# The Development of Laboratory-Scaled Mini Roller Coaster Media for Non-Conservative Energy Observations

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**Abstract.** Analysis accurately for observing the non-conservative forces on the object's motion can contribute to a deeper understanding of Conservative Laws. A study to design the laboratory-based media was implemented using research and development methods to produce an experimental device that can observe the changes in mechanical energy (same as non-conservative energy). The method chosen is 4D which consists of defining, designing, developing, and disseminating. In this study, the discussion is limited to the stage of developing for self-evaluation data. The results for defining are the analysing data of students needs, for the designing are the calculation of the rail track's size and shape, and for the development are the mini roller coaster device. Utilize the video-based laboratory, the media can be used for analysing the change of vertical acceleration and height with time and the changes of mechanical energy that can show the existence of the non-conservative energy.

**Keywords:** media development, mini roller coaster, non-conservative energy.

## 1 Introduction

The discussion of the energy concept of objects moving in a trajectory has always been a concern, especially when studying the dynamics of object motion. Both because of the many related concepts that we can learn based on a case of motion or the difficulty of these concepts to understand. We often encounter various physical phenomena such as motion, force, and energy changes in real life. However, not all of these concepts can be observed or imagined by students directly. For example, we must imagine the law of energy conservation concepts in an object moving abstractly.

Students' submission of physical concepts abstractly is almost a common thing done by teachers/lecturers. It is not wrong, but the problem is that not all students have the same imagination ability, so absorbing abstract information will not be the same. The result is the failure experienced by some students in understanding concepts. The bad thing that might happen is misconceptions. The solution to reducing the occurrence of conceptual errors due to the inability of students to imagine abstractly is with the help of learning media. Such as teaching aids, experimental tools, or practical tools [1].

**Learning Media**

The curriculum, lectures, and the learning and teaching process influence education's success, including learning media. Every learning activity requires strategies, methods, and learning media [2] that positively affect students. The learning media in question must convey or distribute messages from a planned source so that there is a learning environment and the recipients carry out the learning process [3]. Choosing and developing learning media proposed by Marpanaji must pay attention to whether teachers implement and develop learning media during the learning process? Do teachers choose the media according to the needs analysis? [4].

ICONSEIR 2021, December 21, Medan, Indonesia

DOI 10.4108/eai.21-12-2021.2317271

**The Non-Conservative Energy**

The law of conservation of energy in this study has limitations within the scope of physics which explains the conservation of mechanical energy. It is said that the total energy of an isolated system is constant. But in fact, non-conservative forces such as friction are difficult to ignore [5]. For example, in a marble moving on a rail, contact between the marble and the trajectory creates a frictional force. It means that a non-conservative force in the system can cause the mechanical energy to change over time.

In the work-energy theorem, the forces that change objects' kinetic energy ($E_K$) are both conservative and non-conservative forces [6]. The equation of net force acting on the object is $F_t = F_k + F_{nk}$. An example of a conservative force $F_k$ is the gravitational force, while an example of a non-conservative force $F_{nk}$ is a frictional force. Using the work-potential energy theorem $W_k = -\Delta U$, the total work done by the combined forces on an object is:

$$W_t = W_k + W_{nk} \quad (1)$$

$$= \int \boldsymbol{F}_k \cdot d\boldsymbol{s} + \int \boldsymbol{F}_{nk} \cdot d\boldsymbol{s}$$

$$= -\Delta U + W_{nk} \quad (2)$$

Based on the work-kinetic energy theorem, the total work done by conservative and non-conservative forces on the system is equal to the change in the kinetic energy of the system $W_t = \Delta E_K$, so Equation (2) can be rewritten as:

$$-\Delta U + W_{nk} = \Delta E_K$$

$$W_{nk} = \Delta E_K + \Delta U$$

$$W_{nk} = \Delta E_M \quad (3)$$

Equation (3) shows that the work done by the non-conservative force equals the change of mechanical energy [7]. When air friction is neglected, gravity is the only force acting on the object. In that condition, the work done by the non-conservative forces is zero ($W_{nk} = 0$). The change in mechanical energy can be written as:

$$0 = \Delta E_M$$

$$\Delta E_K + \Delta U = 0 \quad (4)$$

$$(E_{Kf} - E_{Ki}) + (U_f - U_i) = 0$$

$$E_{Ki} + U_i = E_{Kf} + U_f \quad (5)$$

If a system is isolated and the forces are only conservative, there is no change in mechanical energy ($\Delta E_M = 0$). It is known as the law of conservation of mechanical energy [8]. No change in the value of mechanical energy does not mean the value of mechanical energy is zero, but the mechanical energy is constant at every point.

**The Laboratory-Scaled Mini Roller Coaster**

The mini roller coaster that will be researched is a prototype designed to resemble the trajectory of a roller coaster game. A roller coaster is a train driven at a certain high speed to cross a particular rail line [9]. The roller coaster train will slide, dip, and spin very fast by utilizing mechanical energy and the force of gravity [10].

A rail is placed at a certain height supported by steel and twisted in such away. Physical phenomena observed from the roller coaster system include potential energy, kinetic energy, conservation of energy, dynamics, gravitational force, and centripetal force. The mini roller coaster device is a miniature that will be used to analyse several physical phenomena and will be operated on a physics laboratory scale.

**Video Based Laboratory: Tracker Video Analysis**

In analysing physical phenomena related to motion, not all of the quantities can be obtained or analysed easily. For example, in observing the free-fall motion of a ball, the data on the ball's position against time is difficult to obtain accurately with just a length and time measuring instruments. Device that can help precisely analyse objects' motion, is tracker video analysis software.

Tracker video analysis is used to analyse and create a two-dimensional motion modelling of the observed object [11]. The selected video tracker analysis is developed by Open Source Physics (OSP) with a Java framework [12]. The representation of the analysis and modelling of the motion is quantitative data and graphs. Its use can provide convenience for teachers and students in understanding kinematics concepts and sharpen physics problem-solving abilities [13]. Analysis of objects' minimum height and velocity on a circular path can also be done using tracker tracking analysis software [14].

Anissofira et al. [15] analysed position versus time on the motion of a roller coaster on one of the rides using tracker software. A deeper analysis of the roller coaster motion experiment was also carried out by Putra et al. [14], but the roller coaster observed was a simple roller coaster designed by himself. The position data against the roller coaster time analysed by the tracker software is processed using the law of conservation of energy and Newton's laws of motion to determine the minimum height and speed of the roller coaster object when it passes through a track. The use of tracker software in other experiments has also been used to analyse Newton's pendulum swing motion [15], rotational motion of fidget spinner toys [16], and parabolic motion analysis [12].

## 2 Research Methods

This study uses research and development methods to observe the non-conservative energy from the non-conservative forces acting on an object moving in a trajectory. A laboratory-scale device was developed with a 4D model consisting of four main stages to achieve the research objectives: define, design, develop, and disseminate [17]. This study limits the development stage to self-evaluation activities to obtain a non-conservative energy analysis of the created media.

**Define**

The definition stage in laboratory-scale learning media development is carried out to determine and define the needs during the process. The instruments in the form of checklists, interviews, and questionnaires were prepared to obtain curriculum data analysis, learning objectives, and analysis of student needs. The results from the definition stage are used as a reference in media design.

**Design**

The designing stage aims to produce a precise rail track design before the media is assembled according to the tools and materials used. The mini roller coaster track will be composed of three-track pieces: a polynomial track, a linear track, and a clothoid track. Each track form is arranged in an integrated manner to form a track resembling a roller coaster ride.

**Develop**

The development stage to self-evaluation activities is carried out so that researchers can self-assess the devices that have been made and test the suitability of the learning media with the applicable media development rules. The resulting device is also tested for its ability to analyse the non-conservative energy due to the non-conservative forces acting on objects moving in a roller-coaster trajectory by observing using a video tracker analysis.

## 3 Result and Discussion

This section presents the research results, which develops a mini roller coaster device that can be used to analyse the law of conservation of energy with tracker video analysis for introductory physics lectures. It discusses the results of each stage of development attained to obtain media products and non-conservative data analyses.

**Analysing Data of Students Needs**

The analysis was carried out by reviewing the curriculum documents of the Physics Education Department so that the media developed was following the curriculum needs. The document being studied is the Plan of Learning of Basic Physics I course. Interviews were also conducted with the lecturers of the course. The results of the analysis data are given in Table 1.

**Table 1**. Curriculum analysis results

| Analysed Aspect | Description |
|---|---|
| Learning Outcome (LO) | The sub-CLOs in The Lesson Plan of Basic Physics: "The students are able to identify the concept and application of work and energy comprehensively"<br>The LO for KU1: apply logical, critical, systematic, and innovative thinking in the context of the development or implementation of science and technology that pays attention to and applies humanities values that are appropriate in the field of physics.<br>The LO for PA1: mastering the theoretical concepts of classical and modern physics in general. |
| The uses of Learning Media in Laboratory Experiment for LO | In achieving the LO assigned on sub-CLOs, the material is taught through a virtual laboratory with online simulations by lecture and practical methods. |

Based on the LO assigned to sub-CLOs, our findings from this analysis are the student learning achievement must be supported by contextual learning methods. The simulation is good in helping students' understanding. They can verify concepts but cannot practice analytical skills. In addition, students are less able to explore more varied cases related to the phenomenon of the law of conservation of energy, if only from online simulations.

We analysed the questionnaire through seven questions to obtain data on student needs, as shown in Table 2.

**Table 2.** Student needs analysis result

| Question | Description |
|---|---|
| Have you studied the law of conservation of energy? | 100% of students answered yes. They have studied it in the Basic Physics course I |
| Is the law of conservation of energy easy to understand? | 92% of students answered it easy. However, this ease of understanding must be supported by appropriate learning methods. |
| Have you conducted an experiments on the law of conservation of energy? | 100% of students answered yes. They conduct an experiment using online simulations. |

| | |
|---|---|
| Do you understand the concept of the law of conservation of energy through these activities? | 96% of students answered yes. Taking data through online simulations is easy to understand because students only observe the results without processing the data. However, in terms of scientific skills, it has many lacks. |
| Is an experiment on the law of conservation of energy in a laboratory still needed? | 88% of students answered yes. An experiment in a laboratory is still needed to complete the limitations of online simulation. |
| Is an experiment can confirm the students' understanding of the concept of work and energy? | 100% of students answered yes. |
| What experimental media do you expect to use in learning? | Students answer the expected experimental media is a laboratory-based device that is assisted by technological advances. |

The needs analysis become our reference at the design and development stage to develop media with the following criteria: (1) able to provide contextual learning experiences to students, (2) has a flexible design (trajectory can be modified as needed), and (3) integrating technological advances for the data analysis during experiments.

**The Rail Track's Design**

The rail tracks are designed with precise calculations related to the width, height, and length of the track and the shape of the trajectory. The details of the design consist of three paths: the first is a polynomial path, the second is a linear path, and the third is a clothoid path.
Objects that move in a trajectory are not operated by machines, but utilize the force and potential of the earth's gravity. An object that is initially at rest must have maximum potential energy ($E_P$) at point A, maximum kinetic energy ($E_K$) at point B, and addition of $E_P$ and $E_K$ (equal to mechanical energy ($E_M$)) at point C, as shown in Figure 1.
The equation of the first path of trajectory is expressed as:

$$f(x) = ax^2 + bx + c \; f(x) = ax^2 + bx + c \qquad (6)$$

where $y = f(x)$. In Figure 1. it can be explained that $x_A = 0$ as the starting point, $y_A = max$, $y_B = min$, dan $y_C \leq \frac{3}{4} y_A$. The value of $y_C \neq y_A$ so the object has $E_P$ and $E_K$ simultaneously and moves to the second path of trajectory.

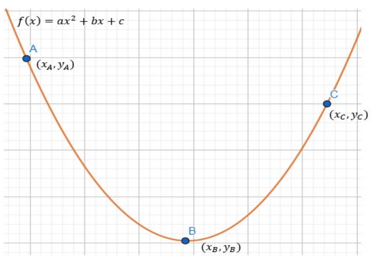


**Fig 1.** The 1st trajectory path

The shape of the second trajectory is a graph of a linear function. The $E_M$ of the object at position $C$, as shown in Figure 2, is the sum of $E_P$ and $E_K$. This trajectory is designed to accelerate the object so that the object has a maximum speed at $D$.

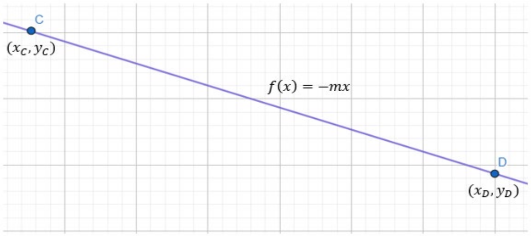


**Fig 2.** The 2nd trajectory path

The shape of the third trajectory path is clothoid. The trajectory has the advantage that its radius of curvature gradually decreases from the bottom, as shown in Figure 3. With the clothoid shaped trajectory, it allows objects to use less energy to travel a loop [10].

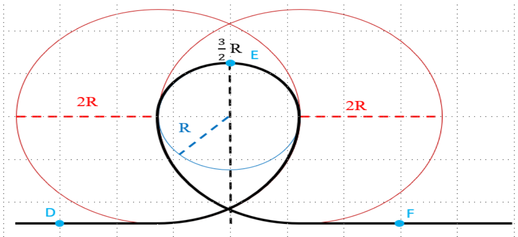


**Fig 3.** The 3rd trajectory path

After the trajectory is designed, the mini roller coaster device is assembled and produced. The media has a dimensions of 120 x 40 x 20 cm, as shown in Figure 4.

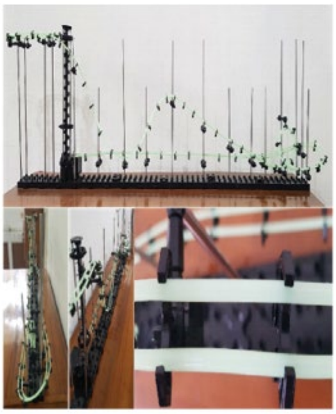

**Fig 4.** Laboratory-scaled mini roller coaster media

### Analysing The Non-Conservative Energy from Mini Roller Coaster Device

With video-tracking analysis, data retrieval was carried out with five repetitions. The data are interpreted to graph the function $y$ to $t$ and the function $a_y$ to $t$, which shows the change in the height of the object and the change in the vertical velocity of the object each time, respectively. In Figure 5, it can be seen that there is a change in the acceleration of the object every time at each position of the object's motion.

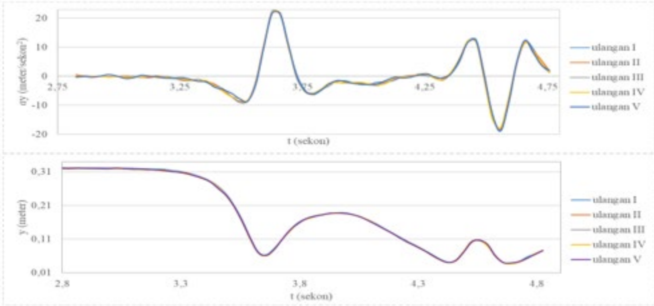


**Figure 5.** Elevation and accelerometer data for the mini roller coaster

There is always a non-conservative force on the object, which causes the $E_M$ to be not constant along the path. The total work done by all conservative and non-conservative forces on the system is equal to $E_K$, mathematically explained in equation (1). From equation (2), we know that the work done by the non-conservative force is equal to $\Delta E_M$. Energy change data for each position on the developed media can be seen in Table 3.

Although observing the existence of this non-conservative force is not easy, with the help of a mini roller coaster with video tracker analysis, we can calculate it and interpret the data from Table 3 into the graph of Figure 6.

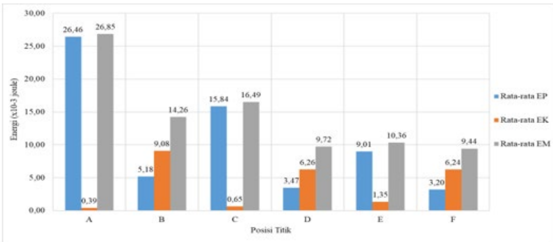


**Fig 6.** $E_P$, $E_K$, and $E_M$ of the objects at each analysis point

**Table 3.** Change of mechanic energy in different position

| Posi-tion | Height (m) | Potential Energy (joule) | | | | | $E_P$ Average (joule) | Kinetic Energy (joule) | | | | | $E_K$ Average (joule) | $E_M$ (joule) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Data 1 | Data 2 | Data 3 | Data 4 | Data 5 | | Data 1 | Data 2 | Data 3 | Data 4 | Data 5 | | |
| A | 0,310 | 0,0266 | 0,0265 | 0,0266 | 0,0264 | 0,0263 | 0,0265 | 0,0004 | 0,0004 | 0,0004 | 0,0004 | 0,0004 | 0,0004 | 0,0269 |
| B | 0,064 | 0,0053 | 0,0052 | 0,0051 | 0,0051 | 0,0052 | 0,0052 | 0,0091 | 0,0091 | 0,0089 | 0,0091 | 0,0092 | 0,0091 | 0,0143 |
| C | 0,191 | 0,0159 | 0,0158 | 0,0159 | 0,0158 | 0,0158 | 0,0158 | 0,0006 | 0,0006 | 0,0007 | 0,0007 | 0,0006 | 0,0007 | 0,0165 |
| D | 0,046 | 0,0035 | 0,0034 | 0,0035 | 0,0034 | 0,0035 | 0,0035 | 0,0063 | 0,0061 | 0,0063 | 0,0062 | 0,0064 | 0,0063 | 0,0097 |
| E | 0,127 | 0,0091 | 0,0091 | 0,0089 | 0,0090 | 0,0090 | 0,0090 | 0,0012 | 0,0014 | 0,0014 | 0,0014 | 0,0013 | 0,0013 | 0,0104 |
| F | 0,046 | 0,0033 | 0,0031 | 0,0031 | 0,0031 | 0,0033 | 0,0032 | 0,0062 | 0,0061 | 0,0061 | 0,0064 | 0,0064 | 0,0062 | 0,0094 |

We can observe that the $E_M$ of an object varies with each position. It shows that there is work in the form of non-conservative energy acting on objects moving along the mini roller-coaster trajectory.

## 4 Conclusion

The findings of this study have shown that the development of a laboratory-scaled mini roller coaster media for observing the non-conservative energy with video tracker analysis can be attained through the stages of define, design, and development to the self-evaluation activities. The media can be utilised to analyse the change of vertical acceleration and height with time and the changes of mechanical energy that show the non-conservative energy existences.

**Acknowledgement**
The authors wish to thank the head of the Basic Physics Laboratory of University of Siliwangi for the support and encouragement to this research. This project was supported by the fund DIPA Ministry of Research, Technology and Higher Education, University of Siliwangi, Number SP DIPA-023.17.2.77504, 23 November 2020.

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