Newton’s Cradle Experiment Using Video Tracking Analysis with Multiple Representation Approach

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Abstract. This paper reports a Physics lesson using video tracking analysis applied in Newton’s Cradle experiment to train student’s multiple representation skill. This study involved 30 science high school students from class XI. In this case, Tracker software was used to verify energy conservation law, with help from data result such as graphs and tables. Newton’s Cradle is commonly used to demonstrate the law of energy and momentum conservation. It consists of swinging spherical bobs which transfers energy from one to another by means of elastic collisions. From the video analysis, it is found that there is a difference in the velocity of the two bobs of opposite ends. Furthermore, investigation of what might cause it to happen can be done by observing and analysing the recorded video. This paper discusses students’ response and teacher’s reflection after using Tracker video analysis software in the Physics lesson. Since Tracker has the ability to provide us with multiple means of data representation way, we conclude that this method could be a good alternative solution and might also be considered better than performing a hands-on experiment activity in which not every school have suitable laboratory equipment.

1. Introduction

Physics is sometimes considered as a subject which contains problem-solving work that mainly involves remembering formulas and doing some mathematical calculation. The phenomenon has becoming more frequent in physics education, which causes physics to be considered as abstract and hard subject [1]. Physics learning activity should be complemented by a proper experiment activity, which is fundamental in building an understanding that physics concepts are highly related to and can be applied in daily life. Nevertheless, the availability of suitable and sufficient laboratory equipment in every high school is sometimes till considered a luxury, especially in order to present a good science experiment. In the case of availability of the suitable laboratory equipment, the produced experimental data means nothing without a proper processing and analysis. Thus, it is essential for high school students to have a good ability to process and analyze experimental data. Experimental data can be presented in various ways (multiple representation), such as by tables, graphs, or diagrams [2]. Student should be proficient to make a cross-representation in order to have scientific reasoning which is fundamental for solving physics problems [3] [4] and doing physics experiments. Ironically, based on case study [5], it is found that the students’ problem solving skill with multi representation approach is still low.

In this study, we use the video based learning analysis as an alternative tool for the students to practice their ability of multiple-representation skill. Advancement of technology has provided much
better ways of teaching physics, one of the case is that physical quantities can be presented interactively in dynamic format [6]. Open Source Physics (OSP) is one of computation modeling software which is suitable to be applied in high school to improve students’ exploration skill at the level of application in the learning cycle [7]. Tracker is one of video analysis and modeling software which is built by OSP Java Framework, which is designed as a proponent to fulfill various needs in physics education [8]. Previous studies have reported the use of Tracker video analysis in Physics education in order to solve various problems which are related to daily life such as pendulum [9], projectile [10], and free fall motion [11]. The results from the previous researches [10] [11] reported that, when the teacher deliver Physics lesson using Tracker video analysis and associated with particular Physics concept, the teacher received a lot of positive response from students. Tracker provides data analysis tool such as graph and table, curve fitting, etc., where we can understand, for example, the motion of a particle during an experiment.

Previous study, show us that a lot of physics experiment could be held thru video modeling. Besides, simplify experiment activity, Tracker video analysis shall be used to analyze physics law [12] such as Simple Pendulum. Those experiment utilize energy conservation law that is one of Physics concept that is frequently found in daily life. Numerous pendulum type, which often applied to the energy conservation law, however there is no study which discuss Newton’s Cradle pendulum type in the physics classroom. Newton’s Cradle is an apparatus that demonstrates the conservation of momentum and energy using a series of swinging bobs (sphere), in which energy is transferred through the stationary spherical bob and finally exerted to the last which pushes the last spherical bob to move upward. Newton’s Cradle apparatus usually consists of 5 identical spherical bobs which is made of iron ball. According to those ideas, video based learning using Tracker video analysis on the Newton’s Cradle experiment has been done to help student to understand energy conservation law.

The underlying concept which applied in the Newton’s Cradle (assuming the spheres have the same mass) is

\[ \text{Energy}_{\text{initial}} = \text{Energy}_{\text{final}} \]  \hspace{1cm} (1)

\[ \Delta EK = \Delta EK' \]  \hspace{1cm} (2)

\[ \frac{1}{2}m(v_f^2 - v_i^2) = \frac{1}{2}m'(v_f'^2 - v_i'^2) \]  \hspace{1cm} (3)

\[ \Delta v^2 = \Delta v'^2 \]  \hspace{1cm} (4)

where the velocity of the spheres (\(v\)) was measured to verify the law of conservation of energy. The law can be verified by analyzing the difference between the velocity of the initial swinging sphere (\(\Delta v\)) at the left end and the velocity of the bouncing sphere (\(\Delta v'\)) at the right end.

2. Experimental Method

This study employ video based learning method using Tracker video analysis software. This research was preliminary study which aims to observe students’ response and understanding for a certain physics subject, i.e., the energy and momentum conservation law which is applied in the Newton’s Cradle experiment apparatus. The video was recorded using Canon Exilim EX-ZR200 with optical zoom of 12.5 times, 30 frame per second high definition mode. The video was recorded with a background of white paper and lighting directly from sunlight that make the video appear to be clear and bright. Tracker 4.61 was installed to all the students’ laptop before the lesson activity.

Students are quite engaged, started form installing the Tracker software (off the school time) until tracking the motion of the Newton’s Cradle by themselves on a video that already shared. For this experiment, students are not allowed to take the video of Newton’s Cradle motion by themselves for time efficiency. The population in this study were 30 students of Class XI in one of the state high school in Bandung, Indonesia. Students are divided into 6 groups which are consists of 5 students. Each group were equipped with 2 laptops for operating Tracker. For the lesson plan, we used 45 minutes which is equal to one lesson session. The students’ worksheet consists of a guide to operate
the Tracker which is equipped with experimental questions related to table and graph analysis of video tracking. The students were given a pre-test at the beginning of the lesson using selected problems from TUG-K (Test of Understanding Graph-Kinematics) [13] which contains mostly questions related to graphs analysis. Pre-test activity was carried out in order to find out to what extend student understanding of multiple representation.

3. Result and Discussion

3.1. Pre-test result
Pre-test consist of 10 multiple choices which are adapted from TUG-K (Test of Understanding Graph Kinematics). TUG-K is considered as a representation to find out students’ basic knowledge in graph analysis. From this pre-test, the average score was 28 out of 100. This score was very low and it indicates that overall students in this class did not have adequate understanding on how to solve problems related to multiple representation analysis.

3.2. Implementation of video based learning using Tracker video analysis.

In this lesson, we use Newton cradle apparatus as shown in Figure 1 which is consist of 5 series of pendulums with spherical bobs.

![Figure 1. Newton’s Cradle experimental device (series of sphere from the right to the left)](image)

Subsequently, the motion of the swinging and bouncing sphere can be tracked. Figure 2 shows the tracking process of sphere 1 from the moment the ball was released from a certain position until it collided with the next sphere. The tracking process produce 10 traces of sphere 1 indicated with the red circle symbol. Newton’s Cradle experiment is commonly used to demonstrate the law of conservation energy, where the kinetic energy of sphere 1 is transferred during the collision with the next consecutive spheres until the transferred energy deliver a force that pushed the last sphere to bounce upward. This last sphere (sphere 5) was also tracked and indicated with blue circles.
After the tracking process, Tracker immediately provide graphical representation of the data, as well as the table that list the position vs. time. The data was presented as \( x-t \) (x position against time), \( y-t \) (y position against time), or even \( v-t \) (velocity magnitude against time) and many more variant of graph. We can adjust which graph that we want to analyze. For this experiment, we need velocity data, however, we present two other graphs as a comparison.

![Figure 2. Tracking swinging Sphere 1 and pushes the Sphere 5 upward](image)

From equation (4), we obtain the expression to prove the law of conservation energy, thus we should expect that \( \Delta v = \Delta v' \) where velocity difference indicates the instantaneous velocity of the swinging sphere (Sphere 1) and the bouncing sphere (Sphere 5). In Figure 3, the experimental data

![Figure 3. Visual display of analyse menu in the Tracker which show graph and table data of Sphere 1 and Sphere 5](image)
result $v-t$ was presented both in graph and table. Each data sequence of the table is related to the order of the sphere tracking.

Table 1 shows the summary data of Sphere 1 and Sphere 5, which are the time (s), $x$ distance (m), $y$ distance (m), and velocity (m/s). We substitute data from Table 1 to equation (4) and we obtain $\Delta v^2 = 0.0256$ m/s and $\Delta v'^2 = 0.0153$ m/s.

| Data Number | Time (s) | Distance $x$ (m) | Distance $y$ (m) | Velocity $v_1$ (m/s) | Distance $x$ (m) | Distance $y$ (m) | Velocity $v_5$ (m/s) |
|-------------|---------|-----------------|-----------------|---------------------|-----------------|-----------------|---------------------|
| 1           | 0       | 0.147           | 0.031           | -                   | 0.042           | 0.010           | -                   |
| 2           | 0.033   | 0.146           | 0.030           | 0.173               | 0.042           | 0.010           | 0                   |
| 3           | 0.067   | 0.138           | 0.023           | 0.378               | 0.042           | 0.010           | 0                   |
| 4           | 0.100   | 0.125           | 0.016           | 0.496               | 0.042           | 0.010           | 0                   |
| 5           | 0.133   | 0.108           | 0.011           | 0.363               | 0.042           | 0.010           | 0.199              |
| 6           | 0.167   | 0.102           | 0.010           | 0.092               | 0.029           | 0.012           | 0.406              |
| 7           | 0.200   | 0.102           | 0.010           | 0.013               | 0.016           | 0.017           | 0.410              |
| 8           | 0.234   | 0.102           | 0.010           | 0.013               | 0.004           | 0.023           | 0.270              |
| 9           | 0.267   | 0.102           | 0.010           | 0                   | 0.001           | 0.027           | 0.075              |
| 10          | 0.300   | 0.102           | 0.010           | 0                   | 0.001           | 0.027           | -                   |

$\Delta v^2 = 0.0256$ m/s \hspace{1cm} \Delta v'^2 = 0.0153$ m/s

From the data analysis, the magnitude $\Delta v^2$ from Sphere 1 and $\Delta v'^2$ from Sphere 5 is not equal but close. Instantaneous velocity of Sphere 1 is greater than that of Sphere 5. This is due to the device of Newton’s Cradle experiment is lack of precision. From the video we could observe that Sphere 2, 3, and 4 were not really stick together. The collisions between the spheres 2, 3, and 4 produced sound, therefore the transferred energy that reached Sphere 5 is decreasing, that is why $\Delta v'^2$ from Sphere 5 is less than $\Delta v^2$ from Sphere 1. This is what caused the swinging motion of the pendulums eventually comes to stop.

3.3. Student response and teacher reflection on using Tracker in the Physics lesson

During the lesson, students were really enthusiastic, especially because all of them were directly involved in data processing, not merely watching the process being demonstrated by the teacher. After the lesson, the students were asked about energy conservation law concept, and they admitted that they gained more understanding about the concept compared to before the lesson. They are very interested to do various kinds of Physics experiments using Tracker video analysis. At the same time, the Physics teacher admits that this method was really helpful for both the teacher and the students. This experiment activity will be arranged to be conducted in the class more often because by using Tracker video analysis, the students can still carry out experiments, even in the case of inadequate experiment equipment. The last, but not least, one of the most important thing is, with this Tracker video analysis, students are able to train their multiple representation skill, considering that the result of the experiment can be presented in various ways such as graph and table. The expected future outcome is that the students will be able to translate inter-multiple representation and to associate the representation to a contextual Physics concept.
4. Conclusion
Video based learning using Tracker video analysis is very good idea to be developed in Physics classroom. This method could be alternative solution despite of conducting hands-on experiment activity in the absence of full adequate equipment laboratory. Tracker software provides tools of multiple representation of the experiment data. The video tracking analysis using Tracker software should also be able to train the students’ multiple representation skill in the context of Physics.

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