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Research Article

Determining the Acceleration Due to Gravity Using a Smartphone-Based Pendulum System

Edison L. Uy[1], Ma. Noreen R. Eredia[1], John Lawrence A. Verzosa[1], Katrina M. Cabanacan[2], Rezy V. Mendaño[3], Carmen R. Lim[4]

[1]Catbalogan National Comprehensive High School, DepEd Catbalogan City, Catbalogan City, Philippines
[2]Eastern Visayas Regional Science High School, Catbalogan City, Philippines
[3]Samar State University, Catbalogan City, Philippines
[4]Schools Division of Catbalogan City, Catbalogan City, Philippines

Abstract
This study aimed to find the acceleration due to gravity using a smartphone pendulum system with the Phyphox application. As the need for new ideas and real-world applications in science education increases, researchers have explored how mobile sensor technology can provide a more precise and user-friendly alternative to traditional stopwatch methods. A simple pendulum setup, consisting of a smartphone, a string, and a fixed support, was used to record oscillation periods at different lengths. Data were analyzed by plotting the square of the time period against the length of the pendulum, which allowed for the calculation of local gravitational acceleration through linear regression. The computed value of acceleration due to gravity was 8.86 m/s², differing by 9.41 percent from the accepted standard value of 9.81 m/s². This difference falls within an acceptable range for classroom experimentation, considering potential error sources such as air resistance, timing delays, and misalignment. The study aimed to achieve four main objectives: to collect data from different pendulum lengths, to calculate local gravity, to compare the results with the standard value, and to verify the accuracy of the experiments. The findings indicate that smartphones can successfully reinforce physics concepts and support hands-on, inquiry-based learning. Using mobile apps boosts engagement, curiosity, and essential skills for the twenty-first century. As schools seek affordable ways to teach laboratory concepts, mobile sensor technologies like Phyphox provide a practical and accessible solution, particularly for classrooms lacking traditional lab equipment.

Keywords: Acceleration Due to Gravity, Simple Pendulum, Smartphone Sensors, Phyphox Application, Technology-Enhanced Physics Experiment

Correspondence
Edison L. Uy
edisonuy23@gmail.com

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1. INTRODUCTION

Understanding the local acceleration due to gravity (g) remains fundamental to the study of classical mechanics, particularly in analyzing motion under uniform gravitational force. In learning Physics, measuring acceleration due to gravity (g) using a simple pendulum has long served as a foundational laboratory activity due to its conceptual clarity and practical simplicity. This method helps learners observe periodic motion and apply mathematical relationships to derive gravitational acceleration based on pendulum length and oscillation period. However, traditional procedures typically rely on manual timing and basic measurement tools, which introduce notable margins of error and may compromise precision in data collection. In the era of Science, Technology, Engineering, and Mathematics (STEM) education, incorporating digital tools into classroom experiments aligns with the global shift toward utilizing technology and inquiry-based learning. Using smartphones as experimental tools is both a scientific innovation and a teaching improvement that connects theoretical physics concepts with real, hands-on exploration.

With the increasing integration of digital technologies in teaching, mobile devices have appeared as practical tools for enhancing Science instruction. Smartphone applications such as Phyphox now offer capabilities to collect real-time experimental data using built-in motion sensors, making physics experiments more accessible and interactive (Staacks et al., 2018). Unlike traditional stopwatch-based procedures, these digital tools minimize human error and enable automated timing and data visualization, which can enhance students' understanding of motion-related concepts (Jeli & Chandra, 2024). According to Fatmala et al. (2020), such innovations have been instrumental in increasing the precision of classroom experiments while also fostering active participation. Moreover, Anni (2021) emphasized that integrating mobile sensing technologies into laboratory tasks empowers students to connect abstract theories with practical applications, thereby contributing to meaningful and inquiry-driven learning experiences.

The use of smartphone-based experiments also supports the shift towards contextualized and technology-enhanced science education. As shown in recent studies, such as the work of Anni (2021) and Pacala and Pili (2023), video and sensor-based analysis platforms have proven effective in tracking motion, determining physical constants, and demonstrating damping effects in oscillatory systems. While previous investigations have employed video analysis tools such as Tracker to measure both g and damping constants, fewer studies have explored the exclusive use of smartphone sensor data in capturing accurate oscillation measurements within a simple pendulum framework. This presents an opportunity to investigate the capabilities and limitations of sensor-based mobile applications in replicating and validating classical physics results.

This study, therefore, seeks to determine the local acceleration due to gravity using a smartphone-based pendulum system through the Phyphox app. Specifically, it aims to 1) to collect and record the time period of oscillation for a pendulum of varying lengths using a smartphone-based sensor system; (2) to determine the experimental value of gravitational acceleration (*g*) based on the time period and length data; (3) to compare the obtained value of *g* with the standard value of 9.81 m/s^2; and (4) to assess the accuracy of the smartphone-based method in measuring gravitational acceleration through error analysis. By conducting this experiment with readily available digital tools, the study also highlights the pedagogical benefits of integrating mobile technology into physics instruction and experimentation.

The findings of this study should benefit educators by providing a cost-effective and scalable option for conducting laboratory experiments using accessible technologies. For students, it encourages engagement, curiosity, and understanding through hands-on learning. For future researchers, this work creates opportunities to explore more mobile-based experiments that support technological skills and problem-solving abilities in STEM education.

1.1. Theoretical Framework

The time period for a swinging pendulum is given by:

$$T = 2\pi\sqrt{\frac{L}{g}} \qquad \text{(Equation 1)}$$

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

$$T^2 g = 4\pi^2 L$$

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

$$g = 4\pi^2 \text{ x slope} \qquad \text{(Equation 5)}$$

Based on the fourth equation, it is clear that you need to graph the length of the string (L) and the Time period (T) squared by calculating the slope of the line and multiplying it by $4\pi^2$. You will be able to find g.

2. METHODS

This experiment was conducted in a controlled classroom setting using materials accessible to secondary learners and educators. The primary aim was to determine the acceleration due to gravity (g) using a smartphone equipped with an internal accelerometer and the Phyphox application. Compared to the study by Pacala and Pili (2023), which utilizes video analysis software and frame-by-frame tracking, this study employs a real-time data logging system available in the Phyphox app, enabling updated, sensor-based measurement of oscillation periods.

2.1. Material and Setup

A smartphone with the Phyphox app installed, a 1.0-meter ruler, a meter ruler, scotch tape for securing the smartphone, and an iron stand that functions as a stable support were used in the experimental setup of the study. The smartphone acts as the oscillating mass of the pendulum and is suspended vertically from a secure point. Displacement (L) was measured from the suspension point to the center of mass of the smartphone. This setup follows the standard procedures for pendulum modeling (Kuhn & Vogt, 2022; Macugalia, 2021; Pili & Violanda, 2018).

Six different lengths were tested: 100.0 cm, 90.0 cm, 80.0 cm, 70.0 cm, 60.0 cm, and 50.0 cm. For each length, the pendulum was displaced to an angle of less than fifteen degrees from the vertical and released without additional force. This small-angle approximation allowed the pendulum to behave in a manner consistent with simple harmonic motion, thereby validating the theoretical framework applied in the analysis (Bissell, 2025; Vidak et al., 2021).

Figure 1. Experimental setup for determining the acceleration due to gravity using a smartphone-based pendulum system. The smartphone is attached to one end of a string and suspended from an iron stand, allowing it to oscillate freely. The Phyphox application is used to measure the time period of oscillation, with string lengths varied across six trials to compute gravitational acceleration.

2.2. Participants

The study included six participants, four females and two males, aged 28 to 45. Their teaching experience ranged from 5 to 25 years. Among them were an education program supervisor from the Department of Education, Schools Division of Catbalogan City, and a college instructor from Samar State University. The other four were secondary science teachers, with three from Catbalogan National Comprehensive High School and one from Eastern Visayas Regional Science High School. All participants chose to take part in the smartphone-based training program. The program aimed to improve innovation in physics instruction and encourage the use of mobile technologies in science education.

Our participation was guided by the need to enrich our teaching practices, especially in schools where access to traditional laboratory equipment is limited. By directly involving ourselves in the design, data collection, and analysis processes, we experienced firsthand the educational value of integrating mobile technologies into experimental physics. This initiative aligns with the Department of Education's advocacy for contextualized, learner-centered, and technology-enhanced instruction. It also supports Sustainable Development Goal 4, which promotes inclusive, equitable, and quality education by empowering teachers through innovative, accessible, and relevant pedagogical tools.

2.3. Data Collection Procedure

As the pendulum oscillated, the Phyphox app automatically recorded the period (T) of each complete oscillation using the smartphone's internal accelerometer. Each trial was repeated three times per length to ensure consistency and minimize human error. The average time period was calculated, and its square (T^2) was used as the primary analytical variable.

The following relationship was applied as stated in equation 1. This equation was rearranged to isolate g and then used in the graphical analysis. A scatter plot of T^2 (x-axis) versus L (y-axis) was constructed using Microsoft Excel, and a line of best fit was generated. The slope of the graph was interpreted $\frac{g}{4\pi^2}$, allowing for the computation of the experimental value of gravitational acceleration using Equation 5.

2.4. Controls and Sources of Error

To minimize variability and maintain consistency across trials, several control measures were implemented. The type of smartphone, release angle, and surrounding environment were kept constant. The pendulum was always released carefully from the same angular displacement, and the same meter ruler was used throughout all measurements to reduce scale discrepancies.

However, specific sources of error could not be eliminated. These included inconsistent swing amplitude, slight misalignment of the string, measurement deviations in length due to parallax, and potential time lag from app initialization. While Pacala and Pili (2023) accounted for uncertainty through propagation formulas and Tracker calibration sticks, this study relied on percent error as the metric for evaluating the result's proximity to the standard gravitational value.

2.5. Data Analysis and Accuracy

The experimentally derived value of g was 8.86 m/s², compared to the standard 9.81 m/s². This corresponds to a percent error of:

$$\frac{9.81 - 8.86}{9.81} \; x \; 100 \; \approx \; 9.41 \; percent$$

This result, while less precise than the 2.24 percent error reported by Pacala and Pili (2023), is within an acceptable range for classroom-based experiments using mobile sensors. It affirms the effectiveness of real-time smartphone data collection as a viable method for physics inquiry in settings where video tracking tools may not be readily available (Fatmala et al., 2020; Anni, 2021).

3. RESULTS

This study aimed to accomplish the following objectives: (1) to collect and record the pendulum's time period of oscillation at various displacements using a smartphone-based sensing apparatus; (2) to compute the experimental value of gravitational acceleration (g) based on time period and displacement data; (3) to compare the obtained value of g with the standard gravitational constant of 9.81 m/s²; and (4) to assess the accuracy of the smartphone-based method through error analysis.

3.1. Oscillation Periods

The first objective was addressed by constructing a simple pendulum and using a smartphone equipped with the Phyphox application. Six distinct string lengths (ranging from 50.0 cm to 100.0 cm) were experimented with. For each length, three trials were conducted, and the average time period of oscillation

(T) was computed. Subsequently, the square of the average period (T^2) was derived to facilitate further analysis.

Table 1. Summary of Observed Data

Length (cm)	Time Period (s)				Time Period² (s²)
	Trial 1	Trial 2	Trial 3	Average	
100.0 ± 0.2	0.30	0.31	0.30	0.30 ± 0.005	0.090 ± 0.003
90.0 ± 0.2	0.27	0.26	0.27	0.27 ± 0.005	0.073 ± 0.003
80.0 ± 0.2	0.26	0.26	0.26	0.26 ± 0.000	0.068 ± 0.000
70.0 ± 0.2	0.23	0.26	0.24	0.24 ± 0.015	0.058 ±0.007
60.0 ± 0.2	0.22	0.24	0.23	0.23 ± 0.010	0.053 ± 0.005
50.0 ±0.2	0.21	0.23	0.18	0.21 ± 0.025	0.044 ± 0.011

3.2. Computed Gravitational Acceleration

For the second objective, the experimental value of *g* was determined using the theoretical relation between the period of a pendulum and its length. A scatter plot was generated with two variables on the x-axis and two on the y-axis. The best-fit line showed a linear relationship, and the computed slope of 0.2243 led to the derived acceleration due to gravity:

$$g = 4\pi^2 \cdot 0.2243 = 8.86\, m/s^2$$

3.3. Comparison with the Standard Gravitational Value

In pursuit of the third objective, the obtained value was compared to the internationally accepted standard of 9.81 m/s^2. The computed percent error was approximately 9.41 percent, calculated as:

$$\left(\frac{9.81 - 8.86}{9.81}\right) x\ 100 = 9.41\ percent$$

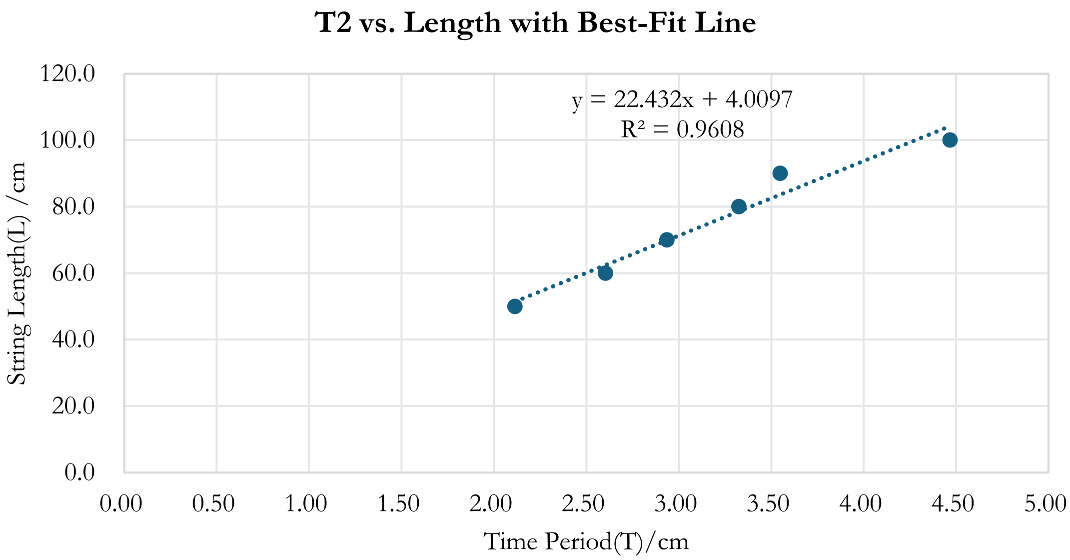

Figure 2. Graph of T^2 vs. Length with Best-Fit Line

This deviation is within acceptable limits for school-based physics investigations, especially considering the constraints of using readily available materials and smartphone sensors instead of laboratory-grade tools. It demonstrates the feasibility of introducing sensor-based experimentation even in resource-limited educational settings.

3.4. Accuracy Evaluation and Error Analysis of the Smartphone-Based Method

Addressing the fourth and final objective, the study assessed the accuracy and reliability of the smartphone-based approach. While the obtained value showed a slight underestimation, several experimental factors were acknowledged, including variation in release angle, potential parallax error in length measurement, slight inconsistencies in timing recognition, and possible limitations in accelerometer sensitivity. Despite these, the relatively low percent error affirms that smartphone sensors, when used appropriately, can yield reasonably accurate measurements of g.

Several studies have supported this conclusion, including the findings of Anni (2021), who reported comparable accuracy in home-based physics experiments using Phyphox. Similarly, Fatmala et al. (2020) demonstrated that integrating mobile sensors improved both engagement and precision in student-led experiments. However, compared to the study by Pacala and Pili (2023), which utilized Tracker video analysis and achieved a more precise result of 10.03 m/s^2 with a 2.24% error, this experiment highlights the trade-offs between accessibility and precision. While Tracker enables detailed frame-by-frame analysis and calibration, Phyphox offers real-time data collection that is simpler, faster, and more suited to classroom integration.

The difference from the standard gravitational value can be traced to several factors. The smartphone's uneven mass distribution might have shifted the center of oscillation and changed the effective length of the pendulum. Also, slight delays in the Phyphox sensor's data sampling rate could have caused timing errors during peak oscillations. External vibrations and air resistance likely added to the observed underestimation. These combined factors demonstrate the sensitivity of mobile-based measurements to the device's placement and the surrounding conditions, particularly when conducted outside a controlled laboratory environment.

4. DISCUSSION

The experiment's findings demonstrate the potential of smartphone-based sensor technology as a viable alternative to traditional laboratory tools for investigating physical principles, such as acceleration due to gravity. The recorded oscillation periods across varying pendulum lengths, when analyzed using the Phyphox application, yielded an experimental value of gravitational acceleration of 8.86 m/s^2. This result, although slightly below the accepted standard of 9.81 m/s^2, falls within an acceptable margin of error for school-based experiments, specifically with a calculated percent error of 9.41 percent. A similar study of Pacala and Mendaño (2025) yielded a value of 9.91 m/s^2.

These results affirm the theoretical framework underlying pendulum motion, as the plotted data established a linear relationship between the square of the period (T^2) and the string length (L). This trend reinforces the mathematical model $T = 2\pi \sqrt{(L/g)}$, validating the reliability of the procedure even when using non-specialized equipment. The derived slope, representing T^2/L, facilitated the approximation of gravitational acceleration and confirmed the feasibility of the approach.

The observed error margin can be attributed to several practical limitations, including minor inconsistencies in initial angular displacement, manual release delays, environmental disturbances, and limitations inherent to smartphone accelerometers. Nonetheless, the hands-on integration of digital tools promoted deeper conceptual understanding, allowing teachers, who served as both researchers and participants, to experience authentic inquiry-driven instruction aligned with the goals of the MATATAG K to 10 Science Curriculum.

The educational value of this smartphone-based approach is supported by existing literature. Anni (2021) emphasized the pedagogical promise of Phyphox for facilitating remote or low-resource experimentation, while Fatmala et al. (2020) found increased student engagement and data accuracy when mobile sensors were employed. Although Pacala and Pili (2023) achieved higher precision using video analysis tools such as Tracker, their method required a more sophisticated setup and post-processing, whereas Phyphox enabled real-time measurement in situ.

Ultimately, this experiment supports the broader educational advocacy for contextualized and technology-enhanced teaching strategies. It reflects the shifting paradigm from traditional passive instruction to learner-centered, inquiry-based approaches that equip teachers and students with 21st-century scientific skills through accessible and innovative tools.

4.1. Implications for Teaching and Learning

The findings of this study offer several pedagogical and practical implications for science education, particularly in physics instruction at the secondary level. First, the successful use of a smartphone-based sensor application (Phyphox) demonstrates the viability of mobile technology as an effective alternative to traditional laboratory instruments (Imtinan & Kuswarto, 2023). In environments where resources are limited, such innovations provide an equitable avenue for delivering experiential and inquiry-based learning (Ifenatuora et al., 2023; Uy, 2023). The relatively accurate determination of gravitational acceleration, despite the basic experimental setup, affirms the capacity of smartphone sensors to produce data with instructional value and scientific merit (Kittiravechote & Sujarittham, 2021; Padon, 2021).

Second, the integration of technology in science instruction supports the development of 21st-century skills among students, particularly digital literacy, scientific reasoning, and data analysis (Ramaila & Molwele, 2022; Rizaldi et al., 2020; Asrizal et al., 2018; Nurhayati et al., 2020). By empowering learners to conduct authentic experiments using familiar tools, teachers can foster greater engagement and ownership of the learning process (Milner-Bolotin & Milner, 2025; Leong et al., 2021). This aligns with the goals of the MATATAG K to 12 curriculum to contextualize and digitize education in ways that enhance both understanding and motivation.

Finally, the comparative analysis with traditional methods, such as the Tracker-based approach of Pacala and Pili (2023), highlights the balance between accessibility and accuracy. While advanced tools may yield lower error margins, mobile-based systems like Phyphox bridge the gap for institutions unable to access high-end equipment, thereby broadening participation in hands-on physics learning.

5. CONCLUSION

This study successfully measured the acceleration due to gravity using a smartphone pendulum system with the Phyphox app. The calculated value of 8.86 m/s^2 has a 9.41 percent difference from the standard 9.81 m/s^2. This supports the idea that mobile sensors are effective for school experiments. The results show the expected link between pendulum length and oscillation period. This suggests that incorporating smartphones into experiments can enhance students' understanding of concepts and foster learning through exploration.

However, there were some limitations. Device alignment issues, limited oscillation angles, and variations between smartphone models caused minor errors. These factors may slightly lower the accuracy and broaden the applicability of the results.

Future research should investigate the use of various mobile sensors. It should also compare the performance of various devices and operating systems. Additionally, integrating smartphone activities into larger STEM projects could enhance understanding of how mobile technology improves both scientific accuracy and student involvement in physics education.

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Research Ethics. This study was conducted in accordance with the ethical standards established by the Department of Education and institutional guidelines for teacher-led, classroom-based research. Given the nature of the study, which involved teacher-researchers as participants and utilized non-invasive experimental procedures, no physical or psychological risks were identified. Ethical considerations, including informed consent and voluntary participation, were duly observed throughout the study's conduct.

Data Availability Statement. All data generated and analyzed during this study are available from the corresponding author upon reasonable request. This includes raw experimental data, time period measurements, and computed values used in the analysis. Processed datasets supporting the findings are included within the manuscript.

Conflicts of Interest. The authors declare that there are no known financial or non-financial conflicts of interest that could have influenced the conduct, analysis, or reporting of this study.

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