Real-Time Graphing of Simple Harmonic Motion of Mass on Springs with an Arduino Based on an Experiment Set for Teaching and Learning Physics

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ABSTRCT
The real-time graphing of simple harmonic motion of mass on springs with an Arduino based on an experiment set for teaching and learning physics in high schools where students can learn from real experiences. The objectives of this study are to create and develop a real-time measurement for vertical oscillations of mass on springs using the Arduino microcontroller and the infrared sensors. This experiment set is improved from the original experiment which was used to measure the period of an oscillation of mass at various points by using signals of the output voltage of the infrared sensors and the Arduino program to record the time on the computer. The results of the experiment were relevant to the theoretical calculation. Students learned to understand the simple harmonic motion experiment of mass on springs and were able to measure the displacement functions depending on time enabling students to get concepts in physics in real-time more accurately and quickly. Physics teachers can build these experiments on their own for a low cost, and these experiments will be very useful for teaching and learning.
Keywords: Real-time graph, Mass on springs, An Arduino-based experiment set, Teaching and learning Physics

INTRODUCTION

The evolution of intelligent electronic devices has made information technology, computer science, and electronics even more relevant to teaching and learning science and increasing the students' learning efficiency (Gingl et al., 2019) especially in 21st century, a century of globalization. Therefore, the aim of learning is to increase the students' skills in analytical thinking, problem solving, communication, creativity, innovation, information literacy, media literacy, and ICT literacy. The graduate students who have these skills are able to live in the society perfectly (Lase, 2019). Currently, teaching media technology is used by teachers to increase the motivation and encourage students to better understand the contents they have learned and also enhance the students' educational results (Pearce, 2007; Sornkhatha & Srisawasdi, 2013).

In teaching physics, technology is used even more to develop experiment sets by connecting computer and electronic devices to increase an efficiency of the experiment sets. Physics laboratory experiments using a computer interface experiments set that provide real-time results are interesting and effective experiments in student supervision. It allows students to visualize and understand the relationship between the theory and observational outcomes in a simple and natural way, enabling efficient interpretation, discussion and analysis of data (Sokoloff, Laws & Thornton, 2007; Amrani & Paradis, 2010). At present, real-time experiments are developed for teaching physics because they are easy and cheap to do. Moreover, they can be used with Arduino board and the computer easily. This helps students to see the results in real-time because it is easy to collect the data and they can take notes of the experiments continuously. Students will get more accurate physics concepts and pay more attention when compared with traditional teaching methods. The real-time experiments create an enjoyable and helpful teaching environment and also meet the needs of students' learning atmosphere by using technology. They help students to see and take a note of the experiments easily and quickly (Erol, Kaya & Hocaoğlu, 2020; Hidayat & Yulianti, 2021; Pili, 2020; El Hadi et al., 2020). The use of real-time computer interface experiments set resulted in a significant increase in students' post-graduate assessment results (Kozhevnikov & Thornton, 2006).

The development of the experiment sets in physics is performed Arduino board, a microcontroller which is popular at present. An Arduino board is a non-complicated microcontroller structure with a simple coding. It is cheap, reachable, and easy to use in teaching physics. Students are able to better understand physics phenomena and get the knowledge of various theories and experimental skills. In addition, they are able to take notes of the experiments easily and quickly (Bezerra et al., 2019; Pereira, 2016; Sari & Kirindi, 2019; Tunyagi et al., 2018;

Buachoom, Thedsakhulwong & Wuttiprom, 2019). Currently, the use of computer interface experiments set on the simple harmonic motion of a mass on spring is constantly being developed by comparing the results with Hook's Law. Arduino boards are generally used to connect to different sensors, for example, using an Ultrasonic sensor (Galeriu, Edwards & Esper, 2014; Buachoom, Thedsakhulwong & Wuttiprom, 2019; Hidayat & Yulianti, 2021). Using Telephone pickups (Pili & Violanda, 2019) and Infrared sensors (Musik, 2017).

The objective of this research is to construct the computer-based experiment set on the real-time measurement set for vertical oscillations of mass on springs. The experimental set has been developed from the original set which has 8 rows (8 sensors per row) (Musik, 2017) to 16 rows, to increase the efficiency of spring constant testing. A spring with a little constant can stretch greatly beyond the capabilities of the original set of experiments. The experiment set, mass on spring, is able to measure experimental results in real-time. This experiment set shows a graph of position, velocity, and acceleration for simple harmonic motion as a function of time in real-time and helps students to understand the physics concepts better. Learning the coding of Arduino is also fun with the experimental results. The real-time experiments set can quickly display data, allowing students to change experimental parameters in a short time. It enhances interaction between groups of students and teachers. This experiment helps teachers and students to take a note of the results easily and quickly. Students will have fun studying these experiment sets consisting of a sensor cycle and an Arduino board in which they can analyze the results of the experiment conveniently and quickly.

METHOD

The creation and development of devices for conducting research and data collection are as follows:

Computer interfaces of mass on springs

Mass on spring motion for the simple harmonic motion test set was prepared by connecting a microcontroller with a computer shown in Figure 1-2. The computer interface experiment set consists of hardware and software. An Arduino (model ET-EASY MEGA 1280) was used as the hardware which was connected to the computer notebook via a USB port for sending mass on spring data. The infrared sensors were used as signal detectors. Microsoft windows 10 operating the system was used as the software. Arduino1.8.15 controlled the experimental performance while Processing 2.2.1 displayed output for displacement vs. time in real-time graphs. Afterwards, the data were used to make the relationships between period squared and mass, graphs of displacement, velocity, and acceleration as a function of time by using the Mathematica program.

Figure 1. Computer-based experiment set.

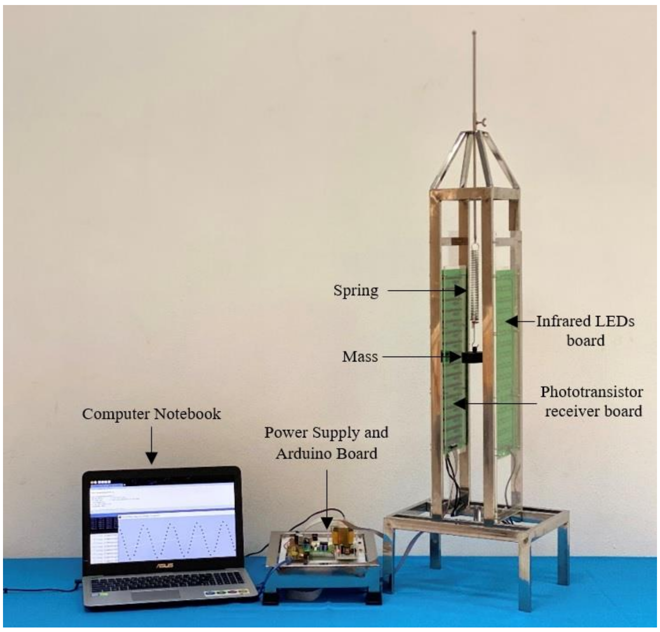


Figure 2. A real-time experiment set for vertical oscillations of mass on spring.

Infrared sensors are designed with sensor plates of 42 cm in height and 13 cm in width. There are also 16 rows of 8 phototransistors fixed along the height opposite to 16 rows of 8 infrared LEDs and each row is 2.5 cm apart, with infrared plates and phototransistors being tightly held together in size and in distance and is 13 cm apart from each other with a set of experiments made of stainless steel as in Figure 3 . For the experiment set, the signals of the output voltage of the infrared sensor circuit is used to measure the time of an oscillating mass at various points and the Arduino program record the time on computer.

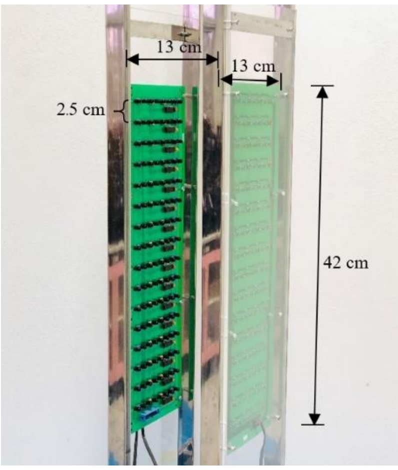


Figure 3. Plates of infrared sensors (16 positions).

Simple harmonic motion of mass on spring theories

In Figure 4, the free spring is hung vertically. The system consists of a mass (m) attached to one end of the spring where the spring constant (k), the other end of the spring is firmly fixed. The spring is stretched by a retraction force proportional to its position (x). According to Hooke's Law, the rebound force can be calculated from the Equation (1).

$$F = -kx \quad (1)$$

When the mass starts and oscillation around equilibrium is x= 0, the period (T) of the motion depends on the spring constant (k) and the mass (m) in the following fashion:

$$T = 2\pi\sqrt{\frac{m}{k}} \quad (2)$$

The inverse of the period is called the frequency f of motion: $f = \frac{1}{T}$

where the displacement is given by:

$$x(t) = A\cos(\omega t + \phi) \quad (3)$$

taking two time derivatives,

$$v(t) = \frac{dx}{dt} = -\omega A\sin(\omega t + \phi) \quad (4)$$

$$a(t) = \frac{dv}{dt} = -\omega^2 A\cos(\omega t + \phi) \quad (5)$$

where $x(t)$, $v(t)$ and $a(t)$ are displacement, velocity and acceleration at time t, ω is the angular frequency, $\omega = \frac{2\pi}{T}$. The maximum displacement is called the amplitude, A. The constant ϕ is called the initial phase constant or phase angle. In this case, $x(t) = A\cos(\omega t)$ at $t = 0$.

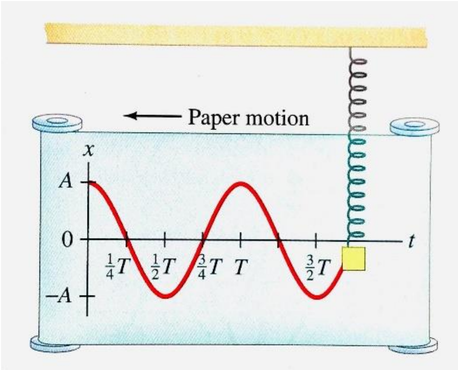
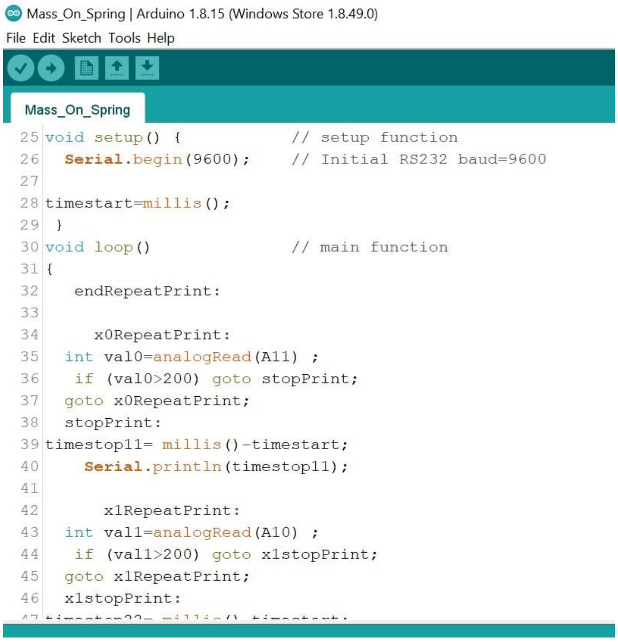


Figure 4. Sinusoidal nature of SMH as a function of time (Giancoli, 2000).

Programing experiment

This experiment uses an Arduino program to control the experimental performance while Processing program is used to display the output of displacement vs. time in real-time graphs. These two programs are open source tools. It is easy to write the code and upload it to the board. Figure 5 shows the example of Arduino code of the experiment.




```
void setup() {            // setup function
  Serial.begin(9600);     // Initial RS232 baud=9600

timestart=millis();
 }
void loop()               // main function
{
   endRepeatPrint:

     x0RepeatPrint:
  int val0=analogRead(A11) ;
   if (val0>200) goto stopPrint;
  goto x0RepeatPrint;
  stopPrint:
timestop11= millis()-timestart;
    Serial.println(timestop11);

      x1RepeatPrint:
  int val1=analogRead(A10) ;
   if (val1>200) goto x1stopPrint;
  goto x1RepeatPrint;
  x1stopPrint:
```

Figure 5. The example of the Arduino code of the experiment.

EXPERIMENTAL PROCEDURE

The spring constants of three the springs are k_1, k_2 and k_3. Determination of the spring constant by Hooke's Law is as follows: $k_1 = 13.721$ N/m, $k_2 = 15.063$ N/m and $k_3 = 24.830$ N/m. The spring constants can be determined by measuring the period of oscillation for different hanging masses from a computer-based experiment sets as $k_1 = 13.563$ N/m, $k_2 = 14.859$ N/m and $k_3 = 23.975$ N/m. The calculation of the percentage difference between the k's are obtained from the Equation (6).

$$\%Difference = \frac{|Difference\ of\ the\ two\ values|}{Average\ of\ two\ values} \times 100 \quad (6)$$

The experiment to study the graphs of displacement vs. time of vertical oscillations of mass on spring in the real-time graphs are shown below.

1. Hang one end of a k_1 spring to the hook of the set and hang a cylindrical metal of mass = 0.187 kg at the other end of the spring.

2. Switch the power on and run the experiment Arduino program and Processing program to display the results respectively.

3. Set the object to the start point. It was set to oscillate gently around the equilibrium, and the amplitude (A=0.11 m).

4. Observe the points which display how the object moves, record the time for 10 periods' movement of the object, and then switch off the program.

5. Change the object to 0.202 kg, 0.211 kg, 0.224 kg, 0.261 kg, 0.282 kg, 0.294 kg, 0.331 kg, 0.348 kg, 0.385 kg and 0.421 kg, and then repeat 2-4.

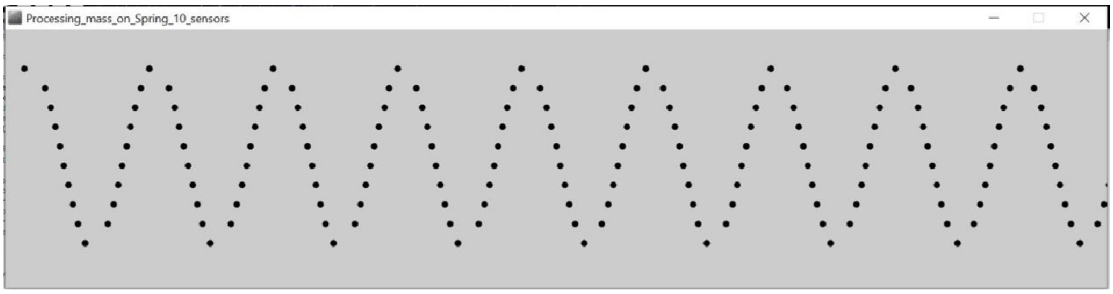
6. Change the spring to k_2 and k_3, hang a cylindrical metal of each mass at a time to the hook, and then repeat 2-4.

The supplemental physics lessons were designed due to a Constructivism Approach for upper secondary school students in order that the students chosen as the samples would have their handbooks for the experiment. The supplemental physics lessons contain the content of simple harmonic motion of a hanging mass on spring. There are 2 types of experiment in students' books. One is a real experiment with the computer-based experimental set and the other is the experiment of theoretical calculation. The experiment part, topic, objectives, experiment's tools, procedure, recording tables, analyzing part, concluding part, post experiment questions, and revision exercises are provided for the students. The computer-based experiment set together with the lesson is tested in physics classes according to a Constructivism Approach. To find out whether the effectiveness of the experiment set together with the lesson reaches the fixed criterion at 70/70, the sample group was composed of 90 upper secondary students studying science and mathematics in M.5 or grade 10 of the year 2020 in Phromkiripittayakom School, MuangNakhonSiThammarat School, and Chawangratchadapisek School in Nakhon Si Thammarat, Thailand. The pre-test, the post-test, the post experiment exercise, the achievement test, and the satisfaction test were assigned to use during 6 periods of the instruction.

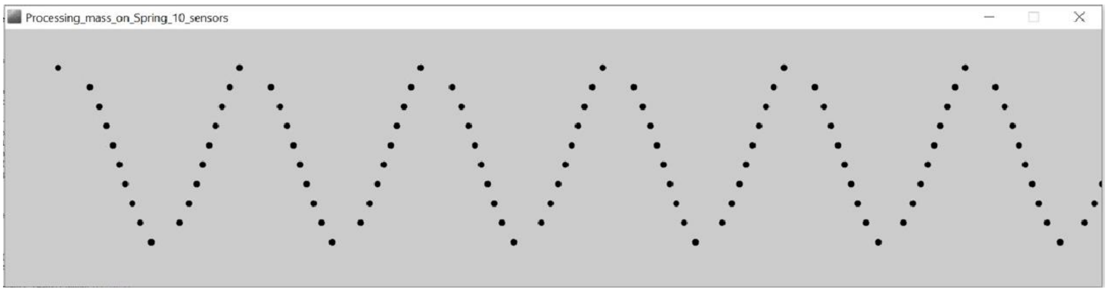
RESULTS

The spring constants can be determined by measuring the period of oscillation for different hanging masses from computer-based experiment sets as $k_1 = 13.563\ \text{N/m}$, $k_2 = 14.859\ \text{N/m}$ and $k_3 = 23.975\ \text{N/m}$. The calculation of the percentage difference between the k's are obtained from the Hooke's Laws and the oscillating masses as $k_1 = 1.155\%$, $k_2 = 1.363\ \%$ and $k_3 = 3.505\%$ respectively. The average percentage difference is 2.008%.

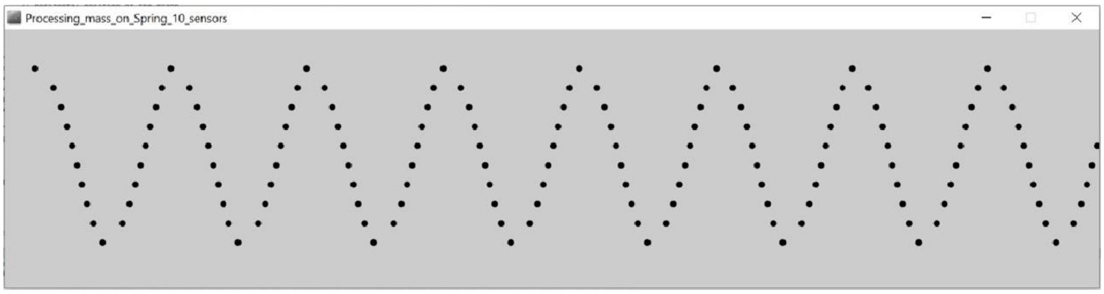
The graphs of displacement vs. time of vertical oscillations of mass on spring in the real-time graphs are shown in Figure 6 . The amplitude of all the oscillations is the same, $A = 0.110\ \text{m}$. The spring constant by the period T of oscillations of a mass-spring system and the masses were regulated as $k_1 = 13.563\ \text{N/m}$, $k_3 = 23.975\ \text{N/m}$, $m_1 = 0.187\ \text{kg}$, and $m_2 = 0.421\ \text{kg}$. From Figure 6 (a) and Figure 6 (b), the more we increase the mass, the higher the period of the oscillations is. Figure 6 (b) and Figure 6 (c) show that increasing the spring constant decreases the period of the oscillations based on their theoretical values.



(a) $k_1 = 13.563\ \text{N/m}$, $m_1 = 0.187\ \text{kg}$



(b) $k_1 = 13.563$ N/m , $m_2 = 0.421$ kg



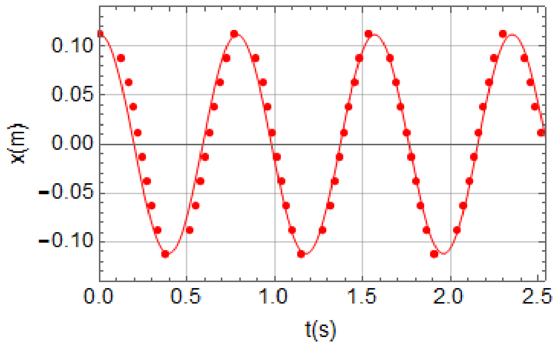
(c) $k_3 = 23.975$ N/m , $m_2 = 0.421$ kg

Figure 6. Graphs of displacement versus the time in the real-time graphs.

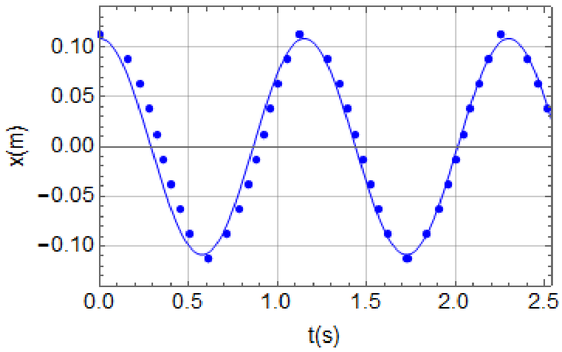
From the experiment results in Figure 6 , the graphs of displacement versus the time was analyzed with Mathematica 11 to find the motion equation as shown in Figure 7 . All the dots represent experimental value whereas the lines are obtained by linear fitting with Mathematica. We have used the Nonlinear Curve Fit option with a user′s defined fitting function. The form of the NonlinearModelFit is NonlinearModelFit [data, a × A Cos[b × omega × t],{a, b}, t] where $A = mg/k$, $\omega = \sqrt{k/m}$, and they are the data set of displacement versus the time from in real-time experiment.

From the motion equation in Figure 7, we plot displacement, x , velocity, dx/dt , and acceleration, d^2x/dt^2 , of a vertical oscillations of mass on springs as a function of time $((x(t),\ v(t),\ \text{and}\ a(t))$ when $\phi = 0$ as shown in Figure 8. The displacement curve is a cosine function, the velocity curve is a sine function, and the acceleration curve is just the negative of the displacement curve. The red line represents the experiment, (k_1, m_1), $v(t) = -0.89773\sin(8.01258t)$, and $a(t) = -7.19315\cos(8.01258t)$. The blue line represents the experiment, (k_1, m_2) , $v(t) = -0.59238\sin(5.46370t)$, and $a(t) = -3.23661\cos(5.46370t)$. The green line represents the experiment (k_3, m_2) , $v(t) = -0.80733\sin(7.27896t)$, and $a(t) = -5.87652\cos(7.27896t)$.

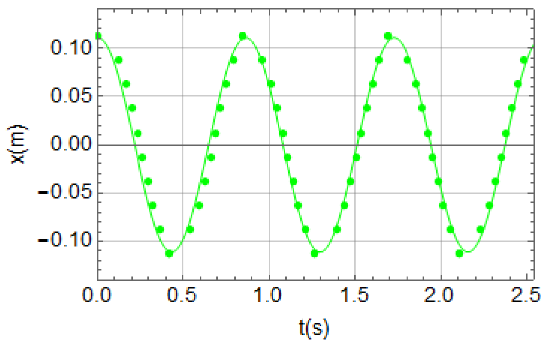
From Figure 7-8, the results of experiment show the amplitude (A) , the period (T) , the angular frequency (ω) , the maximum velocity $(v_{\max})$, the maximum acceleration $(a_{\max})$ and the maximum force $(F_{\max})$ as shown in Table 1. As mass increases, the period increases, which means the angular frequency decreases when mass increases (according to $\omega = \sqrt{k/m}$, and the period increases as ω decreases (according to $T = 2\pi/\omega$). The amplitudes don't vary predictably with mass because they are all based on the height to which the mass is raised initially. The same values were then found by the derivation based on $x_{\max}$ and k as shown in Table 2. The values for $x_{\max} = 0.110$ m



(a) $k_1 = 13.563$ N/m , $m_1 = 0.187$ kg



(b) $k_1 = 13.563$ N/m , $m_2 = 0.421$ kg



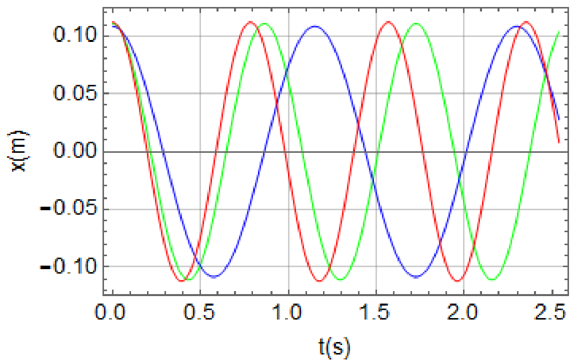
(c) $k_3 = 23.975$ N/m , $m_2 = 0.421$ kg

Figure 7. Graphs of displacement versus the time were analyzed with Mathematica, the equation of motion as a function of time. The equations for displacement are shown below.

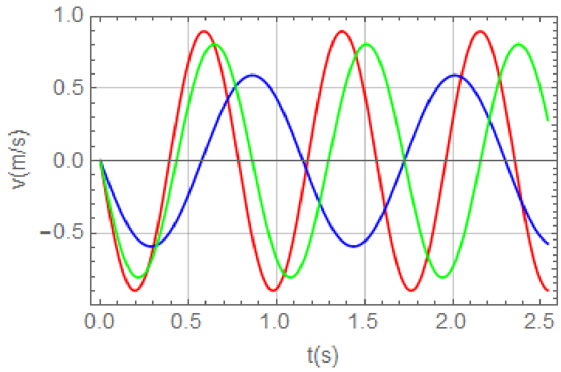
(a) $x(t) = 0.11204\cos(8.01258t)$

(b) $x(t) = 0.10842\cos(5.46370t)$

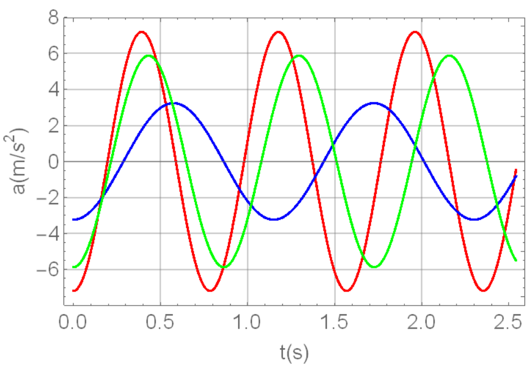
(c) $x(t) = 0.11091\cos(7.27896t)$



(a) Displacement versus time



(b) Velocity versus time



(c) Acceleration versus time

Figure 8. Graphs of displacement, velocity, and acceleration as a function of time.

Table 1. Measured values by vertical oscillations of mass on springs.

Initial condition experiment	$x_{max} = A$ (m)	T (s)	ω (rad/s)	v_{max} (m/s)	a_{max} (m/s^2)	$F_{max} = ma_{max}$ (N)
k_1, m_1	0.11204	0.78417	8.01258	0.89773	7.19315	1.34512
k_1, m_2	0.10842	1.14999	5.46370	0.59238	3.23661	1.36261
k_3, m_2	0.11091	0.86320	7.27896	0.80733	5.87652	2.47401

Table 2. Derived values. The values for $x_{max} = 0.110$ m.

Initial condition experiment	$\omega = \sqrt{k/m}$ (rad/s)	$T = 2\pi/\omega$ (s)	$v_{max} = x_{max}\omega$ (m/s)	$a_{max} = x_{max}\omega^2$ (m/s^2)	$F_{max} = kx_{max}$ (N)
k_1, m_1	8.51642	0.73777	0.93681	7.97824	1.49193
k_1, m_2	5.67593	1.10699	0.62435	3.54378	1.49193
k_3, m_2	7.54637	0.83261	0.83010	6.26425	2.63725

The differences between the values in Table 1 and Table 2 are compared in Table 3. The percentage differences are typically less than 10 %. The experimental data were measured and were relevant to the theoretical calculation.

Table 3. Comparison between measured and derived values.

Initial condition experiment	$\Delta\omega$ $(\%diff.)$	ΔT $(\%diff.)$	Δv_{max} $(\%diff.)$	Δa_{max} $(\%diff.)$	ΔF_{max} $(\%diff.)$
k_1, m_1	6.10	6.10	4.26	10.35	10.35
k_1, m_2	3.81	3.82	5.26	9.06	9.06
k_3, m_2	3.61	3.61	2.78	6.39	6.39

This experiment set together with the lesson was tested in physics classes using a Constructivist Approach to find out whether the effectiveness of the experiment set together with the lesson reaches the fixed criterion at 70/70. Three classes of 90 upper secondary students (M.5 or grade 10 of the academic year 2020) in Phromkiripittayakom School, MuangNakhonSiThammarat School, and Chawangratchadapisek School in Nakhon Si Thammarat, Thailand were set to be purposive samples. The pre-test, the post-test, the post experiment exercise, the achievement test and the satisfaction test were assigned to the samples during 6 periods of the instruction as shown in Table 4.

Post experiment test scores were compared with achievement test scores and the results were 77.85/88.44. It was concluded that the effectiveness of the experiment set together with the lesson perfectly reached the criterion at 70/70. Pre and post achievement mean scores were compared and the result was 0.01 significant difference leading to the consumption that computer-based experiment set together with the physics lesson of vertical oscillations of mass on springs based on a constructivist approach had higher post achievement scores than pre-achievement scores. As a result, it verifies that the consumption is relevant to the hypothesis.

Table 4. Pre-test and post-test achievement scores

Level Grade 10 3 classes	**Number of samples (N)**	**Pre-test**		**Post-test**		**t-test**
		$\bar{x}$	**S.D.**	$\bar{x}$	**S.D.**	
Phromkiripittayakom School	30	8.267	2.449	18.033	1.377	18.858**
MuangNakhonSiThammarat School	30	8.000	2.407	17.433	1.135	21.904**
Chawangratchadapisek School	30	8.767	3.501	17.600	1.354	13.767**

Total	90	8.344	2.785	17.689	1.289	18.176**

**Significant difference at 0.01

The satisfaction test was designed to find out the level of the students' satisfaction to the computer-based experiment set with the lesson through the following topics and the results are shown in Table 5. The satisfaction mean scores for all 5 topics were at a high level of $\bar{x} = 3.547$ and $S.D. = 0.909$. The holistic satisfaction mean scores were at a high level of $\bar{x} = 3.983$ and $S.D. = 0.635$.

Table 5. Satisfaction mean scores to the computer-based experimental set together with the lesson.

Number	Inquired topic	Satisfaction Score			
		$\bar{x}$	S.D.	Level of quality	Ranking
1	Instructor	3.667	0.828	high	3
2	Lesson content and learning activity	3.504	0.874	high	5
3	Documents and teaching aids	3.807	0.775	high	1
4	Learning atmosphere	3.744	0.785	high	2
5	Learning achievement and what can apply from learning	3.613	0.683	high	4
Satisfaction mean of 5 topics		3.547	0.909	high	
Holistic satisfaction		3.983	0.635	high	

DISCUSSION

The computer-based experiment set on the real-time measurement set for vertical oscillations of mass on springs is developed in this study and used for teaching and learning physics. The sensors were put in 16 exact positions to help learners more easily observe the movement of the spring-loading mass more easily. The period of oscillation can be measured when increasing the mass, m, increases the period of oscillation high accuracy, and increasing the spring constant, k, decreases the period of oscillation, and significantly relevant to the theory (Bauer & Westfall, 2011). Students can see the graphs of displacement as a function of time in real-time. (Buachoom, Thedsakhulwong & Wuttiprom, 2019; Hidayat & Yulianti, 2021). This experiment set can also be applied to physics teaching on the law of conservation of energy.

The experiment makes use of the Arduino board, a motion sensor, and the computer program to collect distance and time data of simple harmonic motion of mass on spring by researchers (Galeriu, Edwards & Esper, 2014; Buachoom, Thedsakhulwong & Wuttiprom, 2019; Hidayat & Yulianti, 2021; Amrani & Paradis, 2010). In this experiment, the period and the spring constant were measured to investigate displacement, velocity, and acceleration versus time. Our results support the findings of other scientists (Galeriu, Edwards & Esper, 2014; Buachoom, Thedsakhulwong & Wuttiprom, 2019; Pili & Violanda, 2019; Hidayat & Yulianti, 2021) who used mass on spring motion experiment set to calculate the constant of spring (k) compared with Hooke's Law. One study in Worcester (USA) (Galeriu, Edwards & Esper, 2014) used the HC-SR04 Ultrasonic sensor and Arduino Uno board to calculate the constant of spring (k-value) and their calculated k-value was 16.750 N/m and the error was 0.119% compared with Hook's Law. A study in Thailand (Buachoom, Thedsakhulwong & Wuttiprom, 2019) used the same method and their k-value was 16.480 N/m with an error of 0.363% . Another study in Indonesia (Hidayat & Yulianti, 2021) used the same method too. Their study k-value was 6.350 N/m and the error was 1.427% . And the study in the Philippines (Pili & Violanda, 2019) used a telephone pickup and a soundcard oscilloscope. It was found that k-value was 26.000 N/m and the error was 2.657 % when compared with Hook's Law.

CONCLUSIONS

This research was the development of the computer-based experiment set using an Arduino board and the infrared sensors, which were designed to study the vertical oscillations of mass on springs. The experiment shows a graph of displacement versus time in real-time. Students did experiments and analysed displacement, velocity, and acceleration as a function of time using Mathematica or other programs. The results of the experiment were found to be relevant to the theory. When tested with a Constructivist Approach, students paid full attention to their experiment and performed their experiment actively. One noticeable advantage was that students could repeat the experiments as many times as they needed in shorter time to observe real-time graphs. This might be a changing point that physics experiment is no longer difficult for them. Students can do the real experiment by themselves. The computer-based experiment set helps learners to comprehend physics concepts and develop their learning skills up to the 21st century skills. It is also very useful for physics teachers to apply the concepts of this experimental set in physics laboratory teaching.

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REFERENCES
Amrani, D., & 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.
Bauer, W., & Westfall, G.D. (2011). *University Physics with Modern Physics*. New York. McGraw-Hill.
Bezerra, A. Z. L. N., Cabreira, F. M., Freitas, W. P. S., Cena, C. R., Alves, D. C. B., Reis, D.D., & Goncalves, A. M. B. (2019). Using an Arduino to demonstrate Faraday's law. *Physics Education*, *54*, 1-6.
Buachoom, A., Thedsakhulwong, A., & Wuttiprom, S. (2019). An Arduino board with ultrasonic sensor investigation of simple harmonic motion. *Journal of Physics: Conference Series*, *1380*, 012098.
El Hadi, M., El Moussaouy, A., Ouariach, A., Essaadaoui, R., Hachmi, A., Laabidi, K., Magrez, H., & Meziani, Y.M. (2020). Real time free fall investigation for educational purposes using Arduino Uno board. *Physics Education*, *55*, 055027.
Erol, M., Kaya, Ş., & Hocaoğlu, K. (2020). Measurement of spring constants of various spring-mass systems by using smartphones: A teaching proposal. *Momentum: Physics Education Journal*, *4*(1), 1-10.
Galeriu, C., Edwards, S., & Esper, G. (2014). An Arduino Investigation of Simple Harmonic Motion. *The Physics Teacher*, 52, 157-159.
Giancoli, C.D. (2000). Physics for Scientists and Engineers Third Edition. Physics Education, *35*(5), 370-371.
Gingl, Z., Mellár, J., Szépe, T., Makan, G., Mingesz, R., Vadai, G., & Kopasz, K. (2019). Universal Arduino-based experimenting system to support teaching of natural sciences *IOP Conf. Series: Journal of Physics: Conf. Series*, 1287, 012052.
Hidayat, N., & Yulianti, E. (2021). Real Time Measurement for Spring-Mass System: The Graphical and Mathematical Representations. *Jurnal Penelitian Pendidikan IPA*, *7*(1), 74-79.
Kozhevnikov, M., & Thornton, R. (2006). Real-Time Data Display, Spatial Visualization Ability, and Learning Force and Motion Concepts. *Journal of Science Education and Technology*, *15*(1), 111-132.
Lase, D. (2019). Education and Industrial Revolution 4.0. *10*, 48-62.
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*(4), 1-11.
Pearce, J. M. (2007). Teaching Physics Using Appropriate Technology Projects. *The Physics Teacher*, *45*, 163-167.
Pereira, N. S. A. (2016). Measuring the RC time constant with Arduino. *Physics Education*, *51*, 1-10.
Pili, U. & Violanda, R. (2019). Measuring a spring constant with a magnetic spring-mass oscillator and a telephone pickup. *Physics Education, 54*, 1–3.
Pili, U. B. (2020). Measuring a Spring Constant Using an Optical Spring-Mass System and a Solar Panel. *Physics Education*, *55*, 1-3.
Sari, U., & Kirindi, T. (2019). Using Arduino in physics teaching: Arduino-based physics experiment to study temperature dependence of electrical resistance. *Journal of Computer and Education Research*, *7*(14), 698-710.
Sokoloff, D. R., Laws, P. W., & Thornton, R. K. (2007). RealTime Physics: Active learning labs transforming the introductory laboratory. *European Journal of Physics - EUR J PHYS*, *28*. S83-S94.
Sornkhatha, P., & Srisawasdi, N. (2013). Supporting Conceptual Development in Newton's Laws of Motion using an Interactive Computer-Simulated Laboratory Environment. *Procedia - Social and Behavioral Sciences*, *93*, 2010-2014.
Tunyagi, A., Kandrai, K., Fülöp, Z., Kapusi, Z., & Simon, A. (2018). Friction coefficient determination by electrical resistance measurements. *Physics Education*, *53*, 1-9.