

# Development of The Computer Simulation of Oscillation in Physics Learning

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## Abstract

The simplest mechanical system that shows such motion oscillation is a simple pendulum, which consists of a mass suspended from a rope, so that it can swing freely in response to the force of gravity. This teaching material is in the Fundamental Physics subject. Other teaching materials related to oscillation motion are simple linear harmonic oscillations. This research aimed to develop the computer simulation of oscillation in physics learning by using MATLAB. The use of simulations within teaching process had a positive impact on students' being able to predict and explain the phenomena. It also designed to provide possibility to explore physics phenomenon which cannot be realized in school conditions. The simulation can direct the student to reveal the existence of equilibrium between the two sides of an equation rather than causal relations. The research method used was Research and Development (R&D) developed by Borg & Gall (1983) for developing educational products. They are the pre-product form was developed by creating computer programs based on algorithms, validation through forum group discussion carried out by several lecturers to provide validation of the pre-product, major product revision, the pre-trial by 10 students, operational product revision, the operational product trial carried out by a class of students at the computer laboratory, final product revision, and dissemination. The steps were research and information collection, planning, develop a preliminary form of product, preliminary testing, main product revision, main field testing, and operational product revision. In the step of the main field testing, it was applied to the class of students. The 33 students and 6 lecturers were asked to respond about it. A qualitative test review was conducted through expert judgement for validation. They provided an assessment of suitability between the item with the indicator in the form of a Likert scale with five answer options. Based on expert judgment related to the feasibility of the test, V Aiken index is also calculated. The data analysis techniques were descriptive analysis conducted using Microsoft Excel and continued by looking for effective contributions to the relationship of each independent variable to work readiness. According to the statements of questionnaire given from the lecturers, the computer simulation of oscillation felt into a good and very good category. Meanwhile, the students' responses showed that it was fair, good, and very good. The oscillation simulation software developed has good criteria and is suitable for use in learning oscillation systems. The benefit of this research is to determine the form of the wave propagation simulation and its superposition which later can be used for physics research and suitable for students to learn physics.

**Key words:** computer simulation, oscillation, physics learning

## INTRODUCTION

A simple harmonic motion is a motion of a particle moving along a straight line with an acceleration which is always towards a fixed point on the line and whose magnitude is proportional to the distance from the fixed point. It can serve as a mathematical model for a sort of motions such as spring oscillation. Moreover, the motion of a simple pendulum, as well as molecular vibration, can be approximated by simple harmonic motion (Gowri,

Deepika, & Krithika, 2017). In reality, this oscillation system deviation has decreased due to the influence of external forces, such as drag. This kind of motion is called damped harmonic motion. If the external driving force works on an oscillation system, then this oscillation system is called forced oscillation (Halliday, Resnick, & Bowen, 2014).

The implementation of modern computer technologies improves the students' perception of the material, such as animation, dynamic object, and the visualization of the studied physics

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phenomena (Daineko, Dmitriyev, & Ipalakova, 2016; Yetilmezsoy, 2017). Computer simulation helped students to get better comprehension of basic features of linear oscillation motion (Pfefferová, 2015). Computer simulation also effective in overcoming student's misconception on simple harmonic oscillation subject (Maulidina, Samsudin, & Kaniawati, 2019). The misconceptions and less-know about the concept make difficulties to the student in understanding the simple harmonic motion (Cahya, Mahen, & Nuryantini, 2018).

In this research, we developed computer simulation software of oscillation system and conduct a feasibility test to show that the simulation software can be used in learning oscillation system. The developed software began with a simple pendulum simulation by numerically describing simple harmonic motion. With the use of simulation software media, the lecturer does not have to explain the subject matter repeatedly. If during this time some of the potential of the lecturer is poured into the presentation of learning materials in front of the class conventionally, then it can be reduced, so that the lecturer's attention can be more directed to development and deepening. In addition, the objectives of learning physics in the laboratory, one of which is the development of fundamental knowledge and skills in analyzing experimental data, will be achieved.

Susilo, Yunianto, and Variani (2012) proposed the simulation of the simple harmonic motion and damped oscillation of Cassy-E 524000 by using Borland Delphi 7.0 software (Susilo, Yunianto, & Variani, 2012). The experiment was carried out by recording a pendulum that is oscillating. Equation of the speed simulation versus time and acceleration versus time were obtained by the first and second derivation of the displacement versus time equation. The equations of motion obtained oscillation are used to simulate the displacement versus time, velocity versus time and acceleration versus time. Meanwhile, the study conducted by Limiansih and Santosa (2013), they investigated a damp oscillation by using a video analysis software i.e. LoggerPro. The experiment was carried out by recording a pendulum that is oscillating (Limiansih & Santosa, 2013). The results

of the analysis are used to show the relationship between the pendulum's angle to the time. Another study that conducted by Paramitha and Pujayanto (2015) is simulation of simple and damped harmonic oscillation by using Excel spreadsheet. By using the Visual Basic Application (VBA) program on an Excel spreadsheet, then the graph of the amplitude to the time function can be illustrated according to reality data (Paramita & Pujayanto, 2015). The existence of Graphic User Interface (GUI) MATLAB can simplify the analysis of the harmonic oscillator concept. This attractive GUI MATLAB display can make users, especially students, more comfortable and less monotonous (Nurullaeli & Astuti, 2018).

An important component of the instruction in teaching undergraduate about theory and experiments, especially about classical mechanics, should be to develop proficiency in using computers for simulations and presentation. The primary goals of the course is to stimulate the motion of physical system which is the visualizations help to build students' intuition about expected behaviours.

As a demonstration of the ease with which this objective can be accomplished using the MATLAB software package, fully executable scripts presented here for three commonly studied systems: point projectiles, simple pendula, and water flowing out of a hole in a tank. A functioning script can be edited easily that sufficiently short and well documented. So the instructors can readily ask their students to modify and adapt them according to their local instructional environments and purposes (Yetilmezsoy & Mungan, 2018).

It offers a large number of professional tools to implement solutions. The software can produce simulations of real oscillations. Based on these simulations, it can predict the properties of the oscillating system. Some surprising effect can also be studied (Schott, 2010). The simulation results are shown in graphical form so that the visual form of each oscillation motion is immediately known. The simulation can direct the student to reveal the existence of equilibrium between the two sides of an equation rather than causal relations. Another research showed that simulation learning media using MATLAB in building physics course can

improved student learning outcomes (Wati & Widiansyah, 2020).

The ability of each student, especially in Physics Education Department of Universitas Sarjanawiyata Tamansiswa (UST) in using MATLAB is not the same. There are some students who are not proficient in writing program syntax, so that the programming language that is expected to make it easier to solve differential equations on mathematical pendulum becomes even more complicated. Therefore, we need GUI MATLAB that can be directly used by students for the calculation or analysis of these mathematical equations. The GUI MATLAB is used as a computational tool for making decisions.

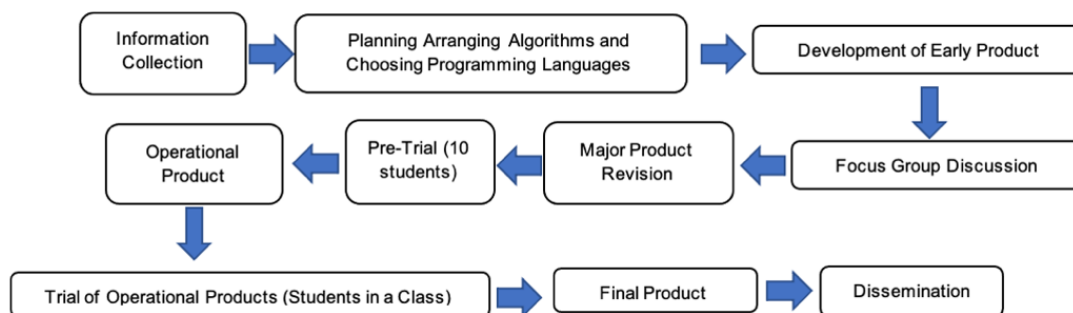
The present research aimed to develop the computer simulation of oscillation in physics learning. We began with simple pendulum simulation as example of simple harmonic motion, then generalize the swing model by including the effect of friction, the influence of external forces, oscillation nonlinearity, and chaos which were not did in those previous study. The simple pendulum simulation in this study was developed by Euler and Euler-Cromer method with the help of GUI MATLAB. The Euler method is a simple method suitable for numerical solutions to systems of the linear equation (Saroja & Nuriyah, 2019).

## METHOD

The research took place in Physics Education Department of Universitas Sarjanawiyata Tamansiswa. In the step of the main field testing, it was applied to the class of students. The 33 students and 6 lecturers were asked to respond about it.

This type of research includes research and development (R&D) according to Borg & Gall in the field of the Educational Technology (Cortés, Rojo, Becerra, & Almendra, 2015), modified with Figure 1, in the field of the Educational. The first step has been taken by gathering information related to making simulations, including literature studies. R&D plot that applied in this research is shown in the Figure 1.

Figure 1 carried out the research stages. They are the pre-product form was developed by creating computer programs based on algorithms, validation through forum group discussion carried out by several lecturers to provide validation of the pre-product, major product revision, the pre-trial by 10 students, operational product revision, the operational product trial carried out by a class of students at the computer laboratory, final product revision, and dissemination.



**Figure 1.** Research and development (R&D) plot

In this study, the data were in the form of scores from respondents. It used 1 to 5 points Likert scale. A questionnaire is a method used to gather information from respondents about product quality and work readiness. The grid of the questionnaire sheet for users consists of 10 items that represent

3 aspects, namely display design, interaction design, and ease of use. Meanwhile, the data analysis techniques were descriptive analysis conducted using Microsoft Excel and continued by looking for effective contributions to the

relationship of each independent variable to work readiness.

A qualitative test review was conducted through expert judgement for validation. They provided an assessment of suitability between the item with the indicator in the form of a Likert scale with five answer options. Based on expert judgment related to the feasibility of the test, V Aiken index is also calculated. The formula of V Aiken is given by Equation (1) (Hidayati, Budiyo, & Sugiman, 2019).

$$V = \frac{s}{[n(c-1)]} \quad (1)$$

with  $s = \sum n_i(r_i - l_o)$

Where:  $V$  is Aiken validity index,  $n_i$  is the number of experts who choose the criteria of  $i$ ,  $r_i$  is the criteria of  $i$ ,  $l_o$  is the lowest rating,  $n$  is the number of expert, and  $c$  is the number of rating.

### Oscillation of Simple Pendulum

Figure 2 shows a simple pendulum motion which has a rope of length  $l$  with an angular of deviation  $\theta$  can be expressed in differential given by Equation (2) (Akpojotor & Ehwerhemuepha, 2013)

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l} \sin \theta \quad (2)$$

where  $g$  is the gravitational acceleration. For small angle  $\theta$ ,  $\sin \theta \approx \theta$ , so the Equation (2) become Equation (3).

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l} \theta \quad (3)$$

The differential of Equation (3) can be written in two first-order differential equations as Equation (4) and Equation (5).

$$\frac{d\omega}{dt} = -\frac{g}{l} \theta \quad (4)$$

$$\frac{d\theta}{dt} = \omega \quad (5)$$

where  $\omega$  is the angular acceleration of pendulum.

In the differential equation for damped oscillator motion, the term  $-q \left(\frac{d\theta}{dt}\right)$  must be added to the right side of Equation (3), so its equation transformed into Equation (6).

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l} \theta - q \frac{d\theta}{dt} \quad (6)$$

where  $q$  is a parameter that measures the strength of the damping and the negative sign indicates that this force is always in the opposite direction to the pendulum's motion (Akpojotor et al., 2013).

We add a sine-shaped driving force with FD amplitude and angular frequency  $\Omega_D$ . The form of the differential equation can be written as Equation (7).

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l} \theta - q \frac{d\theta}{dt} + F_D \sin(\Omega_D t) \quad (7)$$

with the last term indicating external driving force.

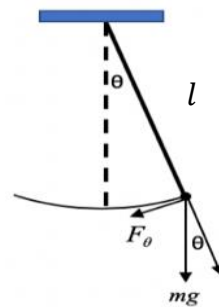


Figure 2. Simple pendulum motion.

Chaotic behaviour can occur if the angle  $\theta$  is not considered small, so the differential of Equation (7) can be written as Equation (8).

$$\frac{d^2\theta}{dt^2} = -\frac{g}{l} \sin(\theta) - q \frac{d\theta}{dt} + F_D \sin(\Omega_D t) \quad (8)$$

The Equation (8) can be written as two first-order differential equations as Equation (9).

$$\frac{d\omega}{dt} = -\frac{g}{l} \sin(\theta) - q \frac{d\theta}{dt} + F_D \sin(\Omega_D t) \quad (9)$$

These last two equations are differential equations for physical pendulum.

### Computational Procedure

MATLAB, the application carried out the second step. The differential equations are solved numerically as follows:

1. Equation (4) and (5) are solved by the Euler method. We convert this equation into a differential equation, using the time step  $\Delta t$  so that time is discrete with  $t = i\Delta t$ , where  $i$  is an integer. Let  $\theta$  and  $\omega$  respectively are shifting pendulum angle and angular velocity at time step  $i$ , Equation (4) and (5) into the differential

equation as follows. For each time step  $i$ , calculate  $\omega$  and  $\theta$  for time step  $i + 1$ :

- a.  $\omega_{i+1} = \omega_i - \left(\frac{g}{l}\right) \theta_i \Delta t$
  - b.  $\theta_{i+1} = \theta_i + \omega_i \Delta t$
  - c.  $t_{i+1} = t_i + \Delta t$
  - d. Repeat for the desired number of time steps.
2. Equation (6) is solved by the Euler-Cromer method, with the following steps.
    - a.  $\omega_{i+1} = \omega_i - \left[\left(\frac{g}{l}\right) \theta_i + q \omega_i\right] \Delta t$
    - b.  $\theta_{i+1} = \theta_i + \omega_{i+1} \Delta t$
    - c.  $t_{i+1} = t_i + \Delta t$
    - d. Repeat for the desired number of time steps
  3. Equation (7) is solved by the Euler-Cromer method, with the following steps.
    - a.  $\omega_{i+1} = \omega_i - \left[\left(\frac{g}{l}\right) \theta_i + q \omega_i - F_D \sin(\Omega_D t_i)\right] \Delta t$
    - b.  $\theta_{i+1} = \theta_i + \omega_{i+1} \Delta t$
    - c. If outside the range  $[-\pi, \pi]$ , add or subtract  $2\pi$
    - d.  $t_{i+1} = t_i + \Delta t$
    - e. Repeat for the desired number of time steps
  4. Equation (8) and (9) is solved by the Euler-Cromer method. For each time step  $i$ , calculate  $\omega$  and  $\theta$  for time step  $i+1$ :
    - a.  $\omega_{i+1} = \omega_i - \left[\left(\frac{g}{l}\right) \theta_i + q \omega_i - F_D \sin(\Omega_D t_i)\right] \Delta t$
    - b.  $\theta_{i+1} = \theta_i + \omega_{i+1} \Delta t$
    - c. If outside the range  $[-\pi, \pi]$ , add or subtract  $2\pi$ .
    - d.  $t_{i+1} = t_i + \Delta t$
    - e. Repeat for the desired number of time steps

## RESULT AND DISCUSSION

In this study, a numerical solution using the Euler-Cromer method was carried out with the help of MATLAB. MATLAB is a high-level language in computations that combines calculation, apparition, and programming (Amalia, Budhi, & Arifin, 2020). Nonlinear problems with impermanent energy will be simulated with a slight modification of the Euler-

Cromer. It is to modify the gradient sequence used to calculate the point displacement. The MATLAB code required to define a basic gradient sequence (Berwick, 2012). The simulations designed to complement the real experiments that are useful in providing a possibility to explore physics phenomenon which can not be realized in some condition, like too long or too short experiments.

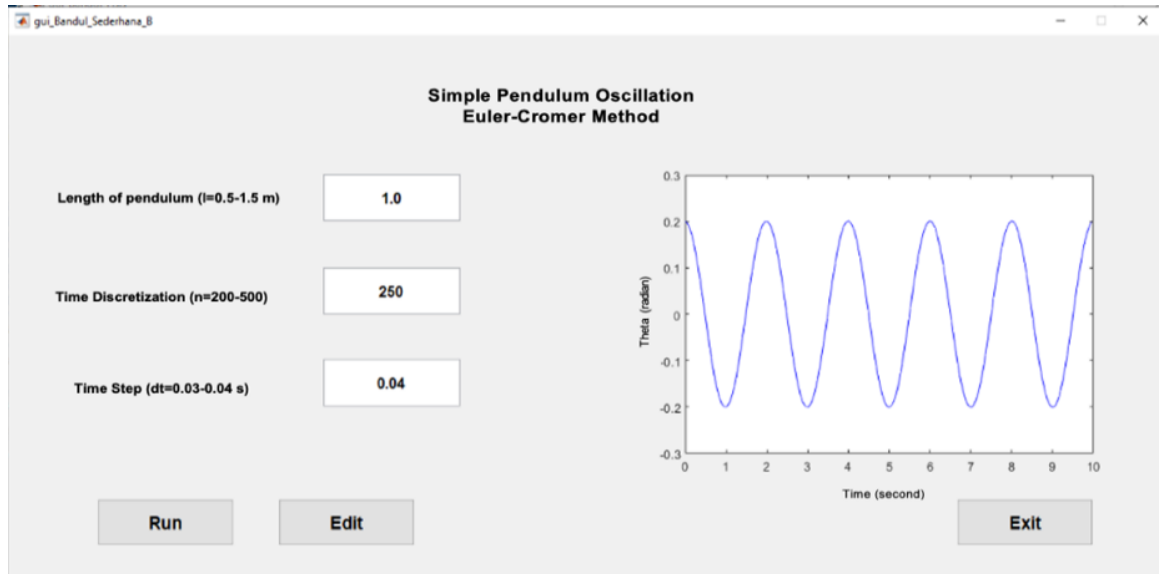
The simulation screen consists of two windows. The first window is pendulum parameters which the student can specify the parameters such as length, the number of points, and time step. The second one displays the graph. The students have their own choice the parameters, so that it will has different displays of graph. Based on the results of the trial, then the program was refined by creating a graphical user interface (GUI). This form of GUI has the following advantages for users.

1. Users can see input and output variables directly,
2. The user can change the input values by clicking the **Edit** button,
3. Users can view the output graph by clicking the **Run** button,
4. Users can leave or exit by clicking the **Exit** button.

GUI used in learning simple pendulum oscilation can minimize the misfit of calculation and facilitate the analysis (Nurullaeli and Astuti, 2018).

### Simple Pendulum with Euler-Cromer Method

In this simulation the following quantities are used: the length of the pendulum  $l = 1.0 \text{ m}$ , gravitational acceleration  $g = 9.8 \text{ m/s}^2$ , the time discretization  $n = 250$ , and time step  $\Delta t = 0.04 \text{ s}$ . Simulation results show that the oscillation is sinusoidal as shown in Figure 3. The equation of (3) and (4) were converted into a differential equation, using the time step  $\Delta t$  so that time is discrete with  $t = i\Delta t$ , where  $i$  is an integer.



**Figure 3.** Simulation of Simple Pendulum with Euler-Cromer Method

According to the displacement of the graph in Figure 3, the Euler-Cromer method set a solution of Equation (5) in the form of a constant amplitude harmonic wave. The harmonic pattern of the time-displacement graph is consistent for a relatively large initial phase angle  $\theta = 0.2$ . The behaviour of system is stable which mean that there is no system solution that leads to infinity or towards zero (Saroja & Nuriyah 2019).

Figure 3. show the constant sinusoidal graph with constant amplitude which has same pattern in simple pendulum experiment (Budi, 2015; Hasan & Rana, 2019).

### Simulation of Damped Oscillations by The Euler-Cromer Method

In this simulation the following quantities are used: the length of the string  $l = 1.0$  m, gravitational acceleration  $g = 9.8 \text{ m/s}^2$ , the number of points  $n = 250$ , damping power  $q = 1.0$  and time step  $\Delta t = 0.04$  s. Simulation results show that the oscillation is sinusoidal as shown in Figure 4.

The graph in Figure 4. shows that there is an oscillation with an approximate period  $2\pi$ , but the amplitude is damped with the evolution of time. Dry

friction becomes more important, due to the increase of time and reduction of velocity.

Figure 4 also tells us that the oscillations of dumping pendulum decrease or slow down with time. It is due to the friction in the surface and air-drag. Therefore, compare to simple pendulum, the amplitudo of damped pendulum decreases with time (Harsh, 2016).

### Chaotic Simulations in Non-Linear Pendulum Forced

In this simulation the following quantities are used: the length of the string  $l = 9.8$  m, gravitational acceleration  $g = 9.8 \text{ m/s}^2$ , the number of points  $n = 10000$ , damping power  $q = 0.5$  driving force  $FD = 0.5$  and  $FD = 1.2$  and time step  $\Delta t = 0.04$  s. Simulation results show that the oscillation is sinusoidal as shown in Figure 5.

If the pendulum experiences a large enough external force, the system can be said to be deterministic and also unpredictable. This system is a non-periodic long term behavior in a deterministic system that exhibits sensitive dependence on initial conditions, called a chaos (Kulkarni & Borkar, 2015).

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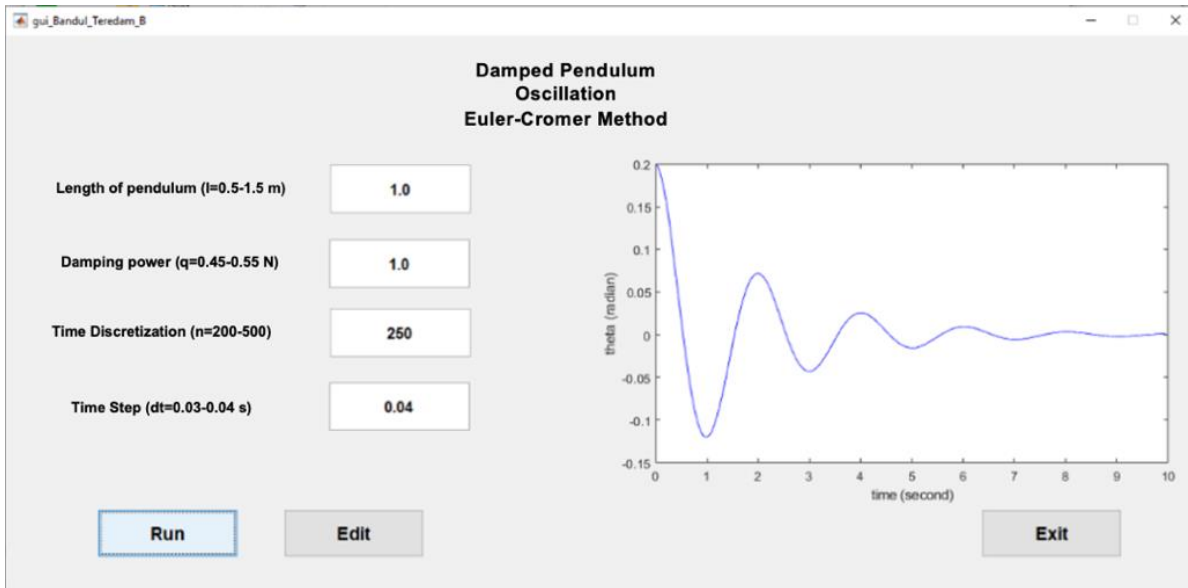


Figure 4. Simulation of Damped Oscillations by The Euler-Cromer Method

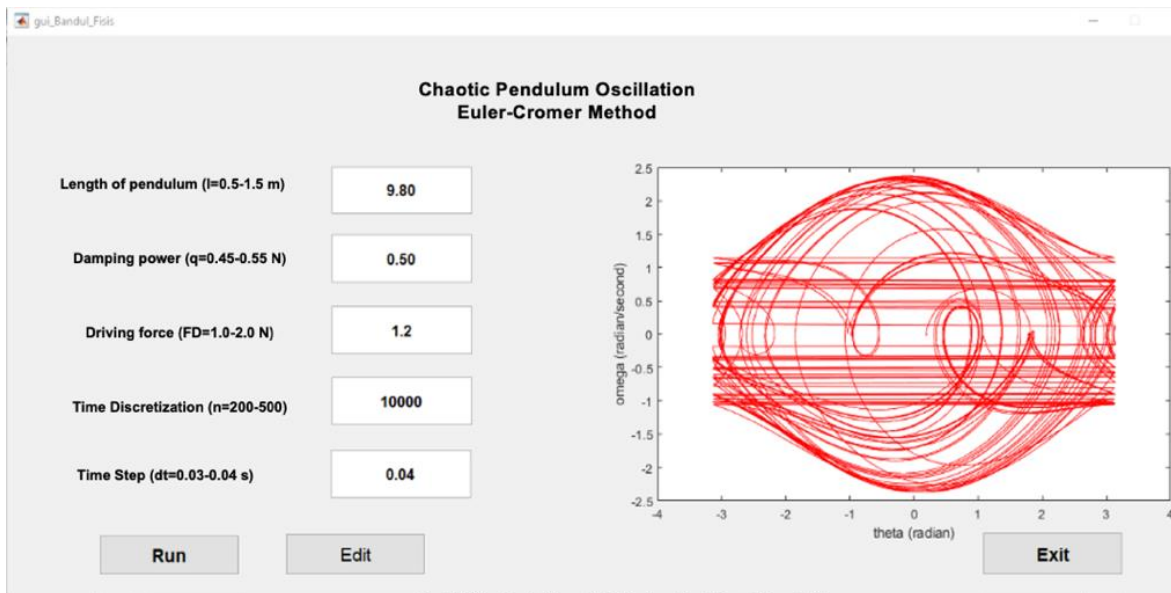


Figure 5. Chaotic Simulation in Non-Linear Pendulum Forced

### Evaluation of Research Products

The evaluation of the research product was carried out through the Forum Group Discussion (FGD). An FGD is a good way to gather together people from similar backgrounds or experiences to discuss a specific topic of interest and feedback results to research participants (Mishra, 2016). The participants of FGD are 6 lecturers and trial through 33 students.

According to the result of calculation of V Aiken's index as presented in Table 1 that V of the test items were 0.79 – 1.00. It meant that all the test items of product evaluation questionnaire by the lecturer had good content of validity in terms of their conformity with the indicator. While in Table 2, V of the test items were 0.83 – 0.95 indicated that all test items of product evaluation questionnaire by the students had good content of validity.

**Table 1.** V Aikens Index Calculation Result of of the Product Evaluation Questionnaire by the Lecturer

Item	$\sum s$	$c - 1$	$n(c - 1)$	$V$	Category
1	19	4	24	0.79	Valid
2	19	4	24	0.79	Valid
3	21	4	24	0.88	Valid
4	21	4	24	0.88	Valid
5	22	4	24	0.92	Valid
6	22	4	24	0.92	Valid
7	22	4	24	0.92	Valid
8	24	4	24	1.00	Valid
9	24	4	24	1.00	Valid
10	22	4	24	0.92	Valid

**Table 2.** V Aikens Index Calculation Result of of the Product Evaluation Questionnaire by the Students

Item	$\sum s$	$c - 1$	$n(c - 1)$	$V$	Category
1	109	4	132	0.83	Valid
2	113	4	132	0.86	Valid
3	116	4	132	0.88	Valid
4	113	4	132	0.86	Valid
5	118	4	132	0.89	Valid
6	117	4	132	0.89	Valid
7	115	4	132	0.87	Valid
8	126	4	132	0.95	Valid
9	124	4	132	0.94	Valid
10	110	4	132	0.83	Valid

In this activity, a questionnaire was given and the results can be shown in Table 3 and Table 4.

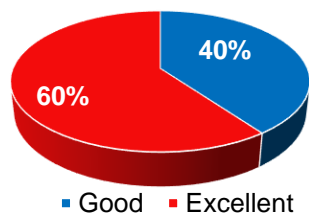
**Table 3.** Results of the Product Evaluation Questionnaire by the Lecturer during the FGD

Statement	Very Bad	Bad	Adequate	Good	Excellent
Display	-	-	-	5	1
Accuracy of typography	-	-	-	5	1
Screen space arrangement available	-	-	-	3	3
The attractiveness of the picture	-	-	-	3	3
The clarity of the picture	-	-	-	2	4
Readability of information on the screen	-	-	-	2	4
Clarity of display elements on the screen	-	-	-	2	4
Ease of using the Run, Edit, and Exit buttons	-	-	-	-	6
Ease charging input variables	-	-	-	-	6
Ease of interpreting picture	-	-	-	2	4

**Table 4.** Results of the Product Evaluation Questionnaire by the Students

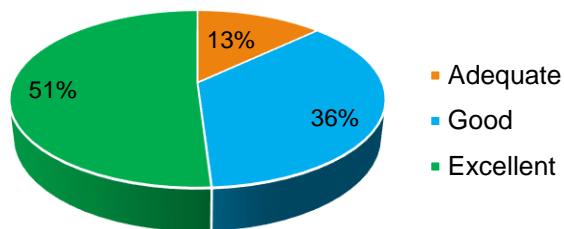
Statement	Very Bad	Bad	Adequate	Good	Excellent
Display	-	-	4	24	5
Accuracy of typography	-	-	-	24	9
Screen space arrangement available	-	-	7	14	12
The attractiveness of the picture	-	-	10	11	12
The clarity of the picture	-	-	6	23	14
Readability of information on the screen	-	-	3	17	13
Clarity of display elements on the screen	-	-	7	15	11
Ease of using the Run, Edit, and Exit buttons	-	-	1	10	22
Ease charging input variables	-	-	-	13	20
Ease of interpreting picture	-	-	5	22	6

Based on Table 3, a diagram can be made as shown in Figure 6.

**Figure 6.** Lecturer Responses about Oscillation and Chaos Motion Simulation Products in Learning Physics

Based on Table 4, a diagram can be made as shown in Figure 7.





**Figure 7.** Student Responses about Oscillation and Chaos Motion Simulation Products in Learning Physics

Evaluation results in Table 3 and Table 4 show that the oscillation simulation software developed has good criteria and is suitable for use in learning oscillation systems. Table 4 shows all respondents gave an excellent value on statements: the ease of using the Run, Edit, and Exit buttons; and changing input variables. This is in line with the results in Table 3 where these statements also have a high rating so it can be seen that the software developed has advantages in user friendly characteristics. The results are compared with relevant findings by Yetilmezsoy et al, the class of 60 are able to investigate the challenging aspects of the extended numerical and graphical tools by using MATLAB (Yetilmezsoy & Mungan, 2018).

The findings were consistent with the constructivist view of learning which stated that a computer simulation-based learning can improve students' creativity significantly, and the students particularly have a good response toward the simulation program. The calculation and graphic schemes appeared very attractive, fast, and showed precise results (Tawil & Dahlan, 2017). Computational activity can improve student ability in graph representation (Dewi et al., 2018). Two most important factor that affect physics learning achievement are interpreting graph and conceptual learning (Purba & Hwang, 2018).

One of the advantages of computer simulations is to allow students access real situations and there is no need to repeat them in here (Polatoglou & Sitsanlis, 2018). The students can control the simulation made and repeat the experiments for better understanding. There is no need for expensive equipment and expendable

supplies. They can control the learning pace, repeat experiments, and try out different approaches in hiring better understanding and actively constructing their knowledge (Vrellis, Avouris, & Mikropoulos, 2016; Freitas & Veletsianos, 2010; Ai-Lim Lee, Wong, & Fung, 2010).

## CONCLUSION

Based on result and discussion of this study, the conclusions the oscillation and chaos motion simulation software in physics learning has been developed successfully. According to the lecturers, this research product is in the good (40%) and excellent (60%) category. Meanwhile, according to the students, this research product is included in the adequate (13%), good (36%), and excellent (51%) category. The research can be developed by applying software in the learning process so that we can see the effectiveness of the software in improving student understanding of the oscillation system subject. Besides that, the research could be more developed by taking up simulation of other systems that are endless possibilities, such as coupled oscillator or a double mass system such as double pendulum or double mass spring system.

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