Computer Simulation Development for Simulation-Based Learning in High-School Physics

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Abstract—**COVID-19 has affected how teaching is carried out at all levels of education, including in high school. Teachers must adapt their teaching methods since students can no longer access school's facilities. This became a concern, especially for subjects that require students to conduct experiments such as Physics. This paper is aimed to design and develop a computer simulation that can be used for simulation-based learning in high-school Physics, particularly on the topic of Newton's law. The topics covered are constant acceleration linear motion, fraction, and force. Through literature studies, the features of the simulation were determined. The implemented features are interactivity through changeable parameters and immediate visual feedback, three graphics to show the acceleration, velocity, and position of an object, and a Comma-Separated Values (CSV) file that contains the detailed calculations of the simulation for debriefing. The simulation has been developed and evaluated through an online group discussion with two high school Physics teachers. Improvement has been made according to the discussion.**

Keywords—**software design, computer-based simulation, simulation-based learning, high-school physics**

I. INTRODUCTION

Teaching and learning process have been significantly affected ever since Coronavirus disease (COVID-19) hit [1]. Teachers and students were not able to physically have a face-to-face meeting freely as they usually did. This became a problem, especially for teachers who taught high-school subjects which require students to do hands-on activities in the laboratory. Students might no longer have access to conduct experiments in a laboratory, which was a concern since doing experiments has been known to be a valuable tool with a range of benefits [2, 3]. COVID-19 disease has forced teachers to adapt their teaching methods. They need a way to deliver the materials and ensure students have access to a diverse learning experience. The teaching methods should enable students to be engaged in the teaching and learning process.

This paper focuses on one of many subjects where experiments can help students to better understand the concept, that is Physics. As a natural science subject, Physics requires students to relate the theory and equations to the phenomenon being observed. However, this was proved to be a difficult task for students [4, 5]. They tend to have difficulties in visually representing the physical system being learnt since they only see equations as ways to calculate solutions [5]. COVID-19 pandemic makes it even harder for students to understand and apply Physics as they now lack not only experiential learning through experiments, but also visual representations of physical phenomena. One solution to these problems is to use computer-based simulation that can facilitate experiments with an engaging and stimulating representation. A few researchers have concluded that computer simulation can help students to have a deeper understanding in Physics [2, 4], and can have superior benefits compared to lab-based experiments [2].

Although many forms of simulations have been used in teaching for a long time [6], the use of computer-based simulation in teaching science has been widely popular in particular [7]. Simulation-Based Learning (SBL) using a software will be more widespread because of COVID-19. The pandemic forced education institution to implement online learning, which made people to realize how useful simulations that can be delivered digitally are. Therefore, teaching and learning using a computer simulation is now of interest. Having access to a computer software that can simulate the concepts being taught will help teachers in explaining the materials and help students in experimenting the concepts by themselves. Computer simulation can also be the solution for students who have difficulties in accessing laboratories due to the lack of facilities at school. In addition, with results from previous

research, SBL is expected to offer even more benefits for students in learning and understanding Physics subjects.

To get the benefits of computer-based simulation, the software must be designed carefully so that it can meet the needs of both teachers and students. In addition, the software also depends on the materials being taught. Therefore, this paper is aimed to design and develop a computer software that can be used in simulation-based learning to enhance students' understanding. The topic chosen is Newton's Law, which is taught in year XI in Indonesia. Literature studies on the use of SBL, especially in Physics, were done to determine the important features of the software. The developed software was then evaluated through a group discussion with two senior-high teachers from two prestigious schools in Indonesia.

II. LITERATURE STUDIES

The first formal research on simulation-based learning was done in the 1960s [6]. SBL itself can be generally defined as the process of obtaining or improving knowledge and skill using simulations [8]. Since simulations have been long used in learning and teaching, they can have many forms, such as game and role-playing. However, one form of simulation that has been widely practiced is computer-based simulation [2].

Although there are many definitions of computer simulation, many of them include the use of programs that can visually represent real or hypothetical phenomenon and allow users to interact with the programs [7]. One important element of a simulation is interactivity [8]. An interactive simulation allows users to experiment on the phenomenon and see immediate visual feedback. This can motivate students to be actively involved in the learning process. Furthermore, students can learn by observing what happened when different parameters are given. Another important element of an SBL, which [9] argued as the most important one, is debriefing. Debriefing refers to guided reflections or discussions after conducting simulations. Although the effectiveness of debriefing was hard to evaluate, much research agreed that debriefing is essential for a successful SBL [10]. Debriefing is particularly important to correct students' misconceptions during simulation. Reference [10] showed how debriefing improved performance competency and self-reflection objectiveness in clinical training.

Numerous research has been conducted in various fields to investigate the benefits of using SBL, especially in medical and management education [6]. Among the many benefits of SBL, some most common ones were the increase in learning motivation through engaging simulation [2, 6, 7, 11–14] and the possibility of a deeper understanding of the simulated phenomenon [2, 4, 11–13, 15]. Other interesting benefits found were the provision of diverse learning experiences [16] and easy integration with online and blended learning [15].

Reference [13] used PhET (Physics Education Technology) simulation to help explain Physics subjects about temperature and heat for 11th grade students in Serang, Indonesia. Pre-test and post-test were used to measure the effect of using PhET simulations on students' Science Process Skill (SPS). Based on the percentage of normalized gain values, the experimental group who used PhET simulations showed better results compared to the control group. The main benefit observed was that simulation could motivate students to be actively involved in the learning process, which resulted in more meaningful learning. Another point of interest was how SBL could enhance students' observation skills regarding the theory behind the physical phenomenon. However, it was noted that the use of simulation requires careful planning on how to use the simulation, including how to perform a reflection session after the simulation.

Another similar research was done where a simple simulation was used to teach linear motion to year VII students in Bandung, Indonesia [14]. Pre-test and post-test were done on a group of students to evaluate their SPS using normalized gain analysis. They concluded that SPS was indeed improved through SBL. The simulation was able to stimulate students to conduct their own experiments, resulting in an active learning process. Moreover, based on the indicators in their test, students' predicting skills had the most improvement. On the contrary, their skill in summarizing and communication, which includes their ability in processing and interpreting data, had the lowest improvement.

The use of simulation, particularly PhET simulation, in Physics subjects for higher education was investigated using pre-test and post-test for control and experimental classes in Konya, Turkey [17]. The study aimed to examine how simulations affect students' beliefs on Physics. Surveys were done before and after the study to examine students' beliefs on Physics. They concluded that using simulations had a positive effect on students' beliefs, which was highly correlated with students' conceptual understanding and average achievements.

As can be seen, the use of simulation in education has been widely popular and has an increasing trend. This can be seen from the number of Scopus-indexed documents regarding SBL [6], the number of articles in Google Scholar with the term "Computer Simulation-Based Learning" [16], and the number of Google Scholar citations for the term "simulation education" [15]. However, most of the articles focused on the implementation of SBL in American and European societies, whereas only a few articles discussed SBL in Asian context [6]. Particularly in Indonesia, based on a quick questionnaire distributed in one of Indonesian major cities, students understanding on Physics was still low, and one of the identified reasons was the monotonous learning process without using simulations [14]. Therefore, developing a computer simulation that is suitable for learning Physics in Indonesia is of interest.

III. SIMULATION DESIGN

Previous research showed that a simple computer-based simulation can be very beneficial in learning Physics. This paper aims to design and develop a Physics simulation software, specifically on the topic of Newton's

Law, for high school students in Indonesia. The topics covered are constant acceleration linear motion, fraction, and force. The simulation imitates a physical system where a force F at an angle α can be given to a box lying on a flat surface with a coefficient of static friction μ_s and a coefficient of kinetic friction μ_k. The box has a mass m and an initial velocity V_0. The gravitational acceleration is $g = 9.87 \ m/s^2$. Static frictional force f_s works on the box when it is not moving, whereas kinetic frictional force f_k works once the box starts moving. An illustration is shown in Fig. 1.
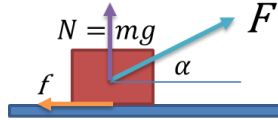
Figure 1. Illustration of the physical system.

There are some equations governing the physical system. First, for a force F at an angle α, calculate the force on the x-axis and y-axis with

$$F_x = F \cdot cos(\alpha), \tag{1}$$

$$F_y = F \cdot sin(\alpha). \tag{2}$$

After aggregating all forces on the x-axis, check whether the total is greater than the static frictional force f_s,

$$f_s = \mu_s \cdot (m \cdot g - F_y). \tag{3}$$

When the total force is larger than f_s, the box starts moving and the kinetic frictional force f_k starts working on the box

$$f_k = \mu_k \cdot (m \cdot g - F_y). \tag{4}$$

The force f_k always works in the opposite direction of the box's movement. After accounting for the direction of f_k, the total force F_{total} working on the box is used to calculate the acceleration a using

$$F = m \cdot a. \tag{5}$$

Finally, the velocity and position of the box at time t can be calculated using

$$V_t = V_0 + a \cdot t, \tag{6}$$

$$x_t = x_0 + V_0 \cdot t + \frac{1}{2}at^2. \tag{7}$$

TABLE I. FEATURES OF THE SIMULATION

No.	Requirements	Features
1	Interactivity	Simulation prompts four parameters, which are mass, initial velocity, static and kinetic coefficient of friction, and prompts how forces are applied.
2	Real-time graphics	Simulation draws three graphics to show the acceleration, velocity, and position of the box.
3	Debriefing	Simulation provides detailed calculations that generate the visual representation.

As mentioned before, many benefits of SBL come from its interactivity. This feature allows students to experiment and test hypothesis by changing the parameters and observing the visual feedback. Therefore, the simulation must allow students to input some parameters. The parameters are mass, initial velocity, and two coefficients of friction. In addition, the simulation must also provide a way to apply various forces to the box and update the visual representation accordingly. Moreover, it was discovered that real-time graphics were helpful to avoid misconceptions on the trajectory of a moving object [18]. Therefore, three graphics to show the acceleration, velocity, and position of the box are added.

Another important component of SBL is debriefing where the instructor leads the students to reflect and discuss the concept after the simulation. Providing detailed calculations of the physical system can help to debrief by showing how the equations govern the system. Therefore, an option to generate these calculations is desirable.

After considering what a simulation on Newton's law should provide, a list of features was generated as can be seen in Table I. The simulation starts by prompting the user to enter the parameters and the forces, including their angle and when they will be applied. All inputs have a default value that can be used as an example for a quick start. The simulation can then be started, and a visual representation of the physical system will be displayed along with the three graphics. The user can finish the simulation and opt whether detailed calculations should be generated or not. Finally, the user can repeat the steps to conduct another experiment. The flow of the simulation is shown in Fig. 2.
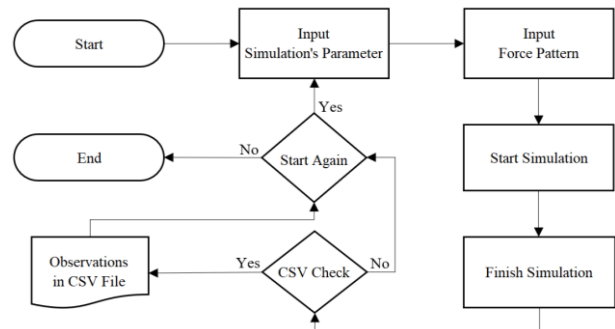

Figure 2. Flowchart of the simulation.

IV. IMPLEMENTATION

A simulation was developed based on the design in III. Since the simulation is intended for Indonesian high-school students, the simulation uses Bahasa, the national language of Indonesia. The simulation was implemented using Java for desktop. Java was used so that the simulation can be run on any computer with Java Virtual Machine (JVM) installed on it. Moreover, Java is also supported in Android apps development, so it will be relatively easy to convert the simulation into mobile apps.

To further support easy conversion, object-oriented programming was used. There are two main classes, the Box and GLBB classes. The Box class models the object

of the physical system. This class manages the position and movement of the object using the equations in III. As for the GLBB class, it represents the physical system itself where the object resides. This class runs the simulation.

In addition, there are two additional classes for the Graphical User Interface (GUI), the FrmMain and PnlControl classes. FrmMain is the main window of the simulation, whereas PnlControl is the panel where user can input the parameters of the physical system. Fig. 3 shows the GUI of the simulation when it is first started. The left part of the window is the PnlControl, whereas the right part is where the simulation will be displayed.
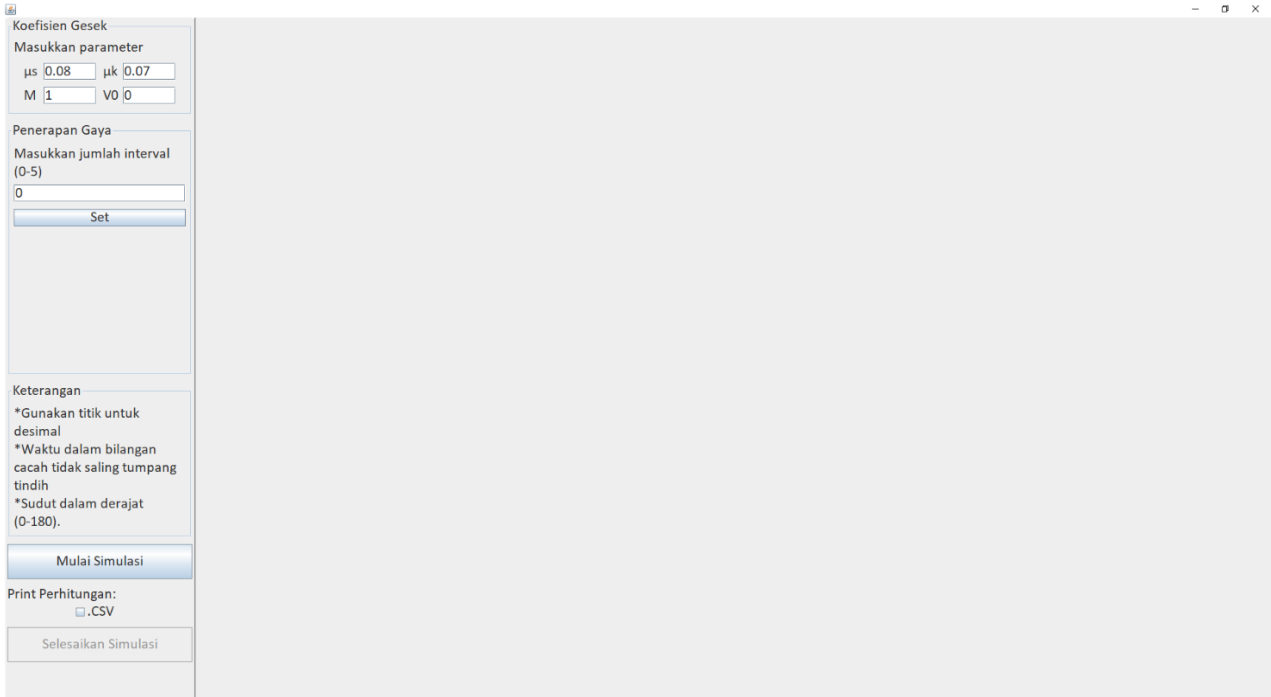
Figure 3. The GUI at the start of the simulation.

The interactivity feature was implemented through PnlControl. The panel consists of three sections with a blue border, two buttons, and an option called "CSV". The first two sections are where the user can interact with the simulation. The first one contains the four parameters mentioned in Table I. In the second section, the user can determine how forces are applied. First, the user needs to determine the number of forces applied and click the "Set" button. The panel will then prompt the user for the forces, their angle, and the interval at which each force is applied.

There are some restrictions on the inputs of the system. When a restriction is not fulfilled, then the associated input box will be highlighted in red, as in Fig. 4. These restrictions are listed in the third part of PnlControl called "Keterangan". The restrictions are as follows:

- The decimal separator used is a dot.
- μ_s must be larger than μ_k.
- The mass of the box must be larger than 0.
- The maximum number of forces applied is five.
- The interval of each force cannot overlap with each other, except at the end of each interval.
- The angle of each force is in degrees, and it can only be between 0 to 180 in the counterclockwise direction from the positive x-axis.
- The y-axis component of each force cannot exceed the box's weight. This case is outside the scope
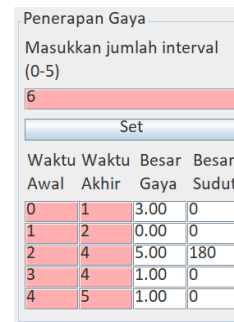

Figure 4. Error indicators in the simulation.

TABLE II. DEFAULT VALUES FOR THE INPUTS OF THE SIMULATION

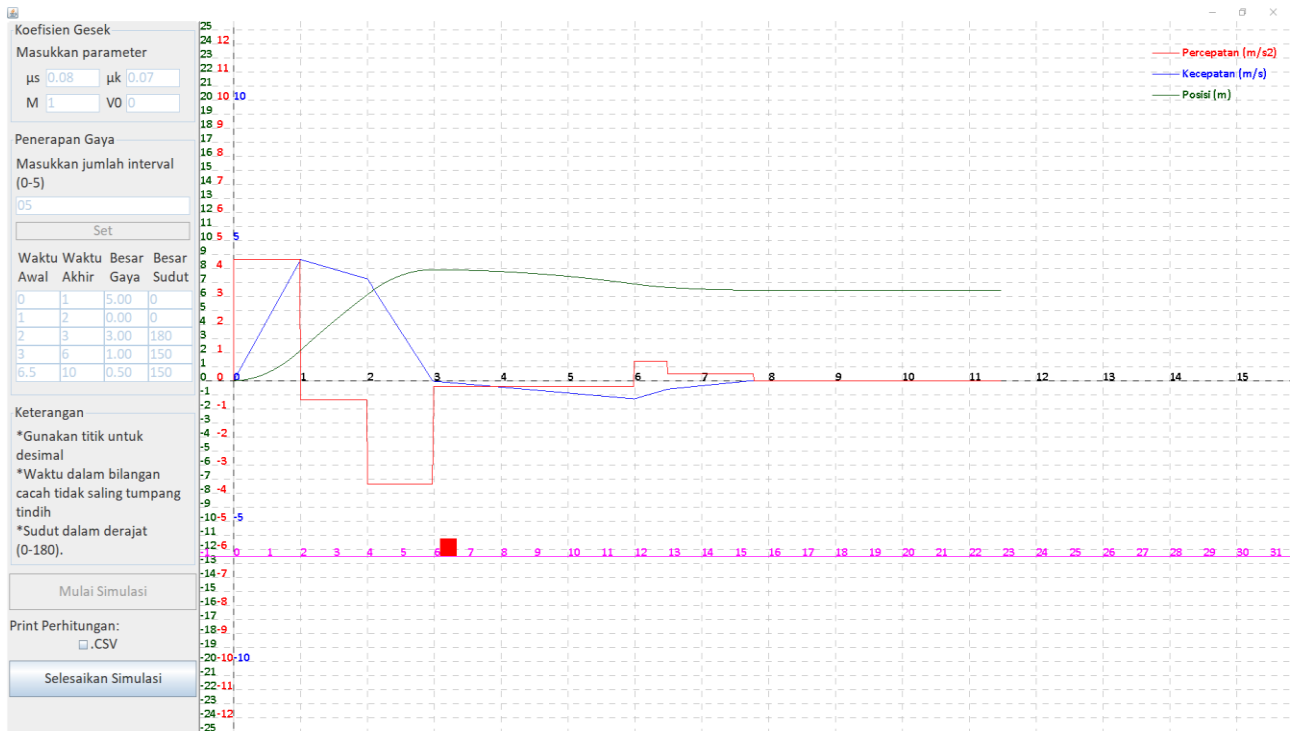| Inputs	Default Values
Mass (m)	1 kg
Initial velocity (V_0)	0 m/s
Static coefficient of friction (μ_s)	0.08
Kinetic coefficient of friction (μ_k)	0.07
Number of intervals	0
Force at the 1st interval	5N at 0° from time 0 to 1
Force at the 2nd interval	0N at 0° from time 1 to 2
Force at the 3rd interval	3N at 180° from time 2 to 3
Force at the 4th interval	1N at 150° from time 3 to 6
Force at the 5th interval	0.5N at 150° from time 6.5 to 10

Figure 5.   The GUI after running the simulation with the default values.

After determining all the inputs, user can click the "Mulai Simulasi" button to start the simulation. Note that user can use the default values directly instead for a quick start. The default values are listed in Table II. An example of the simulation run with the default values can be seen in Fig. 5.

The second feature of the simulation, the real-time graphics, was implemented on the same panel where the simulation runs. Three graphics with different colors were implemented for acceleration (red), velocity (blue), and position (green), as shown in Fig. 5. There is only one set of numbers on the x-axis showing the time of the physical system, whereas the y-axis has three sets of numbers with different colors. The color of the numbers indicates the type of graphic associated with it. The graphics help show how the box's movement and position changes over time as different force patterns are applied. Moreover, the graphics are particularly helpful at both ends of each interval and when the box change direction.

The third feature was implemented by enabling the simulation to generate a CSV file containing all the calculations of the physical system. To activate this feature, user can check the "CSV" checkbox at the bottom of the panel, then click the "Selesaikan Simulasi" button to generate the CSV file while finishing the simulation. An example of the CSV file viewed using a spreadsheet can be seen in Fig. 6. This CSV file was generated after running the simulation in Fig. 5. The detailed calculations are intended to help the user in observing the relationship between the equations and the visual representation. Particularly, these calculations can be used to show how equations (6) and (7) work exactly at the time when different forces are applied (at the start

of an interval) and when the box stops moving while a force is still being applied (around time three and seven in Fig. 5).

One thing to consider when generating the CSV file is the decimal separator used by the computer. Depending on the locale of the computer, a comma or a dot is used as the decimal separator for Indonesian and English locales, respectively. The digit group separator must also be considered.

1	t	Kecepatan	Percepata	Jarak
2	0	0	0	0
3	0	0	1.3091	3
4	0.01	0.01309	1.3091	3.00007
5	0.02	0.02618	1.3091	3.00026
6	0.03	0.03927	1.3091	3.00059
7	0.04	0.05236	1.3091	3.00105
8	0.05	0.06545	1.3091	3.00164
9	0.06	0.07855	1.3091	3.00236
10	0.07	0.09164	1.3091	3.00321
11	0.08	0.10473	1.3091	3.00419
12	0.09	0.11782	1.3091	3.0053
13	0.1	0.13091	1.3091	3.00655
14	0.11	0.144	1.3091	3.00792
15	0.12	0.15709	1.3091	3.00943

Figure 6.   An example of the generated CSV viewed in a spreadsheet.

The different separator symbols need to be considered so the CSV can be opened correctly using a spreadsheet program. Therefore, at the start of the program, a dialog as in Fig. 7 prompts the user to enter the preferred decimal separator. If the user enters a comma, then a comma is used as the decimal separator and a dot as the digit group separator. Otherwise, the inputted symbol is the decimal separator, and a comma is used as the digit group separator.
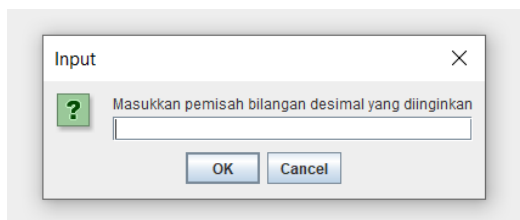
Figure 7. A dialog to determine the decimal separator for the CSV file.

V. EVALUATION

The developed computer-based simulation was evaluated in an online group discussion using Bahasa. It was attended by three of the authors, a moderator from Universitas Pelita Harapan, and two high-school Physics teachers from two prestigious high schools in Jakarta Metropolitan Area. The discussion was uploaded to YouTube with the title "Bagaimana Program Java dapat membantu Belajar Fisika? UPH - SMAK1".

Both teachers agreed that simulations are necessary in teaching Physics, especially in online learning situation. In fact, one of the teachers already utilized online simulations, such as PhET simulation, in his class. Comparisons were made between the developed simulation and other online simulations. The most defining features of this simulation are the three simultaneous graphics, which allows for easy comparison, and the CSV file.

The comments on the simulation were mostly positive, but some improvements were suggested. First, the display should be made more interesting or fun for high school students. As an example, the box could be replaced with other objects that is more relatable. Another improvement was to add the measurement unit for both the inputs and the axes. The last suggestion was to not show all three graphics simultaneously, but instead let the user choose which graphics to show. Options should be provided so that the teacher can choose which graphic to show according to the material.

VI. CONCLUSION

A computer simulation for Physics subject covering the topic of Newton's Law, particularly constant acceleration linear motion, fraction, and force, has been developed using Java programming language. The simulation has three features. The first one is interactivity through simulation parameters. The simulation also has three real-time graphics showing the acceleration, velocity, and position of the object. Finally, the simulation provides a detailed calculations of the physical system in a CSV file that can be used in debriefing session.

Evaluation has been done through a group discussion with two high-school Physics teachers from two prestigious high schools in Jakarta Metropolitan Area. Three improvements were suggested, which are to make the display more interesting for high school students, to add measurement units for the inputs and the axes, and to allow the user to choose which graphics to show. These suggestions will be considered to further improve the simulation. Another research will then be conducted using the final version of the simulation to discover the effectiveness of simulation-based learning in teaching high-school Phsycis in Indonesia.

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