Digital oscillation rails: developing physics learning media to determine the acceleration value of earth's gravity

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Abstract. This research aims to develop a feasible learning media for high school physics learning on mathematical swing material, especially in determining the value of Earth's gravitational acceleration. The learning media developed is a visual aid in the form of digital oscillation rails. This is a research and development research using the ADDIE model (analysis, design, development, implementation, and evaluation). The results of validation, teacher responses, and trials to students indicate that the developed digital oscillation rails are in the highly feasible category. Digital oscillation rails made of two oscillations tracks. The average values of gravitational acceleration obtained based on three experiments are 9.05 m/s² for a track with 25 cm radius and 9.97 m/s² for a track with 15 cm radius.

Keywords: teaching aids, mathematical swings, physics learning media, digital oscillation rails

1. Introduction

One of the problems that should be paid attention in learning is the students’ low learning achievement [1], which causes low learning motivation [2]. One way to motivate and improve students’ learning outcomes is by learning using instructional media, such as teaching aids [3–5]. Teaching aids are the media in learning [6–8]. The learning material will be assisted by the existence of teaching aids [9]. Teaching aids enable students to gain meaningful experiences because they can play an active role in learning [6, 10]. Thus, the learning process becomes more effective, active, and qualified [11, 12, 2, 10].

In the modern era, science and technology have been developed rapidly especially in Indonesia [13, 14]. To compensate, improving the quality of physics learning becomes a challenge in the world of education [15]. A good education can contribute to the advancement of a nation [16-18]. Increasing the quality of education is not only seen in school institutions, such as learning facilities and infrastructure [19], but also the better and more qualified students [20, 21].

Based on observations made at some high schools in South Ogan Komering Ulu Regency, South Sumatra, the use of physics learning media at the schools was not optimal, for example in mathematical swing material. In the first school, the teacher did not use learning media such as teaching aids for
mathematical swings material even though in this material the students were taught to determine the Earth's gravitational acceleration. Because of the inadequate laboratory facilities, physics learning was still teacher-centered. Teachers only relied on textbooks. Teachers still used conventional methods so that students were having difficulty in learning the subject matter provided by the teacher [22]. The same condition also occurred in the second school. Physics learning was still teacher-centered even though the school already had an adequate laboratory. This affected the students' learning motivation [23]. Students became less enthusiastic in learning physics [24], and considered physics lessons to be boring because there were no variations in learning. Ultimately, it affected the students' learning outcomes. Different conditions were found in the third and fourth schools. In learning the mathematical swing, the teacher used teaching aids, namely a simple pendulum. A simple pendulum consists of several different weights and masses hung on a static using a rope. Then the students were asked to determine the deviations and count the number of vibrations. The duration was measured using a stopwatch while the deviation was measured manually using a protractor. Meanwhile, the number of vibrations and periods were also calculated manually. The data obtained were then analyzed to find the value of Earth's gravitational acceleration.

The results of interviews with teachers and some students showed that the calculation of the value of gravitational acceleration using a simple pendulum has several weaknesses. Errors in determining the size of the deviation, time, and length of the rope are likely to occur because the quantities are calculated manually. Furthermore, environmental conditions such as strong wind can affect the calculation of the vibration. This certainly should not be allowed to happen because it can have an impact on the value of the gravitational acceleration.

There have been several studies carried out in developing teaching aids for mathematical swing material, more precisely the teaching aids to calculate the acceleration of Earth's gravity. First, the development of marble oscillation rails [25]. This tool can be used to determine the acceleration of Earth's gravity. However, this tool still has some shortcomings; namely, the path used is made of wire which is too large in diameter. This causes friction between the wire and large marbles causing the oscillation of marbles to be slightly lower. The next is the development of a digital oscillation detector [26]. This tool also has disadvantages. Even though it is equipped with a digital system, this tool still uses a swing similar to a simple pendulum. As mentioned before, the pendulum swing movements will be influenced by wind factors. Based on the explanation, the digital oscillation rails were developed. Digital oscillation rails were made to produce digital data displayed on the LCD screen to minimize errors in determining the gravity value of the earth. It is hoped with this tool, determining the value of the acceleration of earth's gravity could be easier, the students become more motivated to learn, and they can explain the concept of mathematical swing well.

2. Research Methodology
This research is Research and Development. The development model used is the ADDIE model (analysis, design, development, implementation, and evaluation) [27]. Developing media using the ADDIE model is an activity using effective tools [28]. The stages of the development of the digital oscillation rails are presented in Figure 1.
Figure 1 The Developmental Stages of the Digital Oscillation Rail Using the ADDIE Model [29-31].

Data collection instruments used were non-test instruments in the form of validation sheets, questionnaire for the teacher, and questionnaire for students. The Likert scale was used on a scale of 1 to 5 (5 is the highest score while 1 is the lowest score). A Likert scale is used in measuring attitudes, opinions, and perceptions of a person or group about social events or phenomena [32]. The data obtained were then analyzed to determine the product’s feasibility. The feasibility percentage was obtained using the following equation [33, 34]:

\[ P = \frac{\sum x}{\sum_i} \times 100\% \]

(1)

Description:
P : Percentage
\( \sum x \) : Number of respondents' answers in one item
\( \sum_i \) : The ideal score

The criteria used can be seen in Table 1:

| Intervals     | Criteria           |
|---------------|--------------------|
| 0% - 20%      | Poorly Feasible    |
| 21% - 40%     | Not Feasible       |
| 41% - 60%     | Fairly Feasible    |
| 61% - 80%     | Feasible           |
| 81% - 100%    | Highly Feasible    |

Furthermore, the value of gravitational acceleration was obtained using the energy translational relationship. See Figure 2.
For example, in initial marbles’ position is A and the balanced position is B. The energy loss by motion with the linear velocity of the ball of A and B is $mgh$ where $h$ is the height of OD. The energy that turns into kinetic energy with the energy equation is as follows:

$$mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$$

$$= \frac{1}{2}v^2 \left( m + \frac{1}{a^2} \right)$$

Where $\omega = \frac{v}{a}$ and $I = \frac{2}{5}ma^2$

$$mgh = \frac{1}{2} \cdot \frac{7}{5}mv^2$$

The pendulum swing period with the acceleration equation is $Vp^2 = 2gh$ is $Tp^2 = 2\pi^2 \frac{R-a}{g}$. The oscillation period for the motion of marbles is $T = 2\pi \sqrt{\frac{7(R-a)}{5g}}$, so that:

$$g = \frac{2\pi^2(R-a)}{5T^2}$$

Note:
- $m$ : Mass
- $g$ : Acceleration due to gravity (m/s²).
- $T$ : Period of vibration (s)
- $\pi$ : 3.14
- $h$ : Altitude (m)
- $\omega$ : Angular velocity ($\text{rad/s}$)
- $I$ : Inertia (kgm²)

3. Results and Discussion

Results of the analysis conducted at several high schools in South Ogan Komering Regency Ulu, South Sumatra is the need for a learning media for physics learning, especially for mathematical swings material in the form of tools that can be used to help students understand the material. To adjust to the demands of the curriculum, the tools should be used to assist students in determining the value of the acceleration of earth's gravity. Considering deficiencies in similar tools that have been developed before, digital oscillation rails were.

After the analysis, the next step is the design. At this stage, the product development started in the form of props. The specification of the teaching aid developed was in the form of digital oscillation rails. The tools and materials needed to be electrical wires, sound sensors, solder, acrylic, power supply, relays, Arduino nano, burners, lamps, boxes, lamp holders, sockets, switch on/off, plywood, wood glue, steel marbles, tin, stopwatch, semi-circular ruler (180°), and wood used as a frame.
The rails were made of a pair of acrylic curved in a half circle which functions as oscillation trajectories. As a comparison, two tracks were made with radii of 15 cm and 25 cm. As the weight load, steel marbles with a small mass were selected so it can be ignored in calculations. The marbles oscillated on the acrylic trajectory. The material used helped to reduce friction. The rails were then attached to the frame made of wood. The trajectories fashioned like this can overcome the wind resistance that might occur when oscillating. The angles of the track can show the size of the deviation. Furthermore, electronic components were arranged together to form LCD components for the digital oscillation rails. The details of each digital oscillation rails component are presented in Figure 3.

![Figure 3](image_url)

**Figure 3** (a) Parts of the Digital Oscillation Rails, (b) LCD Components, (c) Sensors, and (d) Steel Marble

Furthermore, Table 2 presents the functions of each component of the digital oscillation rails.

| No | Components                      | Functions                                                                 |
|----|---------------------------------|---------------------------------------------------------------------------|
| 1  | Upper Sensor                    | Detecting oscillation of marbles on a track with a radius of 15 cm        |
| 2  | Upper Junction with Angles      | Showing the size of the deviation used during experiments on a path with a radius of 15 cm |
The steps to determine the value of the acceleration of earth's gravity using digital oscillation rails are: 1) prepare the tools and materials, 2) release the marbles on the digital oscillation rail with a deviation of no more than $15^\circ$, 3) let it make 5 times the vibration (oscillation), 4) check the time and period displayed on the LCD, 5) take note of the observations, and 6) use equation (2) to determine the value of gravitational acceleration. Perform this activity on both rails. The results obtained are presented in Table 3.

| Experiments | Tracks with radii of 25 cm | Tracks with radii of 15 cm |
|-------------|----------------------------|--------------------------|
|             | Period (T) | Gravitational Acceleration (g) | Period (T) | Gravitational Acceleration (g) |
| First       | 1.2 s    | 9.20 m/s$^2$         | 0.89 s    | 9.76 m/s$^2$         |
| Second      | 1.23 s   | 8.76 m/s$^2$         | 0.89 s    | 9.76 m/s$^2$         |
| Third       | 1.2 s    | 9.20 m/s$^2$         | 0.86 s    | 10.40 m/s$^2$        |
| Average     | 1.21 s   | 9.05 m/s$^2$         | 0.88 s    | 9.97 m/s$^2$         |

The digital oscillation rails were validated by the experts. The validation was done twice. After the first validation process, the product was revised according to the advice and suggestions so that it meets the product feasibility criteria. Next, the product was validated one more time. The final validation results of the material expert are presented in Figure 4 while the results of validation from the media expert are presented in Figure 5.
Figure 4 and Figure 5 show that the average percentage of the validation results by the learning material and learning media experts are 89% and 83%, respectively. These results indicate that the digital oscillation rails developed are in the highly feasible category.

Digital oscillation rails were also tested in learning activities by high school physics teachers. The teacher's responses to the developed digital oscillation rails are presented in Figure 6.

Figure 6 shows that the average percentage of teacher’s responses is 86%. That is, the developed oscillation rails are in the highly feasible category.

Furthermore, trials for students consisted of small-group trial and field trial. The number of respondents for the small-group trial was 40 students while the field trial was 115 students. Students come from four high schools in South Ogan Komering Ulu Regency, South Sumatra. The trial results are presented in Figure 7 and Figure 8.
Figure 7 and Figure 8 show that the averages percentages of small-group trial and field trials are respectively 86% and 87%. These results indicate that the digital oscillation rails are in the highly feasible category.

From all the data that has been collected, it can be concluded that the digital oscillation rails are feasible to be used in physics learning, especially in determining the value of Earth's gravitational acceleration. The use of sensors can facilitate the use of props because it integrates technological advances. The digital oscillation rails use a digital system so that the time measurement will be automatic with the LDR sensor that has been programmed so that a more accurate time can be obtained and the data will appear on the LCD screen [5].

Table 3 shows that digital oscillation rails can be used to determine the value of Earth's gravitational acceleration. These results support the results obtained in previous studies [37-41]. Thus, the media developed were concrete. Concrete visual aids are used in visualizing in three dimensions, namely facts, concepts, principles, or procedures [42]. Developed teaching aids can also motivate students in learning physics so that students' learning achievement could be increased. This result is in line with several previous studies [43, 44]. Teaching aids also support in exploring the students’ potential to be independent students [45].

The developed digital oscillation rails have several disadvantages, namely: 1) the digital oscillation rails only have three features (number of vibrations, time, and period) and 2) the sensor used still uses an infrared sensor so that when operated at a bright place it can disrupt the system. Thus, it is suggested for the next researchers, namely: 1) adding features digitally to make it easier to find the value of the gravitational acceleration and 2) the sensor used should be ultrasonic. This sensor generates ultrasonic waves through an object called piezoelectricity, this tool in general emitting ultrasonic sound waves towards a target that reflects waves towards the sensor [46, 47].

4. Conclusion
Learning media is a supporting component that can affect the quality of physics learning. Along with the development of technology, teachers are expected to be creative in creating high-quality physics learning. Digital oscillation rails are just one of the many types of physics learning media that can be developed. It is the teacher's job as an educator to fulfill that task. This research produces digital oscillation rails that are suitable to be used in learning physics in schools. Digital oscillation rails are made using two tracks for oscillations. The average values of gravitational acceleration obtained based on three experiments are $9.05 \text{ m/s}^2$ for a track with 25 cm radius and $9.97 \text{ m/s}^2$ for a track with 15 cm radius.

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