particularly when dealing with variables like string length and swing angle (Aisiyah et al., 2022). Advances in technology, such as PhET Interactive Simulations, have demonstrated effectiveness in enhancing conceptual understanding and reducing experimental errors (Kristantiniati & Ishafit, 2022; Pranata et al., 2024). However, the integration of PhET simulations with the weighted average technique to improve the precision of gravitational acceleration measurements has yet to be extensively explored. This study addresses this gap by combining PhET simulations and the weighted average technique to provide more accurate and representative values of gravitational acceleration. The approach not only enhances the accuracy of gravitational measurements but also reinforces the role of simulation technology in physics education, offering an innovative and practical solution to overcome limitations in traditional experimental methods.

The weighted average technique in determining gravitational acceleration can be used to analyze data obtained from simulations. This method allows for the integration of multiple measurements to obtain a more accurate value, considering that gravitational acceleration measurements can be influenced by various factors such as location and environmental conditions (Rosdianto, 2017; Toda et al., 2020; Salim et al., 2022). In this context, the experiment conducted by Nurhayati et al. demonstrates that measurements taken with the appropriate method can yield consistent and reliable values for gravitational acceleration (Nurhayati et al., 2021; Toda et al., 2020).

This paper discusses the method of determining Earth's gravitational acceleration using a simple pendulum with the aid of PhET simulations. The study aims to determine Earth's gravitational acceleration in the Banten region using a pendulum assisted by the Phet pendulum-lab simulation mode. This simulation allows researchers to minimize experimental errors and enrich the understanding of gravity through in-depth visualization. Additionally, the weighted average technique is used in data analysis to produce more accurate and representative gravitational acceleration values. Thus, this research not only contributes to gravity measurement methods but also strengthens the role of simulation technology in physics education. Furthermore, this study provides new insights into the effectiveness of using simulations in physics education.

RESEARCH METHOD

Research Design

This study employs an experimental design with a quantitative approach. The research objective is to determine Earth's gravitational acceleration using a pendulum through the PhET simulation medium. The experimental process is conducted virtually with the aid of interactive simulations to collect data on the pendulum's period and string length. The PhET simulation allows for the interactive adjustment of experimental variables, such as the height of the fall and the mass of the object, which can influence the measurement results (Sabri, 2024).

Research Procedure

The primary tool used in this study is a computer or a device that supports PhET simulations, specifically the pendulum lab simulation. Additionally, data analysis software, Microsoft Excel, is used for data processing. The repeated measurement procedure is as follows:

1. Open the web page at: https://phet.colorado.edu/en/simulation/pendulum-lab.

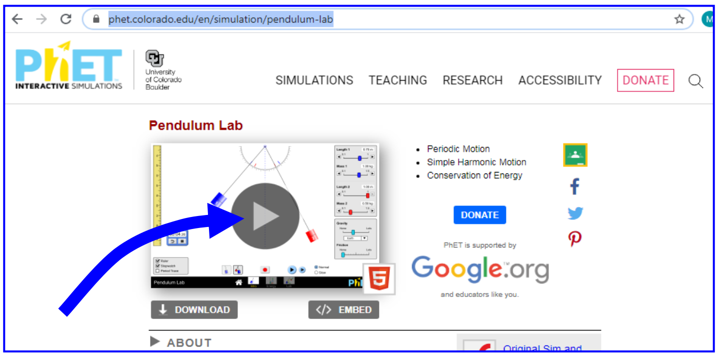

Figure 1. Pendulum lab menu in the pendulum lab simulation.

2. Activate the "pendulum lab" menu as shown in Figure 1, and click on the right-facing triangle.
3. Click "ruler" and "stopwatch" in the lower-left corner of the page to activate the ruler and digital stopwatch. Position the stopwatch so it does not interfere with other tools.
4. Set the string length to 0.8 m by adjusting the "length 1" button. Use the ruler to ensure the length is accurate.
5. Set the mass to 2 ounces by clicking the "mass 1" button.
6. Select "Earth" gravity or leave it as default.
7. Remove friction.
8. Displace the pendulum to the desired angle (do not make it too large). A simple protractor is available to estimate the displacement angle.
9. Release the pendulum and record the time for 10 swings in seconds and hundredths of a second.
10. Stop the pendulum and the stopwatch by clicking the black triangle button at the bottom.
11. Record the time for 10 swings.
12. Reset the pendulum to its vertical position by clicking the red circular "reset" button at the bottom of the pendulum. Repeat steps 9-12 ten times.
13. Repeat step 12 for different string lengths until 5 variations are completed. Previous studies have shown that free-fall time measurements can be conducted with high accuracy using digital instruments or sensors, which can also be applied in simulations (Rosdianto, 2017; Hamdani & Supardiyono, 2020).

Data Analysis Technique

Data analysis is conducted using a weighted analysis technique to ensure the accuracy and validity of the results obtained. The analysis steps are as follows:

1. To determine the average period and its error, the following equations are used:

$$\bar{T} = \frac{\sum_{i=1}^{N} T_i}{N} \tag{1}$$

$$s_T = \sqrt{\frac{\sum_{i=1}^{N} \left(T_i - \bar{T}\right)^2}{N-1}} \tag{2}$$

where T_i is the i-th period, and N s the number of experimental repetitions.

2. For repeated measurements, the average gravitational acceleration is determined using the following equations:

$$\bar{g} = \frac{4\pi L^2}{\bar{T}^2} \tag{3}$$

$$s_g = \frac{8\pi L^2}{\bar{T}^3} s_T \tag{4}$$

where $\bar{T}$ is the average period, and s_g is the standard deviation of g.

3. The weighted average assigns greater weight to data considered more accurate or relevant, thereby enhancing the accuracy of the results (Muspa & Suwondo, 2020). For the weighted average technique, the average gravitational acceleration is determined using the following equation:

$$\bar{g} = \sum_{i=1}^{6} \frac{\bar{g}_i}{s_i^2} \bigg/ \sum_{i=1}^{6} \frac{1}{s_i^2} \tag{5}$$

while its error is given by

$$\bar{g} = 1 \bigg/ \sqrt{\sum_{i=1}^{6} \frac{1}{s_i^2}} \tag{6}$$

where $\bar{g}_i$ is the i-th average gravitational acceleration.

RESULTS AND DISCUSSION

Table 1 presents the repeated measurement data for the pendulum's period taken 10 times for a string length of 80 cm.

Table 1. Repeated Measurements of Pendulum Period for a Given String Length.

No	String length, *l* (80 cm)	Periode
1	80	1,80
2	80	1,82
3	80	1,80
4	80	1,82
5	80	1,80
6	80	1,80
7	80	1,80
8	80	1,80
9	80	1,81
10	80	1,80

Using the period data and the corresponding equations (3) and (4), the calculated gravitational acceleration is: g = 9,72 ± 0,28 m/s^2.

Table 2. Repeated Measurements of Pendulum Period for 5 Variations in String Length

No	Periode (s) T_1 (80 cm)	Periode (s) T_2 (85 cm)	Periode (s) T_3 (90 cm)	Periode (s) T_4(95 cm)	Periode (s) T_5 (100 cm)
1	1.80	1.86	1.92	1.96	2.02
2	1.82	1.85	1.91	1.97	2.01
3	1.80	1.86	1.90	1.96	1.99
4	1.82	1.85	1.92	1.97	2.02
5	1.80	1.86	1.91	1.95	2.01
6	1.80	1.86	1.89	1.94	2.02
7	1.80	1.85	1.86	1.96	1.95
8	1.80	1.84	1.92	1.95	1.92
9	1.81	1.86	1.90	1.94	1.98
10	1.80	1.85	1.92	1.95	2.01
Trat	1.81	1.85	1.90	1.95	1.99

To determine gravitational acceleration using the weighted average technique, Table 2 displays the average period and corresponding gravitational acceleration. The period and its associated error for a given string length were calculated following equations (1) and (2), while the gravitational acceleration and its error for a given string length were determined using equations (5) and (6).

Table 3. Pendulum Period and Gravitational Acceleration for Variations in String Length

No	String length (cm)	Periode (s)	Gravitational Acceleration (m/s^2)
1	80	1,810 ± 0,007	9,72 ± 0,28
2	85	1,850 ± 0,009	9,75 ± 0,13
3	90	1,900 ± 0,008	9,77 ± 0,19
4	95	1,950 ± 0,008	9,85 ± 0,20
5	100	1,990 ± 0,007	9,92 ± 0,39

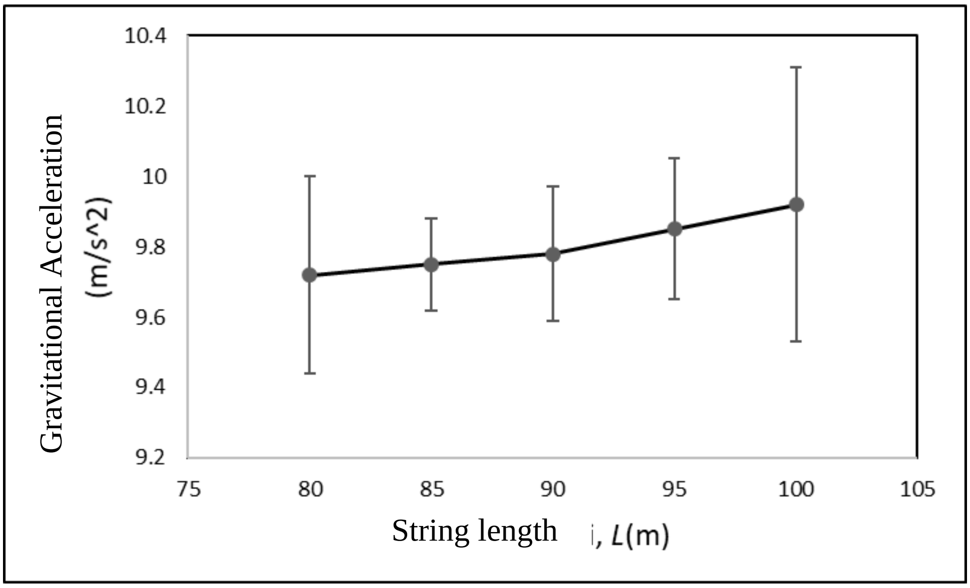

Figure 1. The graph of Earth's gravitational acceleration with varying string lengths.

The necessity of using the weighted average technique arises from the observed tendency of the gravitational acceleration *g* to vary with the length of the pendulum L. As the length increases, the value of *g* also tends to increase. Therefore, determining *g* based on only one specific length is not entirely accurate. This is where the importance of determining *g* using the weighted average technique becomes evident. This technique accounts for variations in *g* and incorporates the weighting factors associated with the uncertainties.

The gravitational acceleration and its uncertainty, calculated using the weighted average technique according to equations (5) and (6), resulted in a value of *g* : 9,78 ± 0,08 m/s^2

Table 4. Comparison of Gravitational Acceleration between Two Methods.

Technique Used	Gravitational Acceleration *g* (m/s²)	Relative Error
Average Measurement	9,72	0,28
Weighted Average Technique	9,78	0,08

The pendulum experiment using the PhET simulation demonstrates variations in the measured values of Earth's gravitational acceleration across different string lengths. The results obtained from the experiment can be seen in Table 1. Although there are slight differences among these results, they generally fall within the range close to the standard value of Earth's gravitational acceleration, 9.8 m/s².

The variation in measurement results can be attributed to the experiment's sensitivity to string length and uncertainties in measuring the period of oscillation. Results with lower uncertainty, such as 9.75 ± 0.13 m/s² and 9.78 ± 0.19 m/s², show better consistency, while results with higher uncertainty, such as 9.92 ± 0.39 m/s², suggest the possible influence of other factors. These factors should be considered in data interpretation, as they can provide insights into the accuracy and reliability of the method used.

To obtain a more accurate and representative value of gravitational acceleration, the data were analyzed using the weighted average technique. This technique accounts for the weight based on the uncertainty of each measurement result, leading to a more reliable final result. Using this method, the calculated average gravitational acceleration is 9.78 m/s² with an error of 0.08 m/s². This indicates that the weighted average technique is effective in combining results from various measurements to yield a value closer to the true value.

The discussion of these results highlights the importance of using the weighted average technique in experimental physics research. In this context, the technique helps reduce the impact of data with greater uncertainty, resulting in more consistent and accurate final results. The final gravitational acceleration value obtained using this technique is very close to the known standard value, reinforcing the validity of the experiment and analysis conducted. While this study shows positive results, several limitations need to be considered. First, although the PhET simulation can replicate many physical experiment scenarios, the results still depend on the mathematical model used in the simulation. Therefore, the obtained results may not fully represent the complexity of the real world, especially in cases where external factors have a significant influence. Second, this study only used one type of string length variation and displacement angle in the measurements, which may limit the generalization of the results to more diverse conditions. In the study conducted by Prihatiningtyas et al., it was found that the application of PhET simulation-based learning can enhance students' psychomotor and affective skills, contributing to better learning outcomes (Prihatiningtyas et al., 2017). By using the weighted average technique, students are able to better understand the variations in measurements and how to process data to obtain more representative results (Defianti, 2023).

Several studies related to the use of technology in physics education highlight the importance of interactive approaches to enhance the understanding of gravity concepts. Determining Earth's gravitational acceleration is a crucial topic in physics that can be taught through various methods, including the use of simulation media such as PhET. Previous research indicates that gravitational acceleration is influenced by factors such as altitude and measurement techniques. For example, Subhan et al. (2022) explain that gravitational acceleration varies with altitude, being lower at higher elevations. This provides a basis for understanding how physical environments impact measurement outcomes. In education, virtual simulations like PhET have proven effective in enhancing students' understanding of physics concepts, including gravitational acceleration. Saregar (2016) found that PhET simulations can improve students' interest and mastery of quantum physics, showing potential for other topics like gravitational acceleration. Laeli (2023) highlighted the Phyphox application as an interactive tool for teaching mechanics, including gravitational acceleration. The use of the weighted average technique has also been explored, with Chusni (2017) reporting that such techniques yield more accurate measurements of gravitational acceleration. Furthermore, independent experiments, as reported by Firdaus et al. (2019), show that students can better grasp the concept of gravitational acceleration through hands-on experiences. Overall, research suggests that combining simulation media like PhET with precise measurement techniques, such as the weighted average, enhances students' understanding of Earth's gravitational acceleration, allowing them to apply theoretical concepts in real-world situations.

This study demonstrates that the PhET simulation is an effective tool for virtual physics experiments, offering precise control over variables and accurate measurements, free from the physical experimental errors typically associated with issues like air friction or timing inaccuracies. This advantage makes PhET a valuable resource in both physics education and research. In educational settings, it provides an interactive approach that helps students grasp gravity concepts more effectively, bypassing the technical challenges often encountered in traditional physical experiments. In research, the simulation supports the development of more accurate and efficient measurement methods, particularly in scenarios where physical experiments are difficult or prone to errors. The impact of this study lies in enhancing the understanding of gravitational acceleration, which contributes to improving physics education and learning outcomes. However, the research is constrained by its reliance on the mathematical model used in the simulation, which may not account for certain external factors like complex air friction or variations in string materials. Additionally, the study's focus on only one string length and displacement angle limits the generalizability of the results. Future studies should expand the parameter variations and test the findings in real-world scenarios to validate these results further. Overall, the use of the PhET simulation, combined with the weighted average technique, proves to be an effective approach for determining Earth's gravitational acceleration, aligning with the demands of 21st-century education that emphasize higher-order thinking skills and collaborative learning (Prihatiningtyas et al., 2017; Oktamuliani et al., 2021).

CONCLUSION

This study successfully determined the gravitational acceleration in Banten using a pendulum and PhET simulation. Two methods were employed: the average and weighted average techniques. The results indicate that the weighted average technique is more accurate, yielding a value of 9.78 ± 0.08 m/s² compared to 9.72 ± 0.28 m/s² from the average technique. The accuracy of the weighted average method is evident in the reduction of relative error from 0.28% to 0.08%. This study confirms that the PhET simulation is an effective and reliable tool for measuring gravitational acceleration, especially when physical experiments face less-than-ideal conditions. The weighted average technique enhances measurement accuracy, highlighting its potential in both physics research and education. However, the study also acknowledges limitations, such as the reliance on mathematical models within the simulation and the limited variation of parameters. Further research is needed to expand these findings and test the results in broader contexts.

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REFERENCES

Aisiyah, M. C., Annas, M. A., Ningrum, I. E., Widodo, A., & Cahyani, H. D. (2022). Studi Eksperimen Bandul dalam Menentukan Percepatan Gravitasi Bumi dan Memahami Konsep Gerak Harmonik

Sederhana. *Tsaqofah*, *2*(3), 393–400. https://doi.org/10.58578/tsaqofah.v2i3.517

Chiodi, G. A., Soutadet, A. J., & Bosio, M. A. (2021). Virtual Laboratory and Mobile Devices as a Support Tool for the Teaching-Learning Processes of Physics in Pandemic Times. *International Journal of Recent Contributions from Engineering, Science & IT (IJES)*, *9*(3), 76. https://doi.org/10.3991/ijes.v9i3.24473

Chusni, M. M. (2017). Penentuan besar percepatan gravitasi bumi menggunakan ayunan matematis dengan berbagai metode pengukuran. Scientiae Educatia, 6(1), 47. https://doi.org/10.24235/sc.educatia.v6i1.1346

Defianti, A., Sakti, I., & Hidayat, S. (2023). Pelatihan pemanfaatan simulasi interaktif phet dalam pembelajaran ipa di smp-sma idhata kota bengkulu. Jurnal Pengabdian Pada Masyarakat Indonesia, 2(2), 20-25. https://doi.org/10.55542/jppmi.v2i2.437

Firdaus, T., Erwin, E., & Rosmiati, R. (2019). Eksperimen mandiri siswa dalam penentuan percepatan gravitasi bumi pada materi gerak jatuh bebas. Titian Ilmu: Jurnal Ilmiah Multi Sciences, 11(1), 31-36. https://doi.org/10.30599/jti.v11i1.385

Giancoli, C. D. (2014). *Fisika Prinsip danAplikasi (Edisi ketujuh jilid 1)*. Erlangga.

Halliday, D., Resnick, R., & Walker, J. (2013). *Fundamentals of Physics*. John Wiley & Sons.

Khafidz Hamdani, M., & Supardiyono, S. (2020). Rancang Bangun Alat Praktikum Gerak Jatuh Bebas Digital Berbasis Sensor Inframerah. *IPF: Inovasi Pendidikan Fisika*, *9*(3), 410–416. https://doi.org/10.26740/ipf.v9n3.p410-416

Khairul Sabri, Nanda Aisyah Kurniati, Dzulfikar Nasriyan Fadhilah, & M Dearil Ardiansyah. (2024). Penentuan Percepatan Gravitasi Bumi Menggunakan Bandul Sederhana Di Daerah Kampus UPI. *Jurnal Pendidikan, Bahasa Dan Budaya*, *3*(1), 29–38. https://doi.org/10.55606/jpbb.v3i1.2693

Kristantiniati, K., & Ishafit, I. (2022). Model discovery learning berbantuan PheT simulation untuk meningkatkan hasil belajar peserta didik pada kompetensi gerak harmonik sederhana. *Edu Sains: Jurnal Pendidikan Sains & Matematika*, *10*(1), 96–109. https://doi.org/10.23971/eds.v10i1.3540

Laeli, S. and Mustava, O. (2023). Alternatif praktikum penentuan percepatan gravitasi menggunakan aplikasi phyphox di masa pasca pandemi. Buletin Edukasi Indonesia, 2(02), 61-68. https://doi.org/10.56741/bei.v2i02.277

Medellu, N. C., Zahran, M., Sari, I. M., & Utomo, T. (2023). *Jurnal Phi Beberapa Kota di Indonesia dan Turki dengan Menggunakan Tracker*. *4*(2), 1–7.

Muspa, R. M. and Suwondo, N. (2020). Pengembangan perangkat praktikum penentuan percepatan gravitasi bumi menggunakan pegas berbasis arduino-linx-labview. Jurnal Penelitian Pembelajaran Fisika, 11(2), 165-171. https://doi.org/10.26877/jp2f.v11i2.6155

Najib, M. N. M., Md-Ali, R., & Yaacob, A. (2022). Effects of Phet Interactive Simulation Activities on Secondary School Students' Physics Achievement. *South Asian Journal of Social Science and Humanities, 3*(2), 73–78. https://doi.org/10.48165/sajssh.2022.3204

Nurhayati, N., A, R. D. A., & aslamiyah, s. (2021). Penentuan nilai percepatan gravitasi bumi dengan model gerak jatuh bebas di laboratorium fisika uin ar-raniry banda aceh. Jurnal Phi Jurnal Pendidikan Fisika Dan Fisika Terapan, 2(1), 15. https://doi.org/10.22373/p-jpft.v2i1.8347

Oktamuliani, S., Centaury, B., Muhaimin, S., Afdal, A., Adrial, R., Muldarisnur, M., … & Mahyudin, A. (2021). Simulasi phet sebagai laboratorium virtual dalam peningkatan pemahaman konsep fisika siswa sman 3 painan, pesisir selatan. Jurnal Warta Pengabdian Andalas, 28(4), 509-513. https://doi.org/10.25077/jwa.28.4.509-513.2021

Pranata, O. D., Seprianto, S., Adelia, I., & Darwata, S. R. (2024). Sosialisasi Integrasi Teknologi dalam Pembelajaran Sains Menggunakan Physics Education Technology (PhET). *Jurnal Penelitian Dan Pengabdian Kepada Masyarakat UNSIQ*, *11*(2), 107–114. https://doi.org/10.32699/ppkm.v11i2.6707

Prastika, E., Purwanto, A., & Nirwana, N. (2020). Pengaruh pendekatan interactive conceptual instruction (ici) berbantuan simulasi phet terhadap hasil belajar siswa. Jurnal Kumparan Fisika, 3(2), 141-150. https://doi.org/10.33369/jkf.3.2.141-150

Pratiwi, T. D. (2024). *Analisis Perbandingan Nilai Percepatan Gravitasi Bumi Menggunakan Metode Ayunan Matematis dan Pegas*. *3*(1), 1–5.

Prihatiningtyas, S., Prastowo, T., & Jatmiko, B. (2017). Pengembangan perangkat pembelajaran fisika smp berbasis simulasi virtual dan kit sederhana dengan model pembelajaran langsung dan kooperatif untuk mengajarkan keterampilan psikomotor dan afektif pada pokok bahasan alat optik. JPPS (Jurnal Penelitian Pendidikan Sains), 2(1), 135. https://doi.org/10.26740/jpps.v2n1.p135-141

Rehman, N., Zhang, W., Mahmood, A., & Alam, F. (2021). Teaching physics with interactive computer simulation at secondary level. *Cadernos de Educação Tecnologia e Sociedade*, *14*(1), 127. https://doi.org/10.14571/brajets.v14.n1.127-141

Rizaldi, D. R., Jufri, A. W., & Jamal, J. (2020). Phet: simulasi interaktif dalam proses pembelajaran fisika. Jurnal Ilmiah Profesi Pendidikan, 5(1), 10-14. https://doi.org/10.29303/jipp.v5i1.103

Rosdianto, H. (2017). Penentuan percepatan gravitasi pada percobaan gerak jatuh bebas dengan memanfaatkan rangkaian relai. SPEKTRA: Jurnal Fisika Dan Aplikasinya, 2(2), 107. https://doi.org/10.21009/spektra.022.03

Salim, M. B., Widiartha, I. W. O., & Suseno, N. (2022). Pengukuran percepatan gravitasi di kota metro. Jurnal Pendidikan Fisika, 10(2), 201. https://doi.org/10.24127/jpf.v10i2.5697

Saregar, A. (2016). Pembelajaran pengantar fisika kuantum dengan memanfaatkan media phet simulation dan lkm melalui pendekatan saintifik: dampak pada minat dan penguasaan konsep mahasiswa. Jurnal Ilmiah Pendidikan Fisika Al-Biruni, 5(1), 53-60. https://doi.org/10.24042/jpifalbiruni.v5i1.105

Saudelli, M. G., Kleiv, R., Davies, J., Jungmark, M., & Mueller, R. (2021). PhET Simulations in Undergraduate Physics. *Brock Education Journal*, *31*(1). https://doi.org/10.26522/brocked.v31i1.899

Serway, R. ., & Jewett, J. . (2018). *Physics for Scientists and Engineers*. Cengage Learning.

Subhan, M., Rahmawati, E., Suswati, L., Yusiran, Y., & Fatimah, F. (2022). Variasi ketinggian mdpl terhadap nilai percepatan gravitasi bumi pada konsep gerak jatuh bebas (gjb) untuk pendekatan pembelajaran. Jurnal Pendidikan Mipa, 12(3), 831-837. https://doi.org/10.37630/jpm.v12i3.660

Toda, S., Tati, M. Y. M., Bhoga, Y. C., & Astro, R. B. (2020). Penentuan percepatan gravitasi menggunakan konsep gerak jatuh bebas. OPTIKA: Jurnal Pendidikan Fisika, 4(1), 30-37. https://doi.org/10.37478/optika.v4i1.367

Verdian, F., Jadid, M., & Rahmani, M. (2021). Studi penggunaan media simulasi phet dalam pembelajaran fisika. Jurnal Pendidikan Dan Ilmu Fisika, 1(2), 39-44. https://doi.org/10.52434/jpif.v1i2.1448