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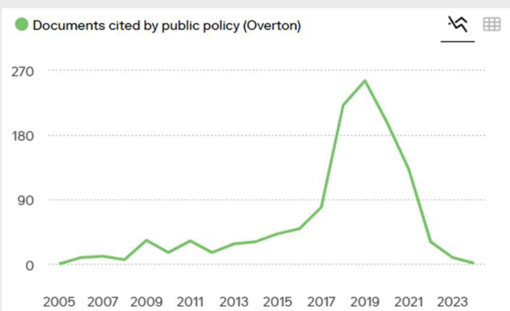

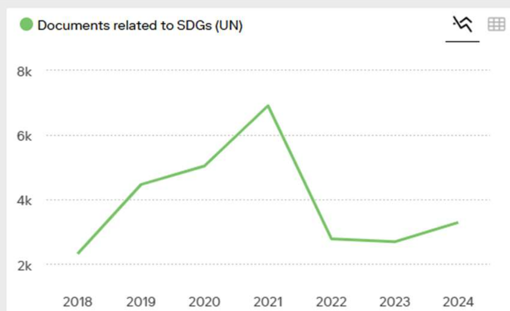

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Preface

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PREFACE

It is our great honour in organizing the 14th International Physics Seminar 2025 (IPS 2025). IPS is an annual meeting hosted by the Physics and Physics Education Department, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta (UNJ) and supported by the Physical Society of Indonesia (PSI) Chapter Jakarta – Banten. The IPS 2025 was conducted on June 21, 2025, in Latief Hendradiningrat Hall at campus site of UNJ, Jakarta, Indonesia.

The theme of the seminar is "Physics: The Fundamentals of Sustainable Development Goals". This seminar aims to bring together academics, scientists, students, and practitioners to share and discuss theoretical and practical knowledge of problems, new physics trends, and its applications. We invited scientists, scholars, engineers, and students from universities worldwide and industry to present ongoing research activities and to support fostering research relations between the university and industry. This seminar provides an opportunity for delegates to discuss and share their experience of new applications directly, to build business or research relationships, and to find global partners for future collaboration.

The scope of the seminar covers a wide array of topics within the field of physics, including:

1. Material Physics
2. Instrumentation and Computational Physics
3. Medical Physics and Biophysics
4. Earth Science and Astronomy
5. Theory, Nuclear, and Particle Physics
6. Energy and Environmental Physics
7. Physics Education

All submitted papers have been initially checked to meet the academic criteria before submitting to the system. All papers were carefully reviewed to ensure the quality for publication before being accepted. We acknowledge all authors who submitted their papers to IPS 2025.

Finally, we express our gratitude to the organizing committee for ensuring the quality of the seminar and to the reviewers for investing the time to ensure the quality of the paper. We acknowledged the academic and financial support from Dean of Faculty of Mathematics and Natural Sciences and Head of Institute for Research and Community Services of Universitas Negeri Jakarta. This seminar has also been supported by Penerbit Erlangga, Walcoo, and Attin. Finally, we would like to express our gratitude to IOP Publishing for administering our publications.

We are looking forward to welcoming you in our future International Physics Seminar (IPS).

Riser Fahdiran
Universitas Negeri Jakarta, Indonesia
Chairman of International Physics Seminar 2025 (IPS 2025)

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All papers published in this volume have been reviewed through processes administered by the Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing.

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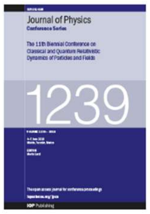

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Exploring Students' Experience Through Gravitational Acceleration Experiments

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Abstract

During experiments, students experience various aspects. However, many students assume that experiments are limited to determining the values of physical quantities. This study examines students' engagement with experimental procedures beyond routine measurements. Using three computer-based experiments a simple pendulum, a picket fence, and a video analysis of free-falling object, students determined the acceleration due to gravity. These experiments provide educational experiences. Students' experiences in conducting experiments include planning, analysis, and reporting. The students used a photogate to measure the oscillation period and software for data analysis. They utilized a pre-assembled setup in the picket fence experiment, whereas in the video analysis they had to design it themselves. Results indicate that varying experimental complexity fosters deeper understanding of experimental physics.

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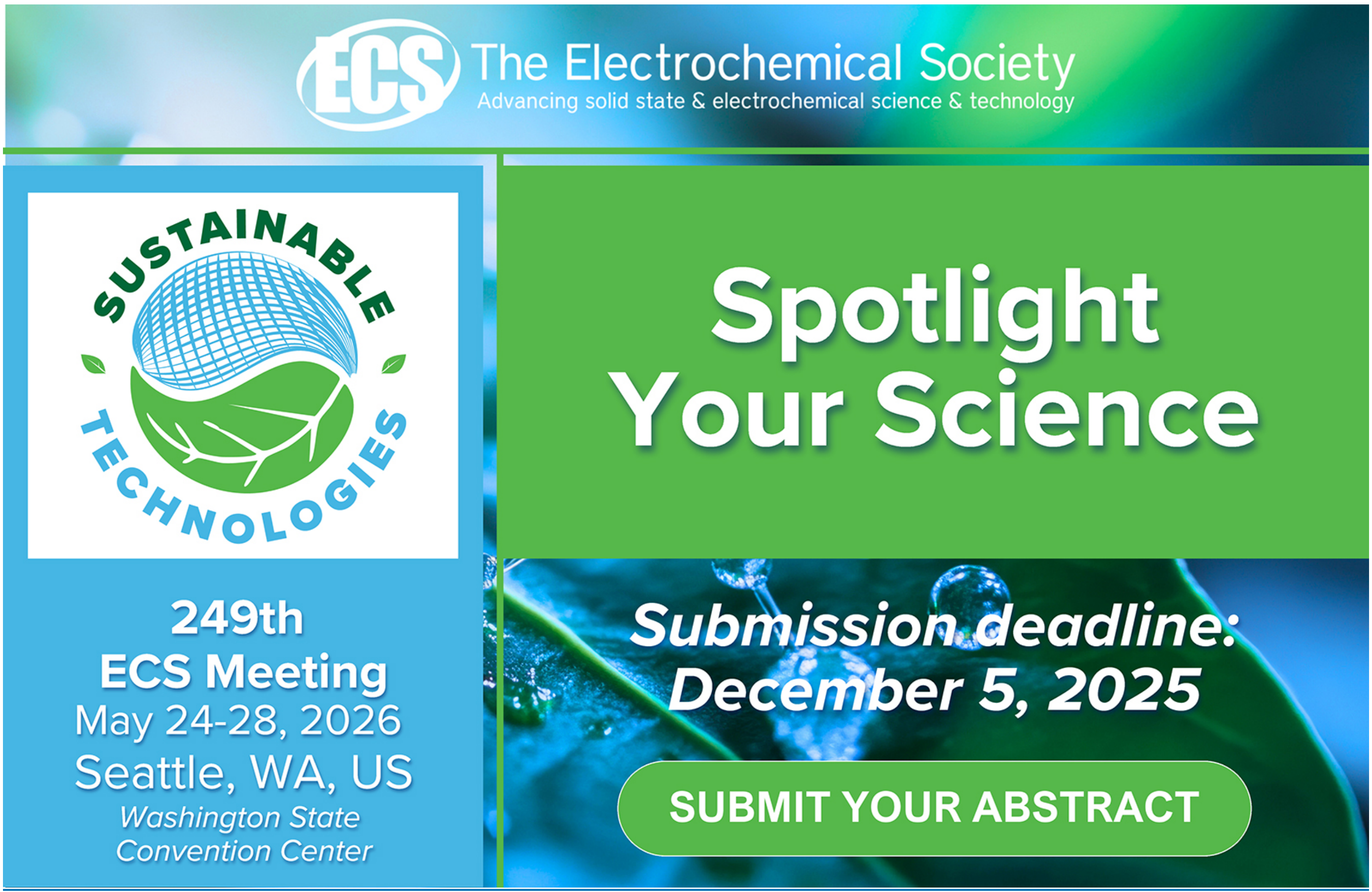

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Exploring Students' Experience Through Gravitational Acceleration Experiments

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Abstract. During experiments, students experience various aspects. However, many students assume that experiments are limited to determining the values of physical quantities. This study examines students' engagement with experimental procedures beyond routine measurements. Using three computer-based experiments a simple pendulum, a picket fence, and a video analysis of free-falling object, students determined the acceleration due to gravity. These experiments provide educational experiences. Students' experiences in conducting experiments include planning, analysis, and reporting. The students used a photogate to measure the oscillation period and software for data analysis. They utilized a pre-assembled setup in the picket fence experiment, whereas in the video analysis they had to design it themselves. Results indicate that varying experimental complexity fosters deeper understanding of experimental physics.

1. Introduction

Experiments play a central role in physics education, enabling students to develop accurate conceptions and avoid common misconceptions. However, many students approach labs passively, aiming only to confirm known results through step-by-step instructions. Often, they follow step-by-step instructions with the sole aim of confirming known results, thereby narrowing the scope of their learning [1].

The American Association of Physics Teachers (AAPT) identifies six core areas of learning outcomes for undergraduate physics laboratories: Constructing Knowledge, Modeling, Design, Technical and Practical Laboratory Skills, Data Analysis and Visualization, and Communication [2]. Laboratory experiments are intended to promote learning through active engagement. In this process, students build knowledge by collecting and analyzing data, and by drawing conclusions from their investigations. They also develop models that represent their observations, thereby linking theoretical concepts to experimental evidence. Additionally, students learn to design experiments to test hypotheses by considering critical factors such as equipment selection, experimental setup, data quality, and safety. A fundamental aspect of this process includes determining physical quantities by fitting data to theoretical models.

Students' approaches to experimentation are often shaped by prior experiences, such as viewing physics labs merely as opportunities to verify established theories. It is well documented that instructional laboratories are frequently structured in a way that allows students to complete procedures with minimal critical thinking [3]. Students are only asked to verify the theoretical model. This can limit their engagement with the broader aspects of experimental practice. This leads to a tendency to manipulate data, rather than looking for the causes of differences [4,5]. Students pay more attention to calculations using equations, but they do not take into account physics concepts [6,7]. Conversely, unexpected results can stimulate deeper inquiry and engagement. For this reason, some instructional labs are deliberately designed to introduce discrepancies between observed data and theoretical models, encouraging students to explore these conflicts [8]. Using familiar objects such as smartphones that have different sensors, Campari et al. engage students in gaining experience with laboratory tasks [9].

To investigate how students experience and engage with experimental processes, we tasked them with determining the acceleration due to gravity using three distinct methods. In this study, students were given the freedom to design, conduct, and analyze their own experiments. The first method involved using a photogate to measure the period of a simple pendulum, followed by calculating the gravitational acceleration using a standard formula [10,11]. The second and third methods focused on free-fall experiments [12,13]. In the second method, students used a picket fence and a photogate to measure acceleration, while the third method employed video analysis. In each case, students were required to develop a model to determine the acceleration due to gravity. All three methods utilized computer-based setups implemented through LoggerPro software [14].

2. Method

This study is a case study involving fourth-semester physics students enrolled in a computer-based experimental physics course, offered as an elective. Conducted over two academic years, the study included a total of 32 participants. As part of the course, students received instruction on the use of various sensors, software tools, video analysis techniques, and their practical implementations. To apply these learning outcomes, students were assigned open-ended experimental tasks that allowed them to develop their own approaches. Unlike traditional laboratory exercises, detailed procedural instructions typically found in laboratory manuals were not provided.

Students worked in groups of two or three and were tasked with determining the acceleration due to gravity. This assignment required them to complete all stages of the experimental process design, implementation, and reporting, while considering all relevant experimental aspects. Each group was required to complete three methods in sequence. The first method involved using a simple pendulum to produce simple harmonic motion. The second and third methods were based on the principles of free fall, requiring students to apply appropriate kinematic relationships. While both methods shared theoretical foundations, they differed in equipment and procedure: the second used a picket fence and photogate, while the third utilized video analysis, leading to variations in implementation and results.

Students' activities were directly observed throughout the experiment. At each stage, students were asked to explain their experimental design, including their initial ideas, setup, data analysis methods, and the equations used to achieve their objective. These explanations, along with follow-up discussions and interviews, were used to validate student engagement and understanding.

Upon completing the experiments, students submitted individual reports and written reflections. Data on student experiences were gathered through direct observation, interviews during the experimental process, and analysis of the submitted reports. All collected data were reviewed and analyzed in reference to the AAPT's six laboratory learning outcome focus areas [2].

2.1 Simple pendulum

For the first task, students should determine the acceleration due to gravity using a simple pendulum. The period T of oscillation of simple pendulum is given by [11]

$$T = 2\,\pi\,\sqrt{\frac{L}{g}} \tag{1}$$

where L is the effective length of a simple pendulum, and g is the acceleration of gravity.

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The period of this simple pendulum for oscillations was measured using a setup presented in figure 1. The pendulum (b) consists of a ball, a massless flexible thread, and a rigid stand. Measurements were made using a photogate (a) connected to a laptop (d) via an interface LabPro (c). Data analysis was carried out using a software Logger Pro. Based on equation (1) students designed the setup, collected the data and determined the acceleration of gravity [11].

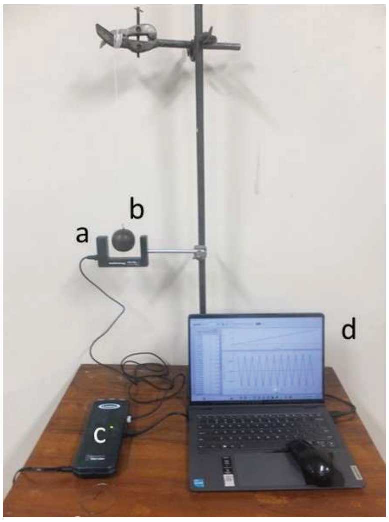

Figure 1. Experimental setup of simple pendulum.

2.2 Free fall dynamics using a picket fence

Unlike the pendulum method, students were tasked with observing the free-fall motion of an object. The height of an object under gravitational acceleration at time t (h_t) is described by the following equation

$$h_t = h_0 + v_0\, t + \frac{1}{2}\, g\, t^2 \qquad (2)$$

where h_0 and v_0 are initial height and velocity, at time t = 0 s, and g is acceleration of gravity.

The velocity of the object at time t (v_t) is given by

$$v_t = v_0 + g\, t \qquad (3)$$

For a special case of free fall object where v_0 =0 and the frame reference is from the initial height h_0 =0, equation (2) and (3) become

$$h_t = \frac{1}{2}\, g\, t^2 \qquad (4)$$
$$v_t = g\, t \qquad (5)$$

The equipment is depicted in figure 2. We use a special setup that already available [12]. It consists of a photogate (a), a picked-fence (b), an interface LabPro (c), and a laptop (d) equipped with software Logger Pro. After releasing the picket fence through the photogate, student obtained the data of time, the position and the velocity directly from the software. Then they had to determine the acceleration of gravity using the relevant equations.

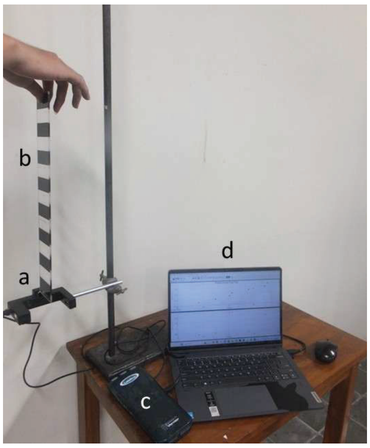

Figure 2. Experimental equipment for free fall dynamics

2.3 Free fall dynamics using a video analysis

Similar to the previous experiment, students were required to determine gravitational acceleration from the motion of a freely falling object. However, they should obtain the data from the video of their own. In this case student designed from the beginning how to provide the object, to calibrate and to record the object movement. Figure 3 shows the setup for experiment, a measuring ruler (a) is used as a standard length. When an object (b) is released from a height, its trace (c) will be obtained from video analysis. Students analysed videos to obtain time, position,

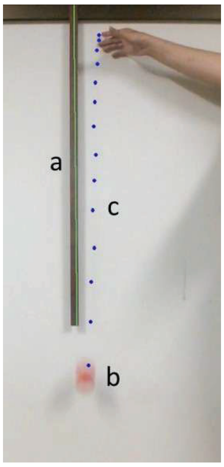

Figure 3. Free falling object experiment. Student releases an object from a height.

and velocity data using software Logger Pro, Finally, they calculated the acceleration of gravity using the relevant equations.

3. Result and discussion

3.1 Simple pendulum

Using a simple pendulum, students successfully completed the assigned task. Although they had previously performed a similar experiment using a stopwatch, this time they utilized a photogate for timing and software for data analysis to determine the acceleration due to gravity.

Direct observations indicated that students were already familiar with the governing equation (1) and could design an experiment accordingly. They correctly identified the dependent and independent variables, varying the pendulum length as the independent variable and measuring the oscillation period as the dependent variable. To control variables, the initial angle of oscillation was kept below 10°, aligning with the condition for the validity of equation (1). Interestingly, some students also recorded the pendulum mass, although it is not relevant to the calculation.

Students demonstrated an understanding of how to graph data and extract parameters. They correctly plotted the square of the period versus pendulum length to establish a linear relationship, from which the slope was used to calculate the gravitational acceleration and its uncertainty. Most groups tested pendulum lengths between 25 cm and 60 cm. Results from 13 groups are shown in figure 4, with average measured values of gravitational acceleration reported as $g = (9.8 \pm 0.1)\ m/s^2$, consistent with the accepted value [10,11]. All groups reported that their results were in good agreement with theory. However, some groups encountered challenges such as unstable oscillations or rotational motion of the pendulum.

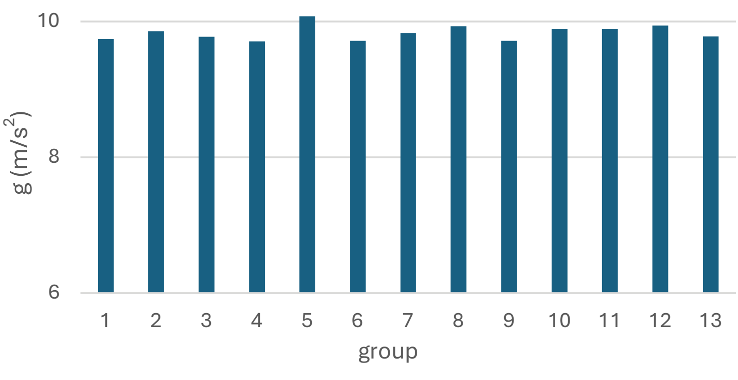

Figure 4. The accelerations of gravities were measured using a simple pendulum carried out by 13 groups.

3.2 Free fall dynamics using a picket fence

This experiment was new to the students. Prior to conducting the activity, the data collection procedure and experimental setup were introduced. Students collected position, velocity, and

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time data directly using the photogate and picket fence system. From this experiment, students generated both linear and parabolic graphs. As in the pendulum experiment, they analysed data relationships to calculate the gravitational acceleration. This analytical process deepened their understanding of free-fall dynamics which is an essential learning outcome of the experiment.

To determine gravitational acceleration, students used equation (2), relating height to time, and equation (3), relating velocity to time. For equation (2), students fit height-time data using a quadratic function

$y = A + B\,t + C\,t^2$,

with gravitational acceleration derived as g=2C.

For equation (3), they fit velocity-time data using a linear model, with the slope representing gravitational acceleration. Results are shown in figure 5, the blue bars and the red bars are determined using the height and velocity data, respectively. Figure 5 indicates both methods yielded consistent values close to 9.8 m/s^2. This result is similar to the experiment of free fall magnet [15,16]. Despite the accurate results, student reports primarily focused on reporting the numerical value of g. They did not elaborate on the theoretical basis for data fitting or the experiment design process, unlike in the pendulum experiment.

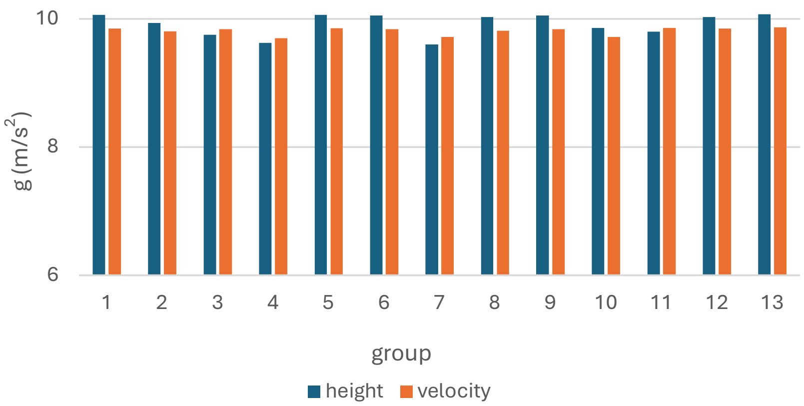

Figure 5. The accelerations of gravities were measured using the free fall motion of a picket fence carried out by 13 groups.

3.3 Free fall dynamics using a video analysis

In this experiment, students were required to produce and analyse their own video of a freely falling object. Prior instructions were provided on video recording and analysis procedures. Similar to the previous experiment, students collected data on position, velocity, and time. Using equations (2) and (3), they determined the acceleration due to gravity. The results are presented in figure 6, the blue bars and the red bars are determined using the height and velocity data, respectively. Figure 6 illustrates the experimental results, which displayed significant variation compared to the previous methods. Acceleration values derived from position-time data ranged from 8.9 $\mathrm{m/s^2}$ to 11.5 $\mathrm{m/s^2}$, while values based on velocity-time data ranged from 6.9 $\mathrm{m/s^2}$ and 9.3 $\mathrm{m/s^2}$.

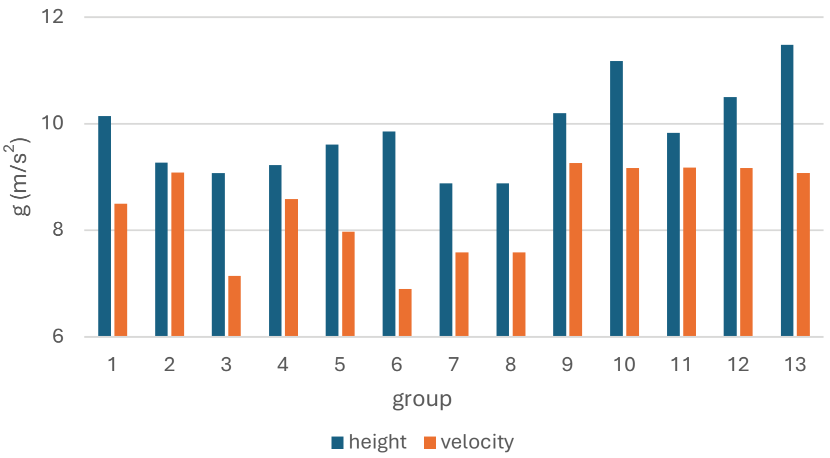

Figure 6. The accelerations of gravities were measured using the video of a free-falling object carried out by 13 groups.

These discrepancies were discussed in the students' reports. Some groups analysed the differences and identified contributing factors such as video quality, object tracking accuracy, calibration issues, and methodological differences. These reports were notably more comprehensive than those of the other two experiments, reflecting deeper engagement with the experimental process. Students explored creative approaches, using various objects such as ping pong balls, tennis balls, erasers, and lemons, and reflected on techniques for improving video clarity and calibration.

3.4 Students experience

Throughout the experiments, students were actively engaged in completing their tasks. Their experiences spanned all phases of experimentation, from design to data analysis and reporting. Their experiences align with the AAPT's recommended laboratory learning outcomes.

All three experiments offered valuable educational experiences. Students practiced constructing knowledge by analyzing and interpreting data, and by relating observations to theoretical models. They also demonstrated modelling by fitting data to appropriate equations to calculate gravitational acceleration. In the picket fence experiment, students used a preassembled setup and collected data with minimal design input. In contrast, video analysis required students to independently design experiments, select objects, control lighting and backgrounds, and conduct motion tracking. In the pendulum experiment, students set up equipment, implemented and collected data independently.

These activities developed students' technical and practical laboratory skills. The experiments incorporated computer-based measurement systems, including new tools like the picket fence apparatus. Most student reports noted the value of these systems in improving accuracy, efficiency, and ease of use. Students presented their findings using graphs and extracted fitting parameters to compute gravitational acceleration. They also compared their results to theoretical expectations and reported their findings in standard scientific formats.

Table 1 compares key characteristics of the three experiments, highlighting the physical phenomena involved (simple harmonic motion or free fall), types of data collected, equipment used, and the nature of the experimental procedure. Notably, students recognized that similar tools such as the photogate could be used across different experimental designs to explore different phenomena.

Many traditional labs focus on linear relationships, where physical quantities are derived from linear graph slopes [17]. In contrast, these experiments introduced both linear and nonlinear modeling. The free-fall experiments yielded both parabolic and linear graphs, requiring students to apply different modeling approaches to determine gravitational acceleration.

Some students made insightful connections across the three experiments. One report explicitly noted the value of using the same equipment in different ways and appreciated the opportunity to compare various methods of measuring gravitational acceleration. However, there was a noticeable tendency for students to focus primarily on obtaining the value of gravitational acceleration. Similarly, Smith and Holmes showed that students paid more attention to the correspondence between experimental results and theory [5]. In particular, reports on the picket fence experiment emphasized the numerical result while omitting discussion of the theory or process. This contrasts with the pendulum and video analysis experiments, where students demonstrated more thorough analysis and reflection.

Table 1. The characteristic of experiment

Aspect	Simple pendulum	Picket fence	Video analysis
Phenomena	Simple harmonic motion	Free fall	Free fall
Data for modelling	Period and length	- Position and time Velocity and time	- Position and time - Velocity and time
Equipment	Photogate	Photogate	Photo analysis
Procedure	Not available	available	Not available

Students also applied prior experience. For example, they reused procedures from previous pendulum experiments, now enhanced with photogate timing. Although some students included irrelevant variables such as pendulum mass it reflects their attempt to approach the task comprehensively. In the video analysis experiment, students exhibited creativity in producing usable data. They tested different objects and backgrounds, leading to a wide range of results. These variations prompted deeper analysis of experimental limitations. This finding is consistent with the work of Kraft et al. who reported that unexpected results often stimulate greater student engagement [8]. This is also in line with Wee et all's suggestion to improve learning using a video analysis approach [18]. In our study, students similarly explored how factors such as calibration, air resistance, video quality, and object tracking influenced their outcomes.

Although students did not always articulate their strategies or reasoning in detail, they expressed that the experiments were fast, easy to perform, and accurate largely due to the computer-based systems. Many reflected that they gained a better understanding of physical phenomena and developed valuable technical skills. Overall, students felt that the learning experience was authentic and meaningful.

4. Conclusion

Experimental work in physics education plays a critical role in developing students' conceptual understanding and practical skills. In addition to reinforcing theoretical knowledge, well-designed laboratory activities provide opportunities for students to engage in experimental design, data collection, analysis, and interpretation. When students are challenged with open-ended tasks, their learning extends beyond simply obtaining numerical results. These experiences encourage deeper engagement with the scientific process and promote the development of essential skills for experimental inquiry. We recommend providing students with a variety of experiences during laboratory activities. This approach will enhance comprehensive learning outcomes.

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