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# Development of a computer-based simple pendulum experiment set for teaching and learning physics

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## Abstract

The development of a cost-effective experiment set is essential for teaching and learning physics in educational institutes. We aim to develop a computer-based simple pendulum experiment set consisting of a simple pendulum, infrared phototransistor, and Arduino board for calculating the gravitational acceleration (g). We used 13 pendulum lengths with five angles for each length to measure the period of motion. We found linear relationships between lengths and period-squared. The *g*-value was $9.806 \pm 0.025$ (average ± standard error) $m/s^2$. Since this experiment set is cost-effective, and more straightforward method to understand, it will benefit the physics learning in educational institutions.

**Keywords**
Teaching and learning physics, Computer-based experiment set, Gravitational acceleration, Simple pendulum.

## Introduction

Physics is one of the most fundamental scientific disciplines, and it forms the core of scientific development (Hartmann and Mittelstrass, 2002). Physics helps students to understand natural phenomena through observations, measurements, mathematics, and experiments (Falkenburg, 2011). However, the conventional teaching methods that include delivering traditional lectures in front of the passive students are often tedious and very difficult for the students to understand physics. Moreover, these methods do not provide adequate opportunities for the students to think critically to solve a problem (Adams et al., 2006; Schauer et al., 2009; Wieman and Perkins, 2005).

Along with the conventional teaching method, laboratory activities are essential as it allows the students to get involved in the learning process. Students start thinking critically while conducting laboratory works. Self-explored experience from laboratory activities helps the students understand and recognize laws of physics, enhance the physics' conceptual thinking, and develop their scientific skills (Darrah et al., 2014; Sari et al., 2019).

It could be more helpful for the students if they get an opportunity to learn physics from the computer-based experiments in the physics laboratory. It helps the students better to understand physics than only lectures in the classroom. It allows the students to develop their skills, which makes physics more accessible (Brelsford, 1993; Darrah et al., 2014; Rutten et al., 2012; Sari et al., 2019; Zacharia and Anderson, 2003). It also increases the students' motivation to collaborate and stay engaged with the learning process, which is very useful for them (Sari et al., 2019). The computer-based experiments have some more benefits for the students, such as teaching the students about data collection and data analysis, understanding the relationships among various variables through plotting graphs based on their collected data. This helps the students to gain knowledge about theory and experiments and develop their research skills (Amrani and Paradis, 2010; Beichner et al., 1999; David et al., 2007; Trumper and Gelbman, 2000).

A low-cost experimental set could be developed in computer-based experiments by using an Arduino board and a computer (Musik, 2017; Sanjaya et al., 2018; Sari and Kirindi, 2019; Tunyagi et al., 2018). This experimental set is cost-effective and easily handled. Students learn from real-time experiments and collect data continuously. Through this type of experiment, students obtain more accurate physics concepts compared to the conventional teaching method. These computer-based experimental sets can include various sensors, including photogate sensor (Yulkifli et al., 2018), ultrasonic sensor (Cutnell and Johnson, 2010; Galeriu et al., 2014; Pili and Violanda, 2019; Sanjaya et al., 2018; Tong-on et al., 2017), and infrared sensor (Musik, 2014, 2017), which makes physics learning more comfortable for the student.

The experiments about motion are fundamental in elementary or advanced physics, where the concept of position, time, speed, and acceleration is crucial. Gravity is known as the key to describe the motion of an object and pendulum experiment is an excellent way to demonstrate the gravity in high school, college, and university study.

In this study, a simple pendulum experiment is introduced which consists of an object with a small mass, also known as the pendulum bob, suspended from a light string. A simple pendulum period depends on the string's length and the amplitude of the pendulum's swing. An Arduino-based microcontroller and infrared phototransistor sensors are used to measure the period of oscillation and calculate the gravity. The aims of this study are (i) to develop a computer-based experiment set on a simple pendulum, and (ii) to measure the periodic motion and the acceleration of gravity (g) in Nakhon Si Thammarat province, southern Thailand. This proposed setup is cost-effective and easy to operate.

## Materials and methods

### Working principle of classical pendulum

A simple pendulum consists of a particle of mass $m$, attached to a frictionless pivot $P$ by a cable of length $L$ and negligible mass. When the particle is pulled away from its equilibrium position by an angle $\theta$ and released, it swings back and forth (Fig. 1) (Cutnell and Johnson, 2010). The period $T$ of a simple pendulum for small angles depends on its length and the local strength of gravity as shown in the following equation:

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

For larger amplitudes, the period is longer than predicted by the small-angle approximation. $T$ is calculated by using the following equations (Amrani et al., 2008; Beléndez et al., 2009; Simpson, 2010):

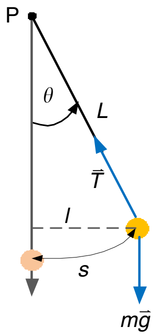


Figure 1: A simple pendulum swinging back and forth about the pivot $P$. If the angle $\theta$ is small about 10° or less, the swinging is approximately simple harmonic motion.

$$T = 2\pi\sqrt{\frac{L}{g}\left(1+\frac{1}{16}\theta_0^2+\frac{11}{3072}\theta_0^4+\frac{173}{737280}\theta_0^6 + \frac{22931}{1321205760}\theta_0^8+\ldots\right)} \tag{2}$$

and:

$$T^2 = \left[4\pi^2\left(1+\frac{1}{16}\theta_0^2+\frac{11}{3072}\theta_0^4+\frac{173}{737280}\theta_0^6 + \frac{22931}{1321205760}\theta_0^8+\ldots\right)/g\right]L \tag{3}$$

Here $g$ is the acceleration of gravity, $L$ is the length of the pendulum, and $\theta_0$ is the angular displacement amplitude.

### Experimental setup

### *Mechanism of harmonic motion*

The experimental setup is made of a stand (stainless steel) with a width of 0.30 m, length of 0.40 m, and a height of 0.16 m. A pole (1st pole in Fig. 2a) is fixed with the stand. The pole's length is 1.00 m, but it can be increased up to 1.48 m by using a support system. A pendulum (stainless steel) is tied with the 2nd pole of the rigid support by using a nylon rope (Fig. 2a). The mass and diameter of the pendulum are 0.032 kg and 0.02 m, respectively. A screw lock is fixed with the 2nd pole to increase or decrease the nylon rope's length along with the pendulum. Pendulum swing angle can be fixed by a projector as shown in Figure 2b (i.e., 35 degrees). An infrared LED and

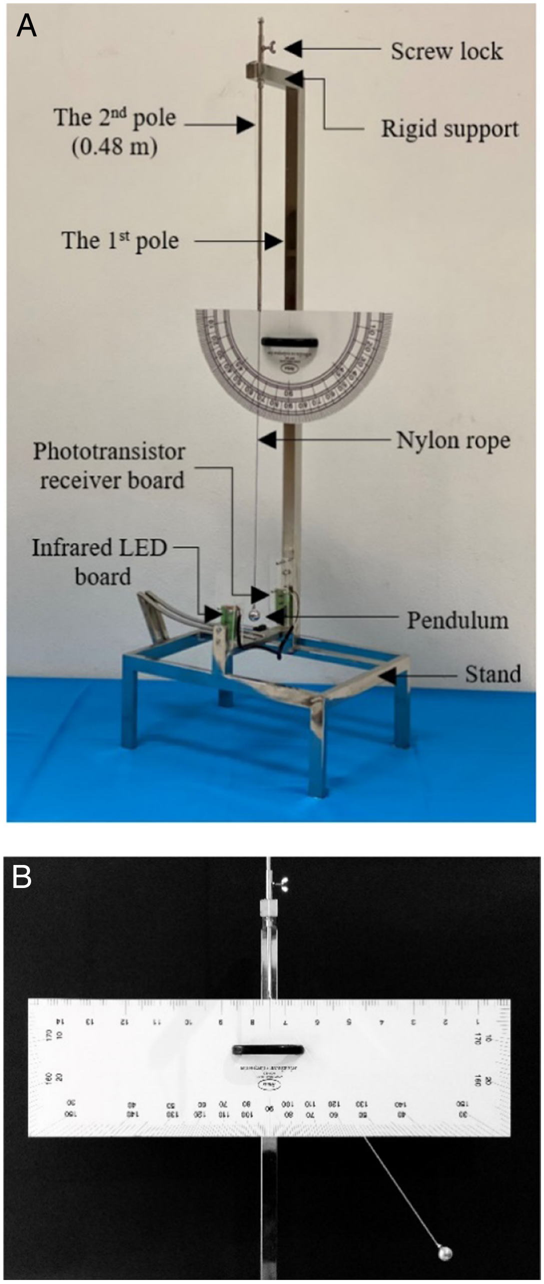


Figure 2: The structure of the experimental set; (a) experimental set, and (b) fix swing angle.

phototransistor sensor are fixed with the stand and the 1st pole, respectively (Fig. 2a).

The infrared phototransistor circuit consists of a phototransistor, an infrared LED, and a resistor (Fig. 3). The phototransistor acts as a receiver, and the infrared LED acts as a transmitter. The resistor is 330 kΩ, 200 Ω, and 1/4 W (Musik, 2017) (Fig. 3). The power supply is 5 V of DC. During operating,

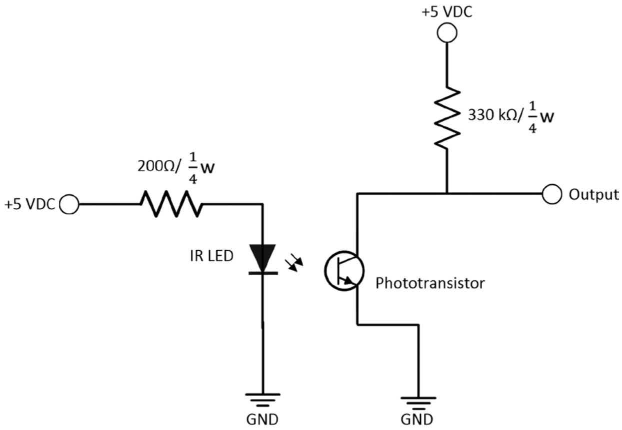


Figure 3: Infrared phototransistor circuit.

when the infrared reaches the phototransistor, the output voltage becomes 0 V, and when an opaque object blocks the path of the light, the output voltage changes to 5 V. The signal of the output voltage is used to measure the swing period of the pendulum through using the Arduino program.

The infrared transmitting circuit consists of four IR LEDs and four resistors of 220 Ω (Fig. 4a). Infrared LED is connected with four resistors (each infrared LED is 5 mm in diameter) in parallel, where the distance between each resister is 1.2 cm. The device is placed on a 3.0 cm × 6.5 cm printed circuit board (Fig. 4b).

The phototransistor receiver circuit consists of four phototransistors in parallel. The diameter of each phototransistor is 5 mm. The distance between each phototransistor is 1.2 cm. This phototransistor receiver circuit is used for collecting the data of period (*T*) (Fig. 5a). This phototransistor receiver circuit is placed on a 3.0 cm × 6.5 cm printed board (Fig. 5b).

## *Computer interface on the simple pendulum*

The computer interface experimental set consists of hardware and software, which are shown in Figure 6. An Arduino (model ET-EASY MEGA1280) is used as the hardware which is connected to the notebook PC via a USB port for sending simple pendulum motion data. The phototransistor is used as a signal detector. A simple pendulum motion test set is prepared by connecting a microcontroller with the notebook PC (Fig. 6). The pendulum moves through the infrared phototransistors which changes the output voltage from 0 to 5 volt. The output from the receivers is sent

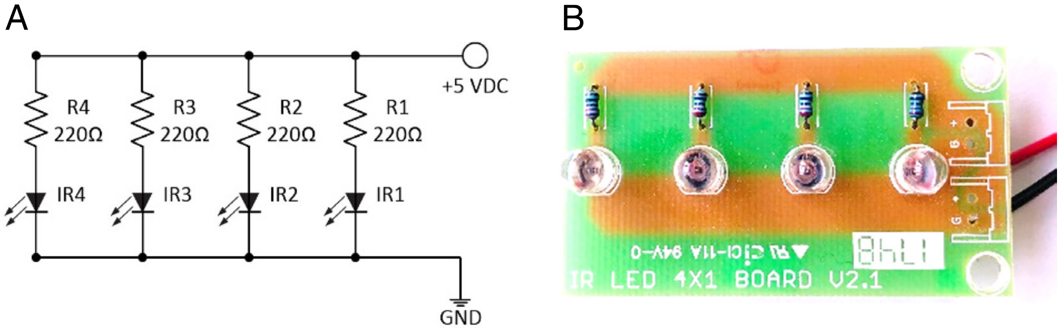


Figure 4: (a) Infrared LEDs circuit, (b) infrared LEDs board.

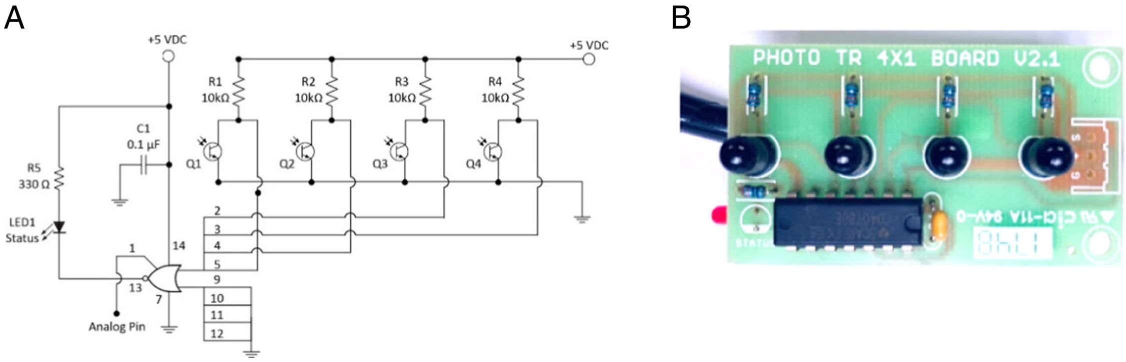


Figure 5: (a) Phototransistor receiver circuit, (b) phototransistor receiver board.

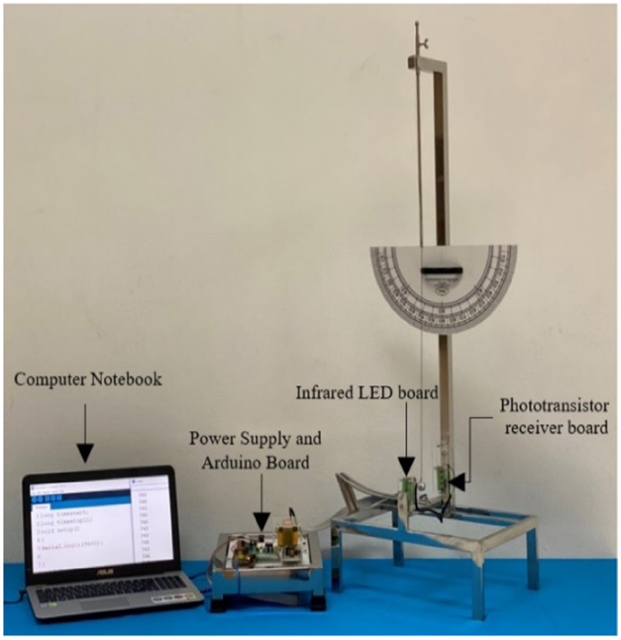
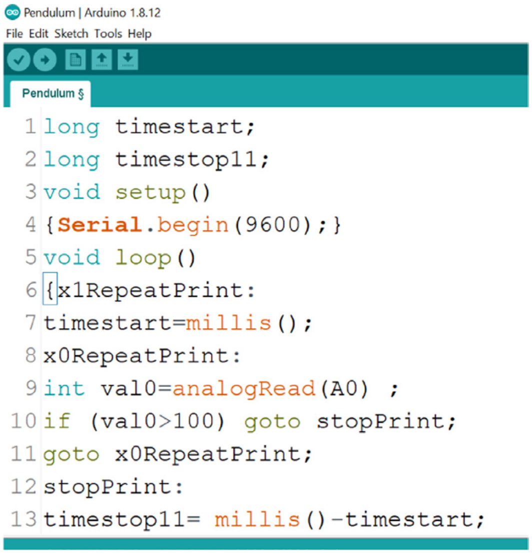


Figure 6: The computer-based experiment set on a simple pendulum.

to microcontroller. The microcontroller receives the output voltage and calculates the *g*-value. Finally, Arduino development board has the ability to store the data for future reference. Arduino 1.8.12 is used to record the period of the pendulum motion. The codes used for data collection are shown in Figure 7.

## Experimental procedure

We took 13 pendulum lengths (0.20-0.80 m, with 0.05 m interval), and for each length, we used five angles (7, 10, 15, 20, and 25°). After confirming a length (i.e., 0.20 m), the first angle (i.e., 7°) was determined by using the projector. The pendulum was swung from the fixed angle 10 times (i.e.,10 periods, *T*) (see Pili, 2020; Yulkifli et al., 2018). During pendulum swing, the experimental data were recorded with the Arduino program and sent to the notebook PC. After finishing one angle, we selected the next angle (i.e., 10°) and swung the pendulum 10 times. In this way, we finished all angles (7-25°). Then we selected the next length (i.e., 0.25 m) and finished all five angles, and every



```
long timestart;
long timestop11;
void setup()
{Serial.begin(9600);}
void loop()
{x1RepeatPrint:
timestart=millis();
x0RepeatPrint:
int val0=analogRead(A0) ;
if (val0>100) goto stopPrint;
goto x0RepeatPrint;
stopPrint:
timestop11= millis()-timestart;
```

Figure 7: Arduino codes used for data collection.

time the Arduino program sent data to the notebook PC. In this way, we finished all five angles (7-25°) for all 13 lengths (0.20-0.80 m). After receiving all period (*T*), the square of the period ($T^2$) was calculated in the Microsoft Excel program. Afterward, graphs (i.e., relationships between lengths and square of periods for each angle) were plotted, and data were analyzed using Wolfram Mathematica program. Then, the value of gravitational acceleration (g) for each angle was calculated. Afterward, the average *g*-value ± standard error (SE) was calculated and compared this *g*-value with the theoretical (g) value.

## Results and discussion

The period squared achieved from each length, and each angle is shown in Table 1. The linear regressions between lengths and period squared for five angles are shown in Figure 8a-e. We observed significant positive relationships between lengths and period squared for each angle. The regression line, $R^2$ and *p*-value are shown in each figure.

The slopes of the linear regressions in Figure 8 are 4.044, 4.035, 4.045, 4.044, and 4.070, respectively and represents by:

$$4\pi^2\left(\begin{array}{l}1+\frac{1}{16}\theta_0^2+\frac{11}{3072}\theta_0^4+\frac{173}{737280}\theta_0^6\\+\frac{22931}{1321205760}\theta_0^8+\dots\end{array}\right)/\,g$$

Then, we calculated the gravitational acceleration (g) of Nakhon Si Thammarat province. We found

**Table 1. Squared period form experimental data.**

| | 7 degree | | 10 degree | | 15 degree | | 20 degree | | 25 degree | |
|---|---|---|---|---|---|---|---|---|---|---|
| Length (m) | *T* (s) | $T^2$($s^2$) | *T* (s) | $T^2$ ($s^2$) | *T* (s) | $T^2$ ($s^2$) | *T* (s) | $T^2$ ($s^2$) | *T* (s) | $T^2$($s^2$) |
| 0.20 | 0.894 | 0.800 | 0.903 | 0.815 | 0.901 | 0.811 | 0.895 | 0.801 | 0.913 | 0.834 |
| 0.25 | 1.003 | 1.006 | 1.014 | 1.029 | 1.014 | 1.029 | 1.017 | 1.034 | 1.031 | 1.063 |
| 0.30 | 1.084 | 1.174 | 1.110 | 1.233 | 1.108 | 1.228 | 1.096 | 1.202 | 1.116 | 1.245 |
| 0.35 | 1.180 | 1.392 | 1.184 | 1.402 | 1.188 | 1.411 | 1.191 | 1.419 | 1.208 | 1.459 |
| 0.40 | 1.257 | 1.581 | 1.250 | 1.561 | 1.263 | 1.596 | 1.274 | 1.622 | 1.290 | 1.664 |
| 0.45 | 1.340 | 1.796 | 1.331 | 1.772 | 1.354 | 1.834 | 1.367 | 1.870 | 1.380 | 1.904 |
| 0.50 | 1.435 | 2.059 | 1.424 | 2.029 | 1.442 | 2.081 | 1.416 | 2.004 | 1.438 | 2.068 |
| 0.55 | 1.470 | 2.159 | 1.483 | 2.200 | 1.499 | 2.246 | 1.511 | 2.282 | 1.530 | 2.341 |
| 0.60 | 1.560 | 2.433 | 1.561 | 2.436 | 1.550 | 2.458 | 1.564 | 2.447 | 1.580 | 2.496 |
| 0.65 | 1.619 | 2.620 | 1.610 | 2.591 | 1.627 | 2.660 | 1.638 | 2.682 | 1.640 | 2.690 |
| 0.70 | 1.678 | 2.815 | 1.676 | 2.808 | 1.698 | 2.885 | 1.673 | 2.799 | 1.692 | 2.861 |
| 0.75 | 1.751 | 3.065 | 1.733 | 3.002 | 1.732 | 3.027 | 1.751 | 3.065 | 1.753 | 3.074 |
| 0.80 | 1.783 | 3.178 | 1.803 | 3.251 | 1.778 | 3.205 | 1.794 | 3.218 | 1.812 | 3.284 |

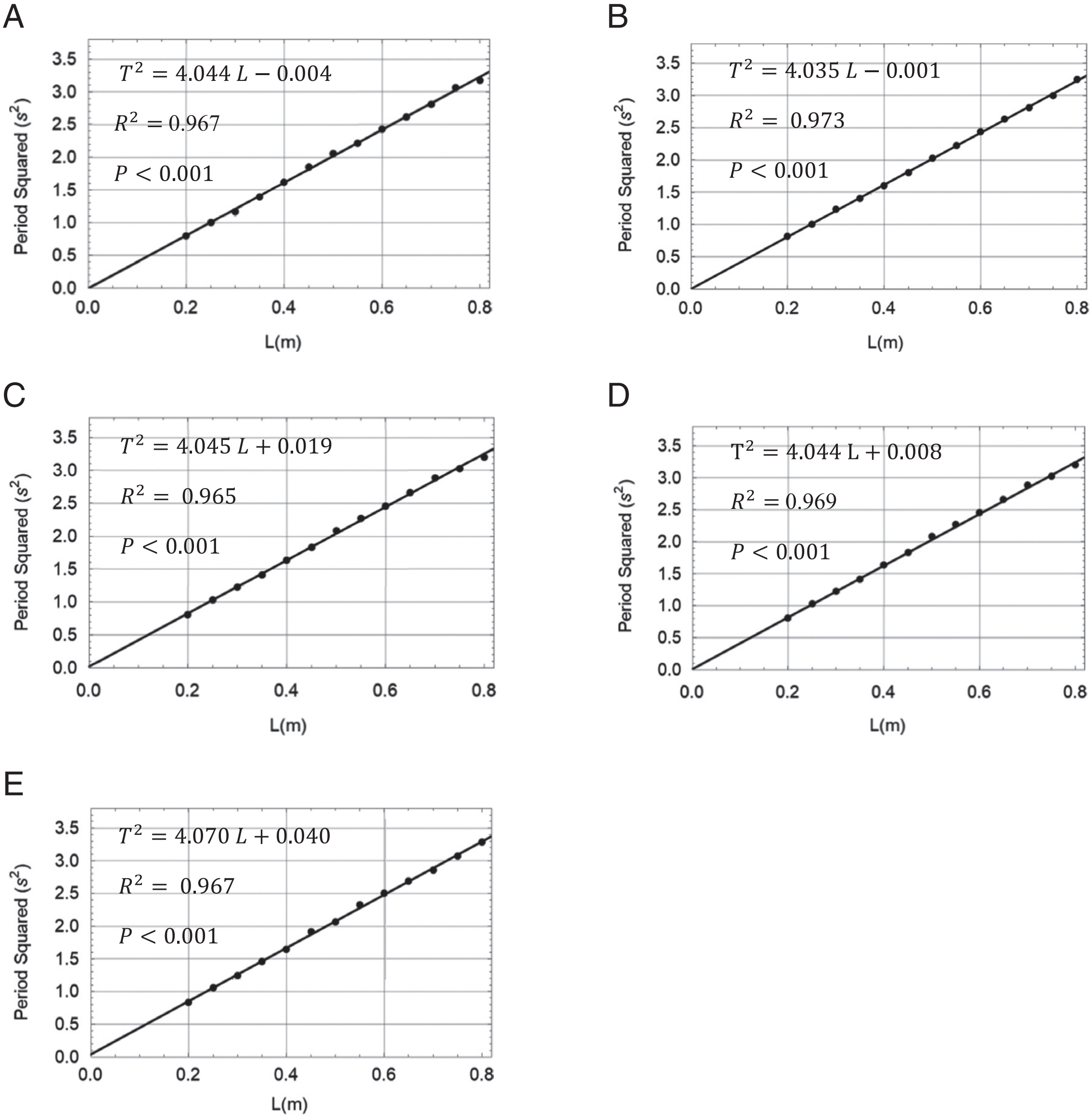


Figure 8: Relationships of length and period squared for the angles (a) 7°, (b) 10°, (c) 15°, (d) 20°, (e) 25°.

that average gravitational acceleration ± standard error was 9.806 ± 0.025 m/s$^2$ which is shown in Table 2. The true value of gravitational acceleration (g) of Nakhon Si Thammarat province was checked in SensorsONE (2021) by putting latitude (8.8297614) and height (20 m) and we found *g*-value as 9.781. The experimental value's (9.806) accuracy to the true value (9.781) was calculated using the following relative error equation:

$$Error(\%) = \left|\frac{9.781 - g_{exp}}{9.781}\right| \times 100 \qquad (4)$$

Our results support the findings of other scientists (Khairurrijal et al., 2012; Pili and Violanda, 2019; Sanjaya et al., 2018; Sinacore and Takai, 2010; Yulkifli et al., 2018) who used simple pendulum motion experiment set to calculate the gravitational acceleration (g) in different places. One study in New York (USA) (Sinacore and Takai, 2010) used pendulum, telephone pickup, and sound card oscilloscope to calculate the *g*-value and their calculated *g*-value was 9.774 m/s$^2$ with an error of 0.3%. A study in Indonesia (Khairurrijal et al., 2012) calculated *g*-value by using infrared transmitter and phototransistor receiver electronic circuit and their *g*-value was 9.77 ± 0.03 m/

**Table 2. Values of gravitational acceleration (*g*).**

| The angular displacement ($\theta_0$) | Gravitational acceleration (m/$s^2$) | Error (%) |
|---|---|---|
| 7° | 9.773 | 0.087 |
| 10° | 9.802 | 0.205 |
| 15° | 9.802 | 0.210 |
| 20° | 9.838 | 0.573 |
| 25° | 9.817 | 0.365 |
| Average | 9.806 ± 0.025 | 0.253 |

$s^2$ with an error of 0.1%. Another study in Indonesia (Sanjaya et al., 2018) calculated *g*-value by using an HC-SR04 ultrasonic sensor, Arduino microcontroller, and the computer interface, and their calculated *g*-value was 9.811 ± 1.067 m/$s^2$. Yulkifli et al. (2018) calculated *g*-value in the same country by using both manual and digital tools. They found that the *g*-value from manual and digital methods were 9.762 and 9.797 m/$s^2$, respectively, where the accuracy (%) of the digital method was higher and relative error(%) was lower compared to the manual method. In the digital method, they used a photogate sensor and computer interface with Arduino pro mini. One more study in the Philippines (Pili and Violanda, 2019) used an ultrasonic sensor and an Arduino Uno board to calculate *g*-value and their calculated *g*-value was 9.82 ± 0.10 m/$s^2$.

## Conclusion

The development of the computer-based experiment set on a simple pendulum in harmonic motion, which experiment apparatus based on a simple pendulum, infrared sensor, Arduino microcontroller, a computer, and Wolfram Mathematica has been successfully shown, the acceleration of gravity of pendulum motion measured $g = 9.806 \pm 0.025$ m/$s^2$ with an error of 0.253%. This experimental setup is a cost-effective and straightforward method. The advantage of this system is that it makes physics experiments easier than traditional lectures in the classroom. Students can better understand the physics theories, which help them to develop their learning skills (Brelsford, 1993; Darrah et al., 2014; Zacharia and Anderson, 2003). Significantly, the use of computer-based learning, along with sensors, might increase their motivation for learning physics. This might help them to achieve their expected learning outcomes (Karamustafaoğlu, 2012). Therefore, this system can be applied in real-time physics teaching, which may help students learn physics concepts and laws efficiently and effectively.

In the future, a matrix real-time simple pendulum method could be developed to test the relationships between displacement/velocity/acceleration and times of motion. This further study will help the physics students to understand the pendulum motion theory easily in the laboratory.

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## Literature Cited

Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D. and Wieman, C. E. 2006. New instrument for measuring student beliefs about physics and learning physics. The Colorado Learning Attitudes about Science Survey. Physical Review Special Topics – Physics Education Research 2: 1–14.

Amrani, D. and Paradis, P. 2010. Use of computer-based data acquisition to teach physics laboratories: case study-simple harmonic motion. Latin American Journal of Physics Education 4: 511–514.

Amrani, D., Paradis, P. and Beaudin, M. 2008. Approximation expressions for the large-angle period of a simple pendulum revisited. Revista Mexicana De Fi'Sica E, 54: 59–64.

Beichner, R., Bernold, L., Burniston, E., Dail, P., Felder, R., Gastineau, J., Gjersten, M. and Risley, J. 1999. Case study of the physics component of an integrated curriculum. Physics Education Research, American Journal of Physics Supplement 67(Suppl. 7): 16–24.

Beléndez, A., Rodes, J. J., Beléndez, T. and Hernández, A. 2009. Approximation for the large-angle simple pendulum period. European Journal of Physics 30: 1–6.

Brelsford, J. W. 1993. Physics education in a virtual environment Proceedings of The Human Factors and Ergonomics Society 37th Annual Meeting, pp. 1286–1290.

Cutnell, D. J. and Johnson, W. K. 2010. Introduction to physics USA: John Wiley & Sons.

Darrah, M., Humbert, R., Finstein, J., Simon, M. and Hopkins, J. 2014. Are virtual labs as effective as hands-on labs for undergraduate physics? A comparative study at two major universities. Journal of Science Education and Technology 23: 803–814.

David, R. S., Priscilla, W. L. and Ronald, K. T. 2007. Real Time Physics: active learning labs transforming the introductory laboratory. European Journal of Physics 28: S83–S94.

Falkenburg, B. 2011. What are the phenomena of physics? Synthese 182: 149–163.

Galeriu, C., Edwards, S. and Esper, G. 2014. An Arduino investigation of simple harmonic motion. The Physics Teacher 52: 157–159.

Hartmann, S. and Mittelstrass, J. 2002. Physics is part of culture and the basis of technology, In Deutsche Physikalische Gesellschaft (Ed.), Physics–Physics Research: Topics, Significance and Prospects, pp. 195–198.

Karamustafaoğlu, O. 2012. How computer-assisted teaching in physics can enhance student learning. Educational Research and Review, 7: 297–308.

Khairurrijal, K., Widiatmoko, E., Srigutomo, W. and Kurniasih, N. 2012. Measurement of gravitational acceleration using a computer microphone port. Physics Education 47: 709–714.

Musik, P. 2014. Development of computer-based experimental set in physics for free falling object. The European Conference on Education 2014: 309–322.

Musik, P. 2017. Development of computer-based experiment set on simple harmonic motion of mass on springs. The Turkish Online Journal of Educational Technology 16: 1–11.

Pili, U. B. 2020. Sound-based measurement of g using a door alarm and a smartphone: listening to the simple pendulum. Physics Education 55: 1–4.

Pili, U. and Violanda, R. 2019. Measurement of the gravitational acceleration using a simple pendulum apparatus ultrasonic sensor and Arduino. Physics Education 54: 1–5.

Rutten, N., van Joolingen, W. R. and van der Veen, J. T. 2012. The learning effects of computer simulations in science education. Computers & Education 58: 136–153.

Sanjaya, W. S. M., Anggraeni, D., Denya, R., Pandriantama, H., Iklimah, I. and Dewi, I. P. 2018. A low cost of simple pendulum experiment apparatus based on ultrasonic sensor and Arduino microcontroller. Jurnal Ilmiah Pengabdian Kepada Masyarakat 1: 51–54.

Sari, U. and Kirindi, T. 2019. Using Arduino in physics teaching: Arduino-based physics experiment to studytemperature dependence of electrical resistance. Journal of Computer and Education Research 7: 698–710.

Sari, U., Pektaş, H. M., Çelik, H. and Kirindi, T. 2019. The effects of virtual and computer based real laboratory applications on the attitude motivation and graphic skills of university students. International Journal of Innovation in Science and Mathematics Education 27: 1–17.

Schauer, F., Cernansky, P., Ožvoldová, M. and Lustig, F. 2009. Integrated e-learning-new strategy of the cognition of real world in teaching physics In Innovations 2009 (USA), World Innovations in Engineering Education and Research iNEER Special Volume 2009, 119–135.

SensorsONE. 2021. Local gravity calculator, available at: https://sensorsone.com/local-gravity-calculator/#height.

Simpson, D. G. 2010. The non linear pendulum, available at: http://pgccphy.net/ref/nonlin-pendulum.pdf.

Sinacore, J. and Takai, H. 2010. Measuring g using a magnetic pendulum and telephone pickup. The Physics Teacher 48: 448–449.

Tong-on, A., Saphet, P. and Thepnurat, M. 2017. Simple harmonics motion experiment based on LabVIEW interface for Arduino. Journal of Physics: Conference Series 901: 1–6.

Trumper, R. and Gelbman, M. 2000. Investigating electromagnetic induction through a minicomputer-based laboratory. Physics Education, 35: 90–95.

Tunyagi, A., Kandrai, K., Fülop, Z., Kapusi, Z. and Simon, A. 2018. Friction coefficient determination by electrical resistance measurements. Physics Education 53: 1–9.

Wieman, C. and Perkins, K. 2005. Transforming physics education. Physics Today 58: 26–41.

Yulkifli, Y., Afandi, Z. and Yohandri, Y. 2018. Development of gravity acceleration measurement using simple harmonic motion pendulum method based on digital technology and photogate sensor. Materials Science and Engineering 335: 1–8.

Zacharia, Z. and Anderson, O. R. 2003. The effects of an interactive computer-based simulation prior to performing a laboratory inquiry-based experiment on students' conceptual understanding of physics. American Journal of Physics 71: 618–629.