Development of Computer-Based Experimental Set in Physics for Free Falling Object

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Abstract
The purpose of this study was to create and to develop the computer-based experimental set for physics labs. The developed experimental set provides learners easier way to study motion of free falling object without air resistance and also easier way to measure the acceleration due to gravity, thus learners get their Physics concept precisely and more quickly than ever. The computer-based experimental sets are consisted of Arduino board connected to a computer or a notebook via a USB port, an infrared sensor circuit, an electromagnet relay circuit, a steel ball and voltage power supply. Arduino1.5.2, Processing 1.5.1 and Mathematica 9.0. were assigned to be software of the experimental set. Arduino1.5.2 controls the experimental performance while Processing 1.5.1 displays output for displacement vs. time in real time graphs and Mathematica 9.0 analyzes the results and simulates experiments. The acceleration of gravity from the experiment by the developed computer-based experimental set displays 9.780121 m/s^2 that is ± 0.013076 % error when compared to the theoretical calculation. The computer-based experimental set was tested in Physics classes with Constructivist, for 186 upper secondary purposive samples, the satisfaction of the samples to their learning activity is at a high level and their pre–test and post-test scores are 45.79 and 70.29 % respectively. The Post-test and the achievement scores at 77.43 and 70.29 lead to the conclusion that the effectiveness of the experimental set reaches the criterion at 70/70.

Keywords: Free Fall, Computer-Based Experiments, Arduino, Constructivism

Introduction

Integrating computer technology into physics laboratory is an effective approach to teach physics nowadays. For computers are such useful devices to help students in performing their Physics experiments in shorter time and also computers motivate students to become self-directed learners (Kezerashvili, 2012). Computer-based instruction has been regarded an alternative. A real laboratory experiment or the use of virtual laboratory experiment yield students better Physics concept than traditional teaching approach as only books and lecture (Baser and Durmus, 2010). Students achievement increases when the Computer-Based Instruction (CBI) technique is implemented as a supplement to classroom education. The reason is that the computer-based instruction provides them with the real time feedback and reinforcement. Moreover, computer-based instruction promotes and creates an exciting and interesting atmosphere in Physics classes (SERIN, 2011). The use of computer-based experiment set with laboratory interfaces allows real-time recording and graphing of physical quantities. The qualitative use of real-time graphing in computer-based experiments has driven up interest in using experiments to enhance physics conceptual understanding (Schauer, Ozvoldova and Lustig, 2006). As mentioned above that students' achievement increases after CBI techniques is implemented to class, the study consequently aims to create and develop computer-based experiment set for free falling object.

For the computers-based experimental set, AVR microcontroller was employed as the experimental controller. There are 3 advantageous characters to employ AVR microcontroller for it is an open source which can be free downloaded. In addition, AVR has developed its smaller hardware chip which results to low cost (Naveenkumar, Prasad, 2013 and Zachariadou, Yiasemides, and Trougkakos, 2012). Moreover, its simplicity that the analog signal from the sensor can be sent to microcontroller via Analog pin (ETT Co., Ltd. , 2009), makes AVR the most suitable for our computer-based experimental set.

Not only the suitable aids but also the suitable learning approach that were administered to the students. Constructivist is considered one of the most popular approach that helps to improve Physics teaching (Schwegler, 2001). According to constructivist, Physics concept can't be developed with only explanation. Thus, teachers or constructors need to be more creative for their lessons as well as their aids which are able to highly enhance students' Physics concept (David, 2002 and Johnston, 2010). For the lesson and the experiment provided, students are exposed to the experiment which they work cooperatively, apply their skills, make their decisions, experience the outputs, draw the conclusion, and finally overcome their Physics concept.

Methods

Computer-Based Experimental Set

Design and construction

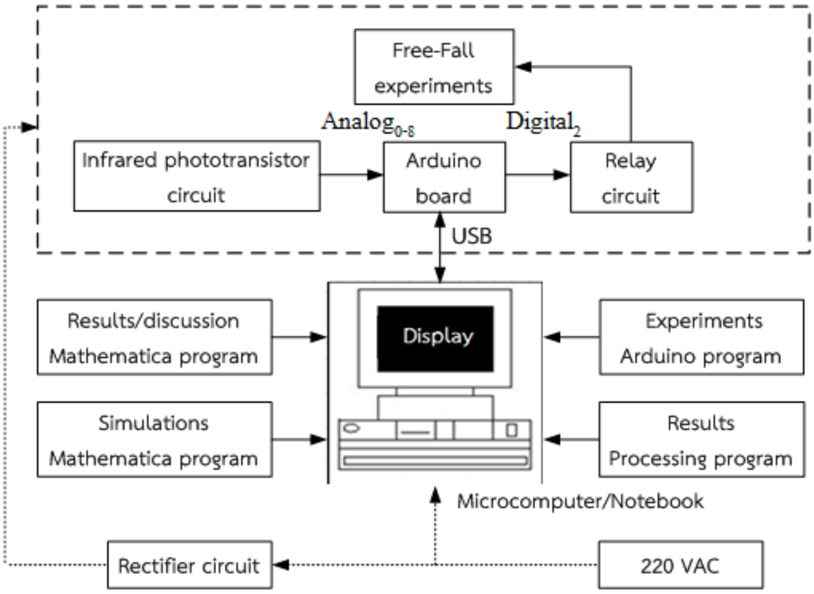
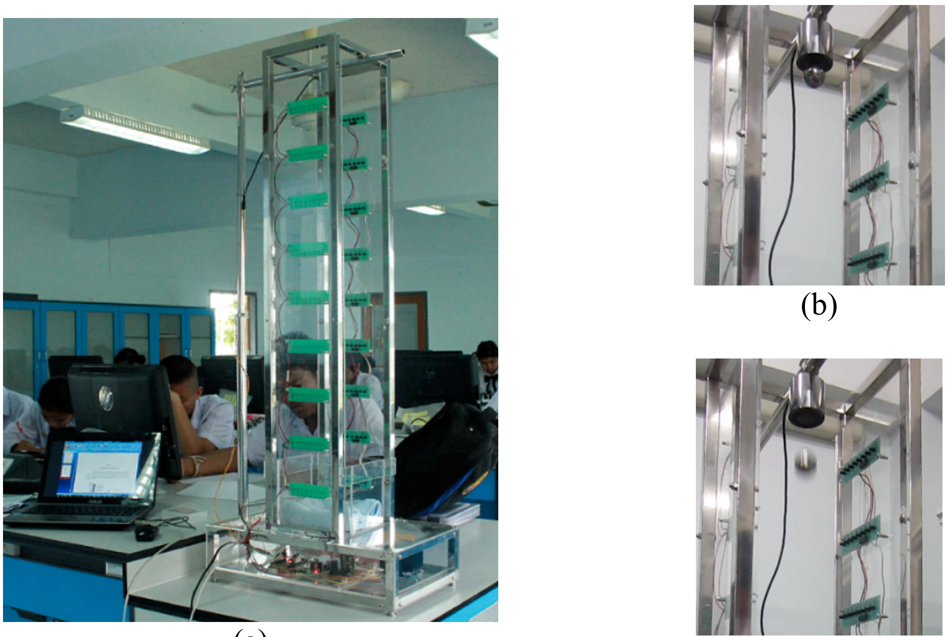


Figure 1 Computer-based experimental set

The computer-based experimental sets consisted of Arduino board, ET-EASY MEGA1280 (Duino Mega) connected to a computer or a notebook via a USB port, an infrared sensor circuit, an electromagnet relay circuit, a steel ball and voltage power supply. Arduino1.5.2, Processing 1.5.1 and Mathematica 9.0. were assigned to be software of the experimental set. Arduino1.5.2 controls experimental performance while Processing 1.5.1 displays output for displacement vs. time in real time graphs. Mathematica 9.0 analyzes the results such as graphs of displacement vs. time, graphs of velocity vs. time and graphs of acceleration vs. time.



(a) (b) (c)

Figure 2 (a) Computer-based experimental set for free falling object.
(b) The relay switch at "on" position. (c) The relay switch at "off" position.

Operating system of the set
A microcontroller is connected to a computer and an electronics circuit in order that the time at any fixed points will be read. Then the real time graph of displacement vs. time of the steel ball will be displayed. There is a relay switch to turn on and off the circuit. The steel ball at the end of the spring is caught when the switch is on and released when the switch is off. When the steel ball is released from 0.90 m height, it moves in free falling motion through the infrared phototransistors and makes the voltage output of the infrared receivers change from 0 to 5 volt. The output from the receivers is sent to microcontroller. Arduino takes charge to check for time the object consumes to reach a certain point, and then the data is stored in the computer.

Infrared phototransistor circuit

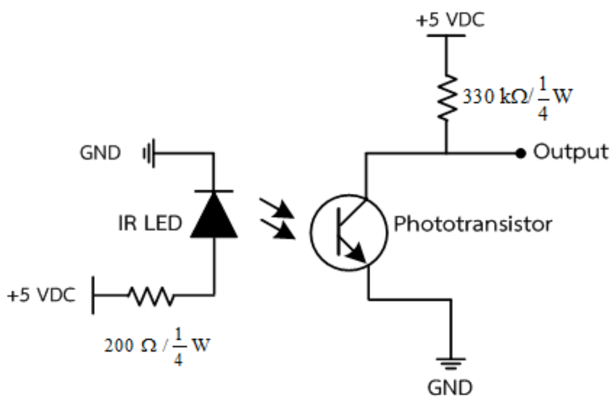


Figure 3 Infrared Phototransistor circuit

Infrared phototransistor is a fundamental circuit which composed of a sender and a receiver. The phototransistor works as a receiver while LED infrared works as a sender. There are 2 resistances of 330 kΩ and 200Ω, ¼ w. The 330 kΩ is for the receiver and the 200 Ω is for the sender. Electric power of the system is 5 volt of direct current. When the infrared reaches the phototransistor, the output voltage is at 0 volt and when the infrared is obstructed by an object, the output voltage changes to 5 volt.

8 IR LED Senders
We design to fix 8 infrared LEDs in a row in order that the falling object will never fall out off the detected area. And there are eight rows of LED fixed along the height of the set to get the data from certain points. Not only the data from the start and stop points, but also 7 fixed points between the start and the stop.

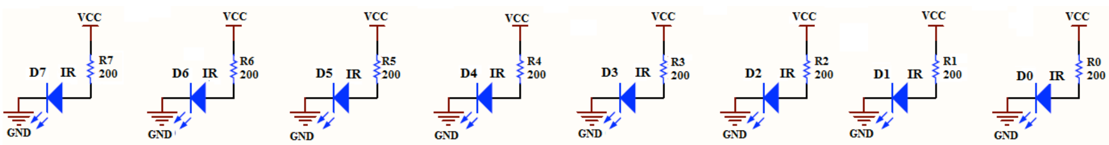


Figure 4 Infrared LEDs circuit

8 IR Receivers

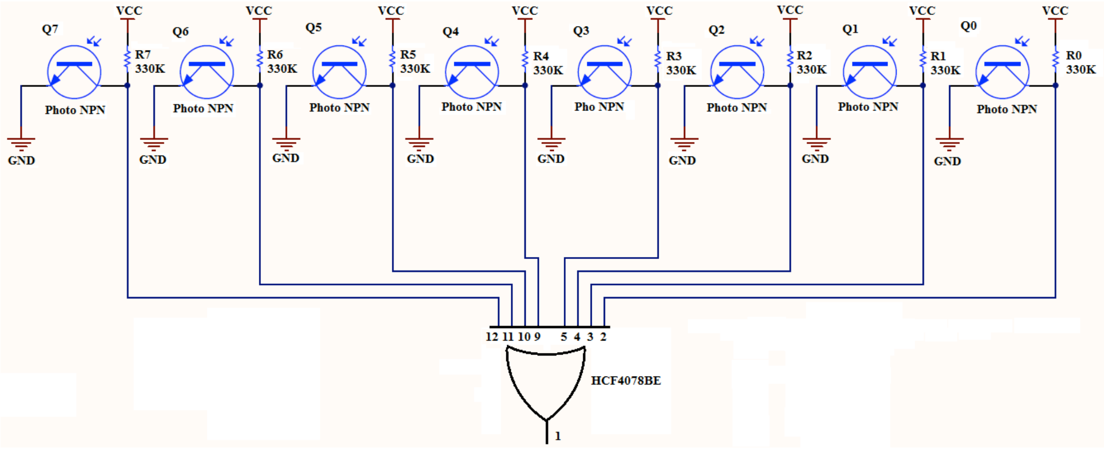


Figure 5 Infrared Phototransistor receiver

We also design to fix 8 phototransistors in a row since senders and receivers work in agreement of each pair. When the infrared is sent from the sender, the receiver in the opposite side will be on charge to work. Consequently, there are also 8 rows of 8 phototransistors fixed along the height opposite to 8 rows of 8 infrared LEDs.

The reason to design 8 rows of sensors because when we study free falling object we don’t study only periods of the movement but also displacement vs. time, velocity vs. time ,and acceleration vs. time, etc. Accordingly, we design to check time of the moving object at 8 fixed points in order that the output would be sufficient for graph plots for what we want to study.

The infrared phototransistor receiver was designed in a sensor plate of 90 cm (high) × 10 cm (wide). Eight rows of 9 IR LEDs were fixed along the height of the plate. Each row is 11 cm to one another. However, each of LED in the same row does the same task; whichever in a row is obstructed means the object is detected. Then the voltage is sent to IC or gate HCF4078BE. With the configuration, the movement of the object would never escape from the sensors.

The supplemental Physics lesson

The supplemental physics lesson was designed due to Constructivist approach for upper secondary school in order that the students chosen as samples would have their handbooks for the experiment.

The supplemental physics lesson contains the content of free falling object. There are 2 types of experiment in students’ book. One is real experiment with the computer-based experimental set and the other is the experiment of theoretical calculation or in other words is graph simulation of the object’s motion for the data that can’t be performed in real experiment. In experiment part, topic, objectives, experiment’s tools, procedure, recording tables, analyzing part, concluding part, post experiment questions and revision exercise are provided for the students.

Theory of free falling for experiment

A free falling object is an object that is falling under the sole influence of gravity. Any object that is being acted upon only by the force of gravity is said to be in a state of free fall. There are two important motion characteristics that are true of free-falling objects:

- Free-falling objects do not encounter air resistance.
- All free-falling objects near the earth's surface, acceleration of object due to gravity is approximately 9.8 m/s^2 (Cutnell and Johnson, 2010).

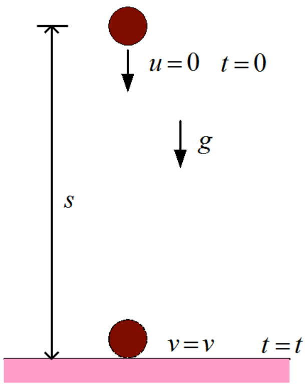


Figure 6 Free-falling motion

We can determine the velocity and location of any free falling object at any time using the following equations.

$$s = \frac{1}{2}gt^2 \tag{1}$$

$$v = gt \tag{2}$$

where g is the acceleration of gravity, v is the velocity, and s is the displacement from an initial location.

Operating free fall experiment: Test for g

1. Connect the USB to the experimental set to a PC or a notebook.
2. Adjust the length from the launch point to the base at 0.90 m (s=0.90m)
3. Switch on the program to control the experiment and display the output.
4. Attach the 0.217 kg steel ball at the launch point.
5. Switch on the experimental set.
6. Observe the graph of displacement vs. time at various points on the monitor.
7. Record time at every point.
8. Change the steel ball to 0.130kg and repeat 3-7.
9. Change the steel ball to 0.085 kg and repeat 3-7.

Results

The trial of experimental set yields the result as shown in the table below.

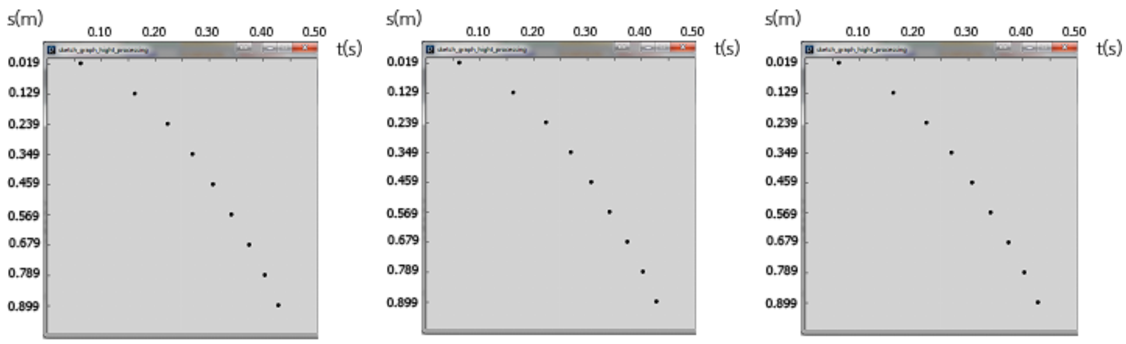
Table 1 : The experiment result of the developed set for free falling object.

s (m)	Experiment					
	$m = 0.217$ kg		$m = 0.130$ kg		$m = 0.085$ kg	
	t (s)	g(m/s^2)	t (s)	g(m/s^2)	t (s)	g(m/s^2)
0.019	0.062667	9.676324	0.062333	9.780090	0.062333	9.780090
0.129	0.162667	9.750403	0.162667	9.750403	0.162000	9.830818
0.239	0.220667	9.816449	0.221333	9.757403	0.222667	9.640897
0.349	0.267667	9.742419	0.267667	9.742419	0.268667	9.670030
0.459	0.305667	9.825315	0.306000	9.803921	0.306000	9.803921
0.569	0.340333	9.825016	0.340667	9.805798	0.340333	9.825016
0.679	0.373	9.760725	0.372000	9.813273	0.372333	9.795710
0.789	0.402	9.764609	0.401000	9.813371	0.401333	9.797077
0.899	0.428	9.815267	0.427667	9.830558	0.427333	9.845931
Average		9.775170		9.788582		9.776610
Average		(9.775170+9.788582+9.776610)/3 = 9.780121 m/s^2				

The acceleration of gravity of free falling object measured by the experimental set yield average $g = 9.780121$ m/s^2 error of 0.013076 %, whereas theoretical g in Nakhon Si Thammarat $= 9.7814$ m/s^2 (Ahern, 2011).

$$error = \frac{|9.7814 - 9.780121|}{|9.7814|} \times 100 = 0.013076 \ \%$$

Graphs of displacement vs. time in real time graphs

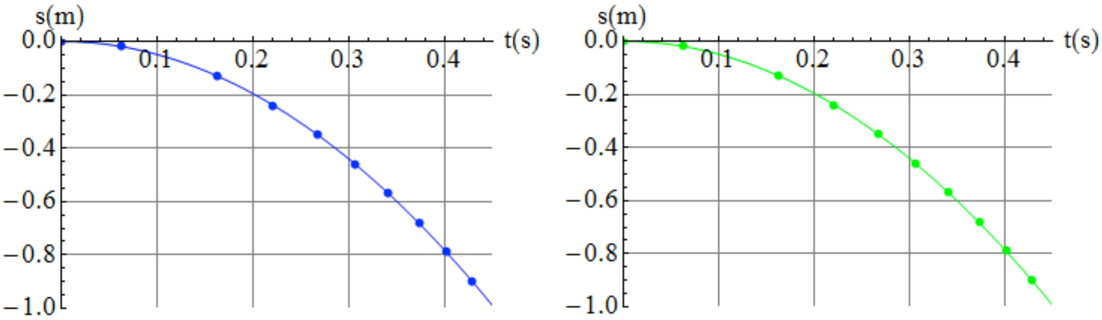


(a) $m = 0.217$ kg (b) $m = 0.130$ kg (c) $m = 0.085$ kg

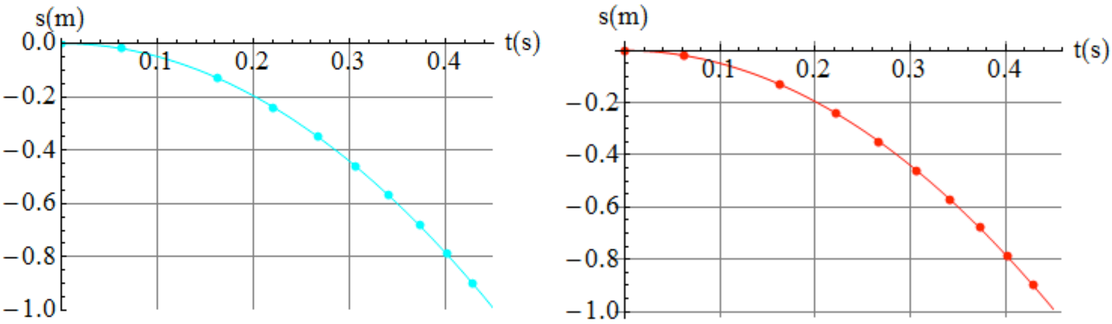
Figure 7 Graphs of displacement vs. time in real time graphs

Graphs of displacement vs. time reveal parabolic curve; increasing time results to non-linear higher value of displacement.

We study the relationship of displacement vs. time (of the experiment), then graph with Mathematica 9 as shown in Figure 8. Dots represent value got from the experiment whereas lines, obtained by curve fitting with Mathematica 9, show appropriate curves for those sets of dots or sets of data.



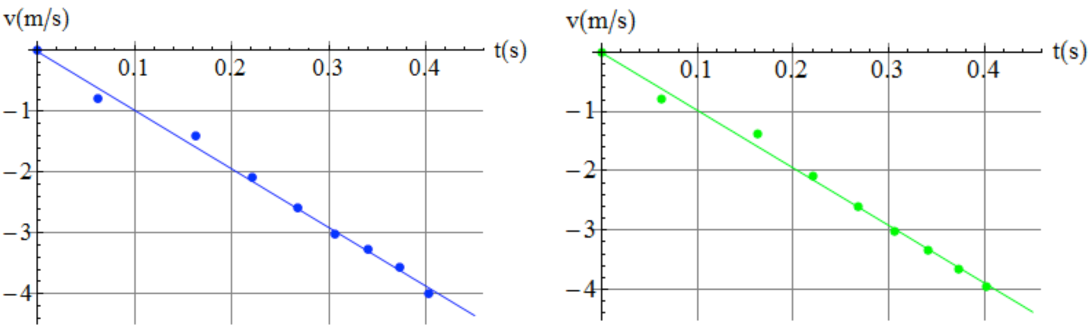
(a) $m = 0.217$ kg (b) $m = 0.130$ kg



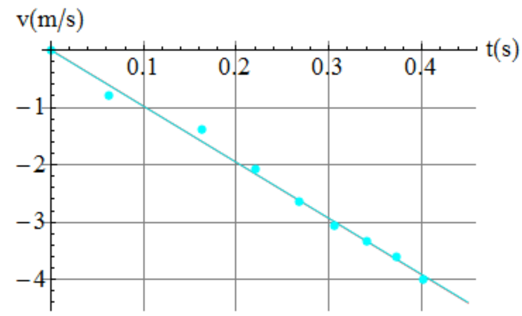
(c) $m = 0.085$ kg (d) Theoretical calculation from, $s = \frac{1}{2}gt^2$

Figure 8 The relationship of displacement vs. time.

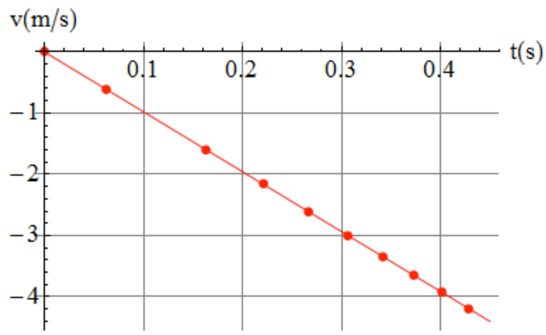
The relationship of displacement and time appears to be parabolic curve. The experimental graph and the calculation graph are in good agreement. (a), (b) and (c) show different mass consumes same time to fall down, that is the relationship of displacement vs. time does not depend on mass.



(a) $m = 0.217$ kg (b) $m = 0.130$ kg



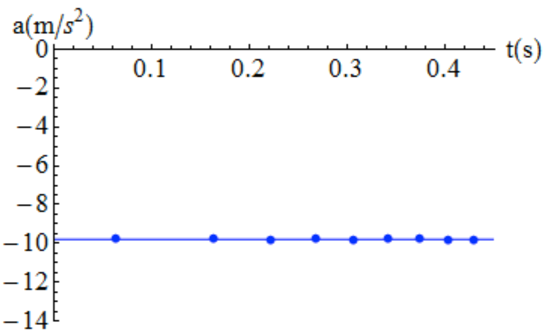
(c) $m = 0.085$ kg



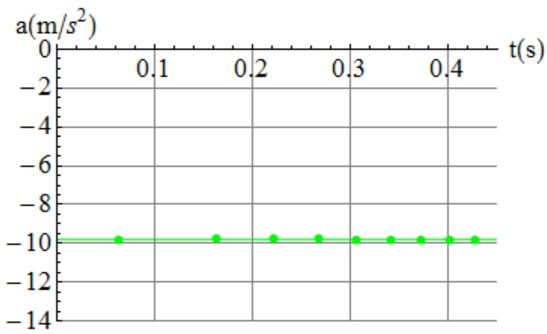
(d) Theoretical calculation from, $v = gt$

Figure 9 The relationship of velocity vs. time.

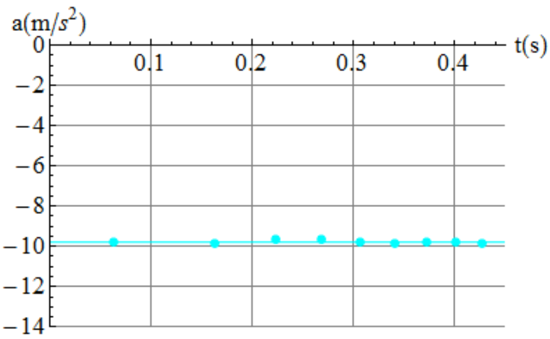
The relationship of velocity and time appears to be linear. Velocity is linearly proportional to time. The experimental graph and the calculation graph are in good agreement.



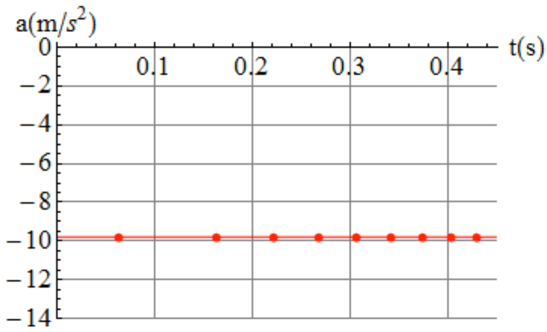
(a) $m = 0.217$ kg



(b) $m = 0.130$ kg



(c) $m = 0.085$ kg



(d) Theoretical $g = 9.7814$ m/s^2

Figure 10 The relationship of acceleration of gravity vs. time.

The relationship of acceleration of gravity and time appears to be linear. Acceleration of gravity is not proportional to time but constant. The experimental graph and the calculation graph are in good agreement.

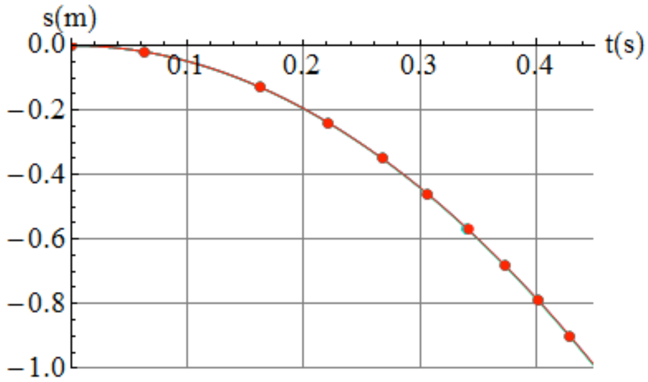


Figure 11 The relationship of displacement vs. time of 3 different mass compared to displacement vs. time of theoretical calculation.

Displacement and time of 3 different mass and of theoretical calculation plotted on the same chart. The 4 curves show no overlapping that means the experiments and the theoretical calculation yield good agreement result.

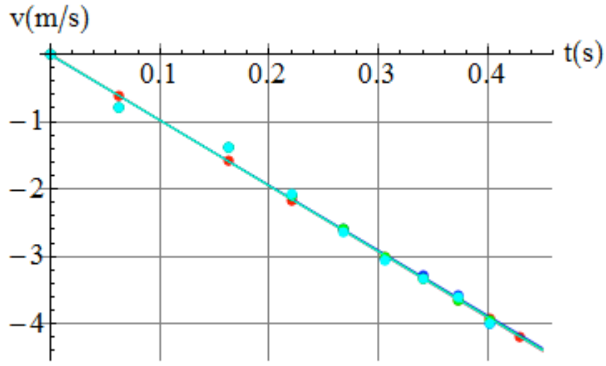


Figure 12 The relationship of velocity vs. time of 3 different mass compared to velocity vs. time of theoretical calculation.

Velocity and time of 3 different mass and of theoretical calculation plotted on the same chart. The 4 curves show no overlapping that means the experiments and the theoretical calculation yield good agreement result.

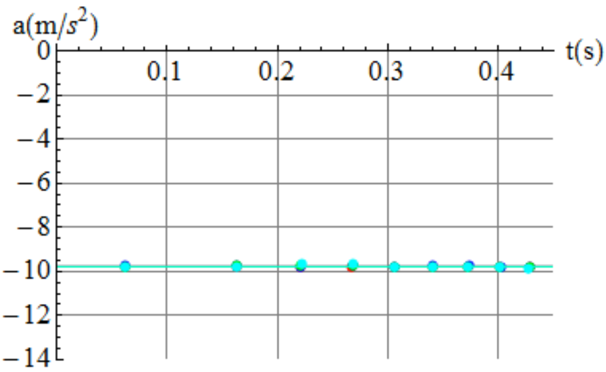


Figure 13 The relationship of acceleration of gravity vs. time of 3 different mass compared to acceleration of gravity vs. time of theoretical calculation.

Acceleration of gravity and time of 3 different mass and of theoretical calculation plotted on the same chart. The 4 curves show no overlapping that means the experiments and the theoretical calculation yield good agreement result.

Effectiveness of the computer-based experimental set with the Physics lesson of free falling object.

The computer-based experimental set together with the lesson is tested in Physics classes according to Constructivist approach. To find out whether the effectiveness of the experimental set together with the lesson reaches the fixed criterion at 70/70, 6 classes of 186 upper secondary students (M.4 or grade 10 of the year 2013) in Princess Chulabhorn's College and Triam-U-dom Suksa school Nakhon Si Thammarat Thailand were set to be purposive samples. Pre-test, post-test, post experiment exercise, achievement test and satisfaction test were assigned to the samples during 6 periods of the instruction.

We compared post experiment test score to achievement test score as 77.43/70.29. From the scores, we concluded that the effectiveness of the experiment set together with the lesson perfectly reached the criterion at 70/70.

Table 2 Pre and post achievement scores

School	Level Grade 10 6 classes	Number of samples (N)	Pre-test		Post-test		t-test
			$\bar{x}$	S.D.	$\bar{x}$	S.D.	
Princess Chulabhorn's College	4/1	24	12.23	3.45	17.90	3.83	6.81**
	4/2	24	12.36	2.97	17.71	3.38	10.38**
	4/5	24	11.20	3.26	18.30	2.60	7.15**
	4/6	24	10.42	2.61	16.50	1.99	7.13**
Triam-U-dom Suksa school	4/1	45	11.18	2.73	16.20	1.84	9.21**
	4/2	45	11.10	3.26	18.80	1.98	9.92**
	Total	186	11.42	3.05	17.57	2.55	20.37**

** Significant at 0.01

Comparing pre to post achievement mean score, we found 0.01 significant difference. This leads to the consumption that samples exposed to Computer-based experimental set together with the Physics lesson of free falling object according to Constructivist approach have higher post achievement score than pre achievement score. The consumption is in good accordance with the hypothesis.

Satisfaction to the Computer-based experimental set together with the lesson.

We invented the satisfaction test to find out level of satisfaction to the computer-based experimental set with the lesson through the following topics and the results are shown below.

Table 3 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	3.71	0.81	high	3
2	Lesson content and learning activity	3.64	0.87	high	4
3	Documents and teaching aids	3.92	0.81	high	1
4	Learning atmosphere	3.86	0.82	high	2
5	Learning achievement and what can apply from learning	3.57	0.90	high	5
Satisfaction mean of 5 topics		3.73	0.84	high	
Holistic satisfaction		3.80	0.87	high	

The table displays satisfaction scores to the computer-based experimental set together with the lesson in every inquiring topic at a high level. The satisfaction mean scores for all 5 topics reveals at a high level of $\bar{x} = 3.73$ and $S.D. = 0.84$. For holistic satisfaction, mean score also reveals at a high level of $\bar{x} = 3.80$ and $S.D. = 0.87$.

We had invented commercial potential evaluation test for the computer-based experimental set of 6 concerning areas before administered to 5 experts. The evaluation result is shown in table 4.

Table 4 Commercial potential evaluation for the computer-based experimental set.

Concerning Areas	Expert's score						Total conclusion
	1	2	3	4	5	Mean	
1. Markets for the product/Duration in markets	4	4	4	5	4	4.2	Good
2. Potential in business competition/Good replacement for imported product	5	5	5	5	5	5.0	Very Good
3. Production possibility worth for investment Utilizing domestic materials	4	3	5	4	5	4.2	Good
4. Innovative and outstanding features/Patent possession for further commercial development	5	4	5	4	4	4.4	Good
5. Possibility for further development	4	4	4	5	4	4.2	Good
6. Legal, ethical, non destructive to Earth	5	5	4	5	5	4.8	Very Good
Average	4.2	4.2	4.5	4.7	4.5	4.5	Very Good

The commercial potential evaluation mean score from 5 experts is 4.5 out of 5 considered in very good level. Comments and suggestions from experts are summarized as the following.

1. The experimental set can be further developed to work with freeware to reduce the cost.
2. The method of construction can be published or written in textbooks.
3. The prototype can be developed for schools or universities.
4. The experimental set has its potential for commercial competition, if improved for easy maintenance and easy to apply.

Conclusions

The computer-based experimental set for free falling object was designed, developed and tested for its output. We found experimental $g = 9.780121 \ \pm 0.013076\ \%\ \mathrm{m/s^2}$. when compared to which of theoretical calculation. When tested in classes with Constructivist approach, students paid full attention to their experiment and performed their experiment actively. One noticeable advantage is students could repeat the experiment as many times as they needed in shorter time to observe real time graphs, and it might be a changing point that Physics experiment is not difficult anymore. The percentage of pre-test and post-test scores are 45.79 and 70.29, and the satisfaction score according to the students' attitude revels at a high level. Lastly we inquired for commercial potential of the set and found its commercial potential at a very good level.

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