Computational Modelling Based on Modellus to Improve Students’ Critical Thinking on Mechanical Energy

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Abstract. Mechanical energy is one of the topics of learning physics in high school that is related to concepts and mathematical equations. Modellus is a computer application designed to explore mathematical models based on functions that are represented in the form of animations, graphics, and tables that are useful for focusing learning activities on understanding student physics concepts. In this study describes computational modelling activities using Modellus software and carried out the Modellus quality testing phase as a medium of physics learning to improve understanding of students' concepts on the topic of mechanical energy. Based on the data obtained, Modellus is included in the "very good" category used in physics learning especially on the topic of mechanical energy and critical thinking skills students obtain an average score of 65.45 in the "good" category using Modellus.

Key words: Modelling, Mechanical Energy, Modellus, Critical Thinking

1. Introduction

In the process of scientific research, computational modelling plays an important role in the expansion of the cognitive horizons of science and mathematics through increased computation, exploration and visualization capabilities [1]. The role of computational modelling is more dominant use in scientific research processes. However, computing modelling is also beneficial in the science-learning process, specifically physics. Physical subjects are difficult subjects as many learn about mathematical equations, so that physics are identified with numbers and formulas. This creates difficulties for students to see and give the physical meaning of the natural phenomena that actually occur. Therefore, modelling can solve the problem of calculations effectively and efficiently. Not only does it solve the problems of effective and efficient calculations, interactive computing modelling can increase physical learning activities so as to improve the ability of critical thinking in understanding students' physics concepts [1] – [3].

Work and energy is a concrete material and occurs in daily life, so there are many problems related to the work and energy that can be used as a reference or guideline in learning. Energy is a system that allows to do work. The energy is a part of classical mechanics that examines the movement of an object from the beginning to the end, as well as the cause of the movement of things. Work and energy are fundamental concepts of physics that must be attached to students. Therefore,
understanding of work and energy needs to be emphasized so that students will be able to receive further topics related to work and energy. Work-energy can be said to be an alternative to solving the problem of motion of objects other than Newton’s law and impulse momentum [4]-[5].

Several attempts have been made to introduce computational modelling in a learning environment inspired by scientific research. Early emphasis on the programming languages of Fortran, Pascal, and Phyton. These programs still need students to develop programming knowledge, which generally takes time and inhibits the physics learning process. To avoid students with programming ideas, and to focus the learning process on relevant physics and mathematics, some computer modelling systems are created, one of which is Modellus [1].

Modellus is used to introduce a computing model that allows easy creation of a physics model that only uses standard physics notation. Then Modellus has the possibility to create animations with objects that have interactive properties expressed in mathematical models and allow exploration of multiple representations, as well as to allow the analysis of experimental data in the form of drawings, animations, graphics, and tables [6].

Modellus is often used in the study of science, namely physics, mathematics and geoscience in the activities of developing interesting computer modelling [1]-[3], apply theories about the projectile motion influenced drag and spin Effect Magnus Ball [7], and determine the terminal velocity of marbles in viscous fluid and to simulated of this motion with using Modellus Software [6]. Modellus is suitable for the learning process of physics with the advantage of being able to trace the phenomenon of physics and find a mathematical relationship that builds the physical phenomenon [1].

2. Method
This research conducted several stages, including the installation of Modellus, media design, validity test, and assessment of critical thinking.

Before designing the Modellus, first performed the installation process of the Modellus program. After the installation process is complete, the next step is to analyse the mathematical equations used on the topic of linear motion and mechanical energy. In this case we have to know about the concept of mechanical energy.

![Figure 1](image-url) A circus diver at the top of a pole has a potential energy of 10,000 J. As he dives, his potential energy converts to kinetic energy. Note that, at successive positions one-fourth, one-half, three-fourths, and all the way down, the total energy is constant.
Whenever energy is transformed or transferred, none is lost and none is gained. In the absence of work input or output or other energy exchanges, the total energy of a system before some process or event is equal to the total energy after. Consider the changes in energy in the operation of the pile driver back in Figure 1. Work done to raise the ram, giving it potential energy, becomes kinetic energy when the ram is released. This energy transfers to the piling below. The distance the piling penetrates into the ground multiplied by the average force of impact is almost equal to the initial potential energy of the ram. We say almost because some energy goes into heating the ground and ram during penetration. Taking heat energy into account, we find that energy transforms without net loss or net gain. The study of various forms of energy and their transformations has led to one of the greatest generalizations in physics—the law of conservation of energy: Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.

The application of the law of conservation energy occurs in free fall motion, parabolic motion, and simple harmonic motion. In this paper will discuss about mechanical energy occur in parabolic motion. For more details, will be explained in the Results and Discussion section.

In running the program Modellus will be found four boxes, are Notes serves as a place of writing, the Mathematical Model serves as a place of writing the mathematical equation that has been analyzed, Graph is the display of the calculation results Graphic and Table is a display of calculated results in the form of a table.

After analyse the equation of mechanical energy, we compile the validity test. The validity test was conducted by a physics lecturer to determine the quality of Modellus used as a physics learning medium to improve students’ critical thinking skills on the topic of mechanical energy. The aspects assessed at this stage are software engineering, learning design, learning and visual strategies. And the last one we compile assessment of critical thinking. Assessment of critical thinking skills is performed at the time of learning by using Modellus on the topic of mechanical energy. The indicators seen during the assessment process are recognizing problems, ability to ask, problem solving, providing simple explanations, and building basic skills.

3. Results and Discussion
3.1 Mechanical Energy Modeling using Modellus
After the installation process Modellus on the laptop, it will appear the initial appearance of Modellus as in Figure 2.

![Figure 2. Modellus display](image)
In this modeling using the application of mechanical energy in the projectile motion, then the trajectory of projectile motion as in Figure 3. To create a simulation of mechanical energy model, then incorporated the following equation:

**Figure 3. Trajectory of projectile motion**

From Figure 3, we can get the initial velocity equation on the y and x axes:

\[ v_{oy} = v_o \sin \alpha \]  \hspace{1cm} (1)

\[ v_{ox} = v_o \cos \alpha \]  \hspace{1cm} (2)

For angles on the Modellus used radians, the conversion of degrees to radians is:

\[ \alpha^\circ = \alpha \times \frac{\pi}{180} \]  \hspace{1cm} (3)

by substitution equations (3) to equations (1) and (2) so:

\[ v_{oy} = v_o \sin(\alpha \times \frac{\pi}{180}) \]  \hspace{1cm} (4)

\[ v_{ox} = v_o \cos(\alpha \times \frac{\pi}{180}) \]  \hspace{1cm} (5)

to determine the height \((y)\) and distance \((x)\) by using the linear motion equation:

\[ y = v_{oy}t - \frac{1}{2}gt^2 \]  \hspace{1cm} (6)

\[ x = v_{ox}t \]  \hspace{1cm} (7)

when the object reaches the height \((y)\) after \(t\) seconds, then the velocity of the object on the y axis is:

\[ v_y = v_{oy} - gt \]  \hspace{1cm} (8)

on the x-axis, this velocity is fixed because it has no gravity acceleration effect so:

\[ v_x = v_{ox} \]  \hspace{1cm} (9)

so the resultant vector velocity is:

\[ v = \sqrt{v_x^2 + v_y^2} \]  \hspace{1cm} (10)

Equations (10) are substituted to the kinetic energy equation, so that

\[ KE = \frac{1}{2}mv^2 \]  \hspace{1cm} (11)

Equations (6) are substituted to the potential energy equation, so that

\[ PE = mgy \]  \hspace{1cm} (12)

Hence acquired mechanical energy equation by summing equations (11) and (12):
\[ ME = KE + PE \]  \hspace{1cm} (13)

Once the equation above is obtained, the equation can be written in the Mathematical Model’s box as in Figure 4.

After writing the equation in the Mathematical Model’s box, then writing the question in the Notes’ box as in Figure 5.

In the Mathematical Model’s box there are two variables that must be filled with numbers, then students can fill in the box using the numbers listed in the question in the Notes’ box. Students can vary the numbers to see the relationship between the variables associated with the equation. Then the researcher took an example of numbers ie at the initial velocity, \( v_0 = 10 \) m/s and angles, \( i = 60 \). When finished writing the numbers in the Mathematical Model’s box we will design the simulation by adding objects to the worksheet, so the object already adjusts to the equation that exists in the Mathematical Model, as well as the Table and Graph. Here are the results of the simulation, Table and Graph.
Figure 6. Simulations display

Figure 7. Graph display
The calculated result on Modellus can be seen from Graph and Table view, Figure 7 and Figure 8, same as manual calculation result. The results shown in the graph can be obtained that the kinetic energy gets smaller when the apple is at its highest point, it is known in Figure 7 that the curve opens up (yellow). While the potential energy is greater when the apple is at its highest point, it is known in Figure 7 that the curve opens down (peach color). The graph of mechanical energy is always constant in Figure 7. This is in accordance with the theory, that is, when the apple is dropped, its potential energy will decrease along the path of its motion towards the ground and its altitude will be smaller. But on the contrary, when you want to reach the ground, kinetic energy becomes very large because the movement of the apple is faster due to the constant acceleration of gravity. When it starts to fall, the potential energy decreases because the potential energy changes to kinetic energy. When energy changes from $P_E$ to $KE$ or $KE$ become $P_E$, the total energy remains the same, namely Mechanical Energy. From this explanation it can be proven that the Law of Conservation of Energy is stated "Energy can be changed from one form to another but the number is always constant." [8]-[9].

Through the simulation results can be concluded that, Modellus can be used for student learning media in analyzing graphs of the law conservation of energy This is in line with the results of Neves's study [4] - [6], which states that Modellus can be used as a learning media that attracts and motivates students and software that is useful for learning the formulation of physics.

### 3.2. Validity test

The validity test was conducted by the physics lecturer of State University of Medan. The assessment is done by filling the validity sheet. The assessed aspects are software engineering, learning design, learning strategy, and visuals. The average score for software engineering aspects is 4.42 in the...
"excellent" category. The average score for the 4.4 learning design aspect in the "excellent" category. The average score for the 4.8 learning strategy in the "excellent" category. The average score for the visual aspects of the 4.4 is in the "excellent" category.

Based on the results of the validity test analysis, it can be said that the Modellus software can be categorized as "excellent" to enhance students’ critical thinking skills on the topic of mechanical energy.

3.3. Assessment of Critical thinking skills
Assessment of Critical thinking skills is performed during the learning process. Obtained an average score of 65, 45 with the category "good". For an average score of each indicator can be seen in Figure 9.

![Assessment of Critical Thinking Diagram](image)

Figure 9. Assessment of Critical Thinking Diagram

Based on Figure 9, it can be said that Modellus can help improve students’ critical thinking skills. Modellus is suitable to accompany the learning process physics with the advantage of being able to trace the phenomenon of physics and find a mathematical relationship in the form of graphics so that there is an increase in students’ critical thinking skills in the subjects Physics. In addition, Modellus media advantage is that students give a good response to cooperation in the group. This is in line with the research done by Neves et.al. That is by using Modellus, the cooperation of students in the group can be said both as well as the use of Modellus on the geophysical teaching is very precise in computational modelling activities. [2]

4. Conclusions
Modellus makes it easy for students to use mathematical equations on the topic of work and energy, especially the mechanical energy. Modellus also graphs the relationship of kinetic energy, potential energy and mechanical energy. The variables included in the work and energy equations are velocity ($v_0$) and angle ($i$). The results obtained are in the form of numbers displayed in the Table’s box. Calculations using Modellus and calculations through the result equation are the same, but calculations with Modellus are more accurate than manual calculations.
The results of the Modellus validity test included in the "excellent" category in terms of aspects software engineering, learning design, learning and visual strategies and critical thinking skills students obtain an average score of 65.45 in the “good” category using Modellus.

Further research is needed regarding the use of Modellus software by combining learning models to obtain better results.

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