# Developing A Simple Parabolic Motion Props: Steps and Their Applicability

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**Abstract**

Physics props are a vital component in helping students understand the various concept of physics. Unfortunately, not all schools—especially rural ones—have access to these props, as they are usually expensive and come with a not-easy-to-understand manual book. This study aims to build parabolic motion props using simple, cheap, and easy-to-find materials. Teachers and students can "shoot" any small objects with these props, take necessary data, analyze them analytically and experimentally using Tracker software, and prove the parabolic motion they usually only find on chalkboards. Several tests were carried out to test the applicability of these props and show that they can be used to demonstrate the parabolic motion of small objects and determine their initial velocities with errors of 1.41%, 1.35%, and 4.2% for ejection angle of 30°, 45°, and 60°, respectively. The test results were also validated by comparing them to the gravity acceleration constant, resulting in errors ranging from 3.40 – 4.83%. These results concluded that teachers could build the same props in their classrooms to enhance students' participation and understanding in learning parabolic motion.

**Keywords:** Physics props; Tracker software; Parabolic motion.

## Introduction

Learning physics is a process that cannot be separated from physics as a product, process, and attitude (Istiyono, 2020). According to Wijaya R, Damris, & Kamid (R. C. Wijaya et al., 2014), Physics learning is seen as conceiving many abstract concepts and theories, so it needs learning media to make the learning process runs effectively and efficiently. Physics teaching aids are essential in the learning process because they make students better understand physics concepts and stick to them longer (Khairul Husna, 2022; Nuvitalia et al., 2016). However, unfortunately, some schools have limited facilities, infrastructure, and funding to implement physics learning using teaching aids (Kurniawan & Ngazizah, 2017; Rahayu et al., 2020). One solution teachers and schools can pursue to overcome this problem is to make their teaching aids using cheap and easy-to-find materials, simple to manufacture but effective in representing Physics topics.

One of the physics topics that is still considered difficult is parabolic motion. Several studies have found that students have difficulty interpreting images, graphics, and vectors (Adhi et al., 2017; Saepuzaman & Karim, 2016). Therefore, several types of learning media have been developed to help improve the understanding of concepts in parabolic motion topics. Wijaya R, et al. (P. A. Wijaya et al., 2018; R. C. Wijaya et al., 2014) developed a media projectile launcher that can be used to determine the farthest range and initial velocity of the bullet. The teaching

aids were tested in class and resulted in an error value of 27.1% - 50.4%, a considerable number that can be regarded as less accurate. Another study by Adhi S et al. (Adhi et al. 2017) ha developed an android-based learning media to increase students' comprehension of parabolic motion concepts. However, to use this, students must have an Android smartphone with sufficient memory to install the application. In addition, Sudjito Debora (Sudjito, 2019) used the help of PhET Projectile Motion simulation for the same purpose as previous studies. The drawback is that students could not experience the experiment process directly because the experiment is done virtually on a computer. Lastly, Salam (Salam et al., 2019) developed a projectile launcher for parabolic motion props but did not explain the props in detail, so they could not be imitated and modified by teachers who needed them.

This study aims to build parabolic motion props that are simple and easy to make with cheap materials. The tools and materials and the manufacturing process are presented in detail so anyone can duplicate them. With this teaching aid, students can carry out actual tests hands-on without needing an Android smartphone or computer. Several tests were carried out to test the ability of these props. To ensure the data accuracy, the tests' process was recorded with a video and then analyzed using the Tracker software (*Tracker Video Analysis and Modeling Tool for Physics Education*, n.d.). The analysis results are compared with the theory, which we hypothesized to be smaller than the previous study by Wijaya R et al. (P. A. Wijaya et al., 2018; R. C. Wijaya et al., 2014). We hope these props can effectively represent the parabolic motion topic while increasing students' motivation (Indah, 2014) in studying the topic in particular and Physics in general.

**Methods**

This research is divided into two major parts: the manufacture of teaching aids and their testing. Each part will be explained in detail so anyone can imitate and modify it according to their specific needs.

1. The Props Development

To demonstrate parabolic motion, we need an object that can throw objects from a certain angle. The props must also be easily duplicated by teachers and students, regardless of their economic background and access to specific commodities. Therefore, we designed the props using tools and materials that were inexpensive and easy to find. This design can be seen in Figure 1.

The thrower used in this study is a lead suction that can throw small objects up to 2 cm in diameter. The lead sucker is attached to a wooden support for precise ejection. Vertical wood is given parallel holes with a specific height distance so that the initial height of the object can be varied by positioning the thrower in a particular hole position and then fastening it with a butterfly nut which also functions as a shaft. The wood can move freely when the butterfly nut is loosened and locks in one position when the butterfly nut is tightened.
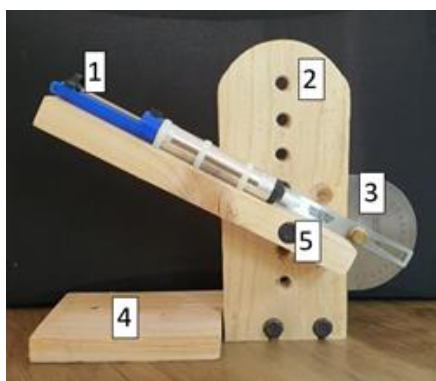
Description:
1. Thrower (lead suction)
2. Vertical wood with holes
3. Protractor
4. Supporting wood
5. Butterfly nut as shaft

Figure 1. Props Design

With this design, the initial angle of the object can also be varied by rotating the thrower to a certain angle measured precisely with a protractor. To maintain the balance of the props, additional support wood is attached to the vertical wood at the base.

The tools needed to make these props include a saw, drill, and glue gun, while the materials needed are shown in Table 1.

Table 1. *List of Materials*

| Items | Amount |
|---|---|
| Dutch Teak Wood | 1 piece |
| Lead suction | 1 piece |
| Protractor | 1 piece |
| Cable ties | 3 pieces |
| Measuring tape | 1 piece |
| Butterfly nuts | 3 pieces |

To build the props, two pieces of wood are cut with a size of 25 x 10 cm, then joined with pieces of supporting wood and vertical wood with butterfly nuts. After that, another piece of wood measuring 30 x 5 cm is cut to the size of the lead sucker so it can be attached to the wood with a glue gun and cable ties.

The next step is to punch holes in the vertical wood the size of a butterfly nut. Each hole is separated by 2.5 cm for easy measurement. Finally, the protractor can be positioned according to the thrower's position to determine the object's ejection angle. The distance traveled by the object is measured with a measuring tape during the data collection.

The tricky part in building the props is ensuring all components are steady. Thus, the props are easily transported from one place or person to another without shifting the components' position. Therefore, accurate measurement is needed, especially in making holes—its size must be the exact size of the butterfly nuts. It can be achieved through trial and error or by seeking the help of the nearest carpenter.

2. Testing The Props

After building the props, several tests were carried out to ensure that the props could function properly. The data to be taken from these tests are the time and distance traveled by objects with variations in mass and initial ejection angle. Time data was taken manually (with a stopwatch) and confirmed further with another tool, i.e., Tracker. Tracker video tools and analysis has been used

extensively in many classroom activities, especially in Physics. Several studies, such as (Aguilar-Marín et al., 2018; Asrizal et al., 2018; Susilawati et al., 2020), used Tracker in their research with satisfactory results. In this study, all tests were recorded using a mobile phone camera; then, the video was analyzed with the Tracker.

To retrieve the data, the props must be placed on a plain and contrasting background relative to the color of the object being thrown. It is necessary to recognize the object each time so that the video analysis process can be carried out automatically. The cell phone is positioned from the side of the props so the entire object's motion can be seen in the video.

The test uses three objects: marbles, plasticine, and stone. To perform the test, the object to be thrown is inserted into the lead suction. Then, the lead suction glued with wooden supports is positioned on the props at a certain height and angle. Once ready, the test can be done by pressing the eject button and the recorder button on the cellphone. The object will be thrown upwards and slowly decelerate due to the pull of gravity so that the path becomes parabolic.

After the object lands back on the floor, the distance between the thrower and the object's falling point is measured using a measuring tape. Each test was repeated three times to ensure data reliability.

The data obtained is then analyzed theoretically to find the object's initial velocity. In theory, the initial speed $v_0$ can be obtained by the equation:

$$v_o = \frac{x}{t \cos \theta}$$
(1)

Where $x$ is the maximum horizontal distance traveled by the object, $t$ is the travel time, and $\theta$ is the ejection angle of the object. Meanwhile, the maximum vertical distance, $y$, is given by:

$$y = v_o \sin \theta - \frac{1}{2} g t^2$$
(2)

where $g$ is the gravity acceleration. Since the parabolic motion occurs relatively short, we cannot get the $y$ data when performing the tests. Therefore, we used Tracker to determine this by analyzing the tests' videos.

To do this, we must install Tracker—which can be downloaded for free at https://physlets.org/tracker/, then analyze the videos by the following steps:
a. Open a test video in Tracker,
b. Set the frame by selecting clip settings,
c. Perform calibration by selecting a calibration stick (a step to compare known-size objects that can be used as a reference),
d. Set the x and y axes,
e. Determine the point mass of the object to be analyzed,
f. Analyze the motion of objects by pressing CTRL+SHIFT simultaneously on the object, then selecting the auto track command. If the analysis is done manually, press the CTRL+SHIFT click keys simultaneously, follow the object's movement, and click on the object at each time.

The tracker will release the test data in charts and tables. Then, the charts shown by the Tracker can be analyzed further by:
a. Selecting the chart type of $(t, x)$ and $(t, y)$,
b. Copying the data of $(t, x, y)$ to Microsoft Excel,
c. Creating charts of $(t, x)$ and $(t, y)$ in Excel,

d. Making chart equations. For the chart of $(t, x)$, it was done by right-clicking on any chart plot point, clicking add trendline, format trendline, and selecting linear. Check in Display Equation and R-squared boxes,

e. Chart equation of $(t, y)$ can be done in the same way as (d) but chose the trendline format as a second order polynomial.

The chart equations resulting from the above steps refer to the line equation $(t, x)$ as follows:

$$x = mt + c \tag{3}$$

where $m$ is the gradient of the chart equation $(t, x)$ so that the initial velocity is determined by:

$$v_o = \frac{m}{\cos \theta} \tag{4}$$

Meanwhile, the $(t, y)$ equations are in the forms of:

$$y = at^2 + bt + c \tag{5}$$

By comparing it with Eq. (2), we can see that:

$$a = -\frac{1}{2} g \tag{6}$$

Thus, we can determine gravity acceleration

$$g = -2a \tag{7}$$

as also been done by (Afifah et al., n.d.).

The props capability to demonstrate parabolic motion was determined by comparing theoretical initial velocity values in Eq. (1) with the results of the tests' analysis in Eq. (4), and comparing results of gravity acceleration Eq. (7) with literature. Because each test was carried out three times, an error analysis was also performed by calculating the average value of the distance traveled $\bar{x}$, uncertainty $\Delta x$ and its relative uncertainty by using Eqs. (8) – (10) below (Omda & Sergent, 2021).

$$\bar{x} = \frac{x_1 + x_2 + x_3}{N} = \frac{\sum x_i}{N} \tag{8}$$

$$\Delta x = \frac{1}{N} \sqrt{\frac{N \sum x_i^2 - (\sum x_i)^2}{N - 1}} \tag{9}$$

$$\text{relative uncertainty} = \frac{\Delta x}{x} \times 100\% \tag{10}$$

where $N$ is the amount of data.

**Results And Discussion (70%)**

In this research, a parabolic motion prop from simple tools and materials has been developed with the manufacturing steps presented in the previous section. The resulting props can be seen in Figure 2. Furthermore, several tests have been carried out to test the effectiveness of these props, with the test settings and the camera captures as shown in Figure 3.
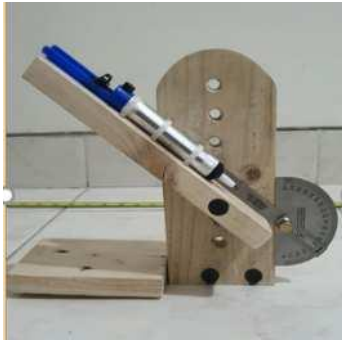
Figure 2. The developed props



Figure 3. Display on the cellphone camera and test settings of the props

The results of testing the developed tool show that this tool is capable of throwing objects at varying angles from 0° to 75°. If this tool is used with an elevation angle greater than 75°, what will happen is that the object being ejected moves in the opposite direction, resulting in an inaccurate measurement. Meanwhile, if the elevation angle is made less than 0° or a negative angle, the object to be ejected will fall because the ejection trajectory is in the shape of a half cylinder and there is no support at the end of the ejected object. In addition, the protractor, which functions to adjust the elevation angle, has better accuracy than an ordinary protractor. This is because the protractor is equipped with a lock and ruler to help set the angle unchanged and more precisely. With a protractor, experiments with accurate results can be carried out by varying the angle at every 5° increment. In addition, the butterfly nut which functions as a shaft can be adjusted to lock strength so that the ejection support does not move and change position during the experiment.

The test was carried out using marbles (mass = 5.43 grams), plasticine (mass = 10.26 grams), and stone (mass = 10.64 grams). Each object is launched from three ejection angles, namely 30°, 45°, and 60°. Although these props allow objects to be launched from any angle of elevation between 0° and 75°, these three particular angle values were deliberately chosen so students could easily determine the cosine value.

**Manual Initial Velocity Determination**

To calculate the initial velocity value based on the theory, the data taken directly from the test is the horizontal distance traveled $x$ and travel time $t$. The results of data collection for each test and their tabulation using Eqs. (1) and (8) - (9) are shown in Tables 2 – 4 below.

Table 2. *Tests' results on marbles*

| Trials Number | θ = 30° | | | θ = 45° | | | θ = 60° | | |
|---|---|---|---|---|---|---|---|---|---|
| | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ |
| 1 | 2.00 | 0.60 | 3.85 | 1.85 | 0.84 | 3.11 | 1.20 | 0.76 | 3.14 |
| 2 | 2.02 | 0.62 | 3.76 | 1.86 | 0.84 | 3.13 | 1.21 | 0.78 | 3.20 |
| 3 | 2.00 | 0.61 | 3.79 | 1.83 | 0.82 | 3.16 | 1.18 | 0.76 | 3.13 |
| Average | $\bar{x} = 1.99$ | $\bar{t} = 0.61$ | $\bar{v}_0 = 3.80$ | $\bar{x} = 1.78$ | $\bar{t} = 0.73$ | $\bar{v}_0 = 3.13$ | $\bar{x} = 1.20$ | $\bar{t} = 0.77$ | $\bar{v}_0 = 3.16$ |
| Relative uncertainty | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.03$ | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.01$ | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.02$ |

Table 3. *Tests' results on plasticine*

| Trials Number | Ejection angle | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | $\theta = 30°$ | | | $\theta = 45°$ | | | $\theta = 60°$ | | |
| | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ |
| 1 | 2.00 | 0.61 | 3.79 | 1.78 | 0.73 | 3.45 | 1.20 | 0.76 | 3.16 |
| 2 | 1.98 | 0.60 | 3.81 | 1.76 | 0.72 | 3.46 | 1.21 | 0.78 | 3.10 |
| 3 | 2.00 | 0.62 | 3.72 | 1.78 | 0.74 | 3.40 | 1.18 | 0.76 | 3.10 |
| Average | $\bar{x} = 1.99$ | $\bar{t} = 0.61$ | $\bar{v}_0 = 3.77$ | $\bar{x} = 1.78$ | $\bar{t} = 0.73$ | $\bar{v}_0 = 3.44$ | $\bar{x} = 1.20$ | $\bar{t} = 0.77$ | $\bar{v}_0 = 3.12$ |
| Relative uncertainty | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.03$ | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.02$ | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.02$ |

Table 4. *Tests' results on stone*

| Trials Number | Ejection angle | | | | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| | $\theta = 30°$ | | | $\theta = 45°$ | | | $\theta = 60°$ | | |
| | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ | $x\ (m)$ | $t\ (s)$ | $v_0\ \left(\frac{m}{s}\right)$ |
| 1 | 1.99 | 0.60 | 3.83 | 1.88 | 0.69 | 3.85 | 1.40 | 0.79 | 3.54 |
| 2 | 2.00 | 0.62 | 3.72 | 1.86 | 0.68 | 3.87 | 1.38 | 0.78 | 3.54 |
| 3 | 1.97 | 0.60 | 3.79 | 1.89 | 0.70 | 3.82 | 1.41 | 0.76 | 3.71 |
| Average | $\bar{x} = 1.99$ | $\bar{t} = 0.61$ | $\bar{v}_0 = 3.78$ | $\bar{x} = 1.88$ | $\bar{t} = 0.68$ | $\bar{v}_0 = 3.85$ | $\bar{x} = 1.40$ | $\bar{t} = 0.78$ | $\bar{v}_0 = 3.60$ |
| Relative uncertainty | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.03$ | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.01$ | $\Delta x = 0.01$ | $\Delta t = 0.01$ | $\Delta v_0 = 0.06$ |

When an object is thrown from a certain angle, it will move straight up and slowly change its trajectory due to the pull of gravity. The difference in the ejection angle of the throw will affect the maximum height reached by the object before the object descends. Objects with a greater ejection angle will achieve higher vertical mileage, shorter horizontal mileage, and longer time to return to the floor. The tests' results show the same phenomenon, as seen in Tables (2) – (4).

The table above also shows no significant difference in the horizontal distance traveled and the average travel time of the three objects for the same ejection angle, even though the masses of the three objects are different. According to Newton's Second Law, with the same force provided by the lead sucker, an object with a heavier mass will move with a smaller (slower) acceleration. However, since the acceleration due to gravity on each surface is the same, heavier objects also receive less gravitational force because $g = \frac{F_g}{m}$. Thus, the mass effects of the two forces acting on this parabolic motion will cancel each other out.

Repeated experiments which were carried out three times showed that the horizontal distance ($x$) and time ($t$) data had a relative uncertainty of 0.01. This means that this tool is precise because it gives a relatively small difference in results. While the results of the initial velocity calculation ($v_0$) have the greatest relative uncertainty of 0.06. It means that teachers or students can redo multiple experiments with the props and get approximately the same results.

**Tracker Analysis Results**

After analyzing the data based on theory, tests analysis were conducted with the Tracker. Figure 4 shows the results of data analysis on marbles with an ejection angle of 45°.
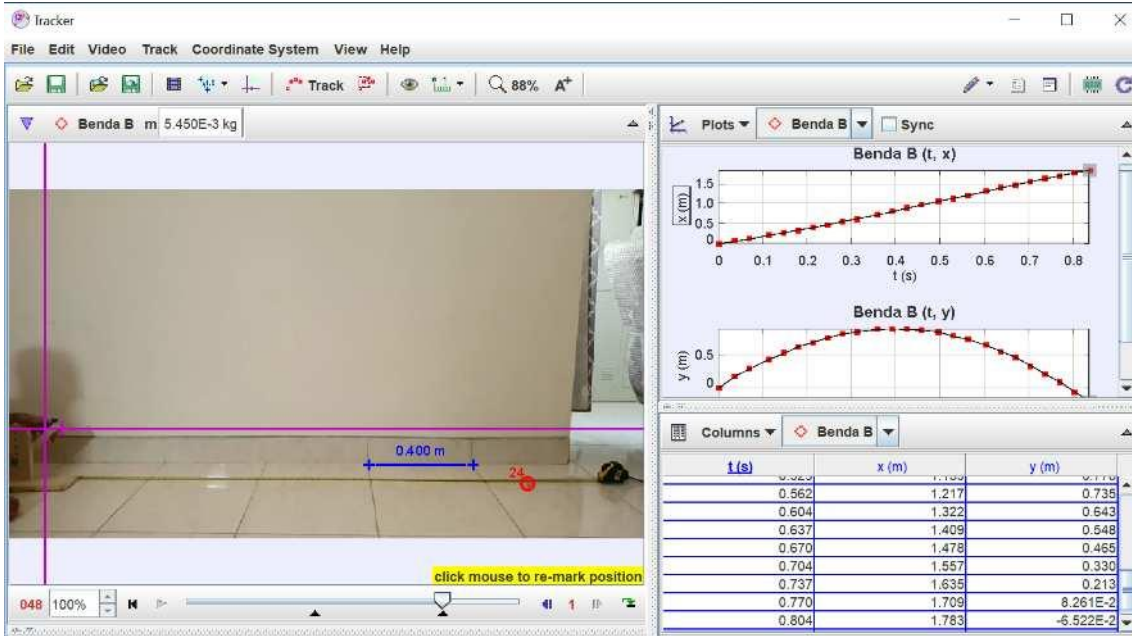
Figure 4. Example of analysis process with Tracker

The left part of Figure 4 shows a video of the test is analyzed, length calibration (blue line), and object position with a tracking number of 24 (red circle). The upper right is the horizontal (x) and vertical (y) trajectory graphs, while the bottom is the tracking data. These data were copied to Microsoft Excel to obtain the chart equation. The results are shown in Figures 5 and 6.
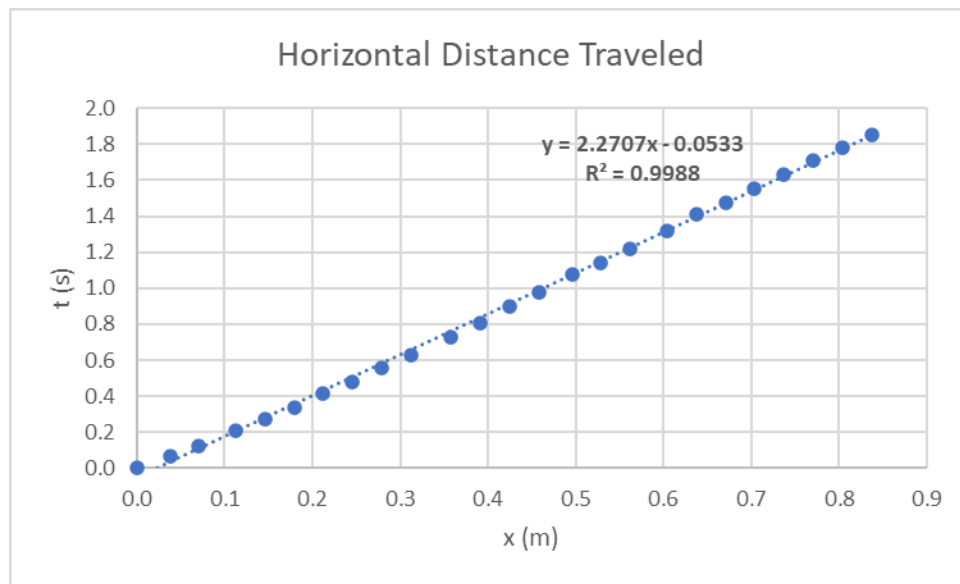


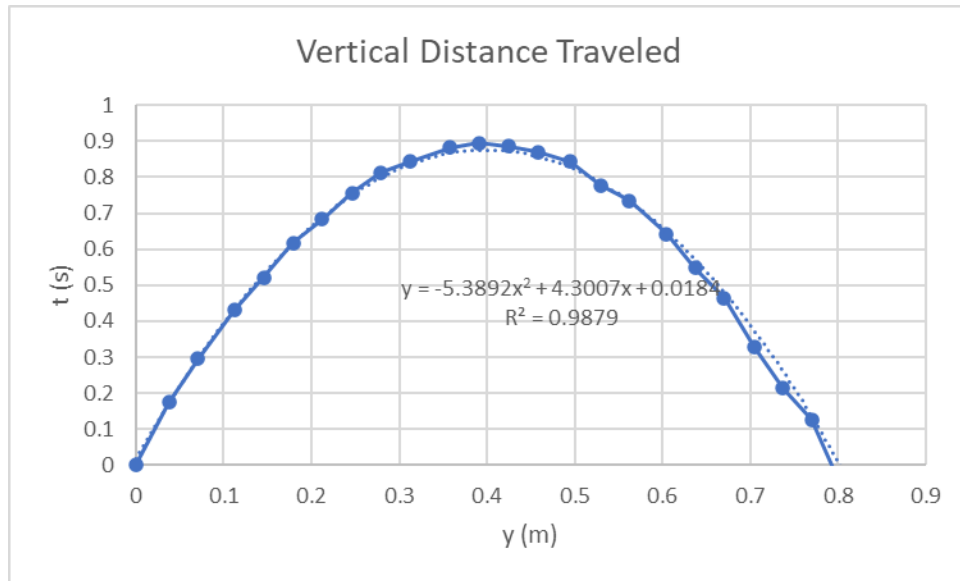Figure 5. Tracker Data Processing in Excel for Graphs$(t, x)$

Figure 5. Tracker Data Processing in Excel for Graphs $(t, y)$

In parabolic motion, the velocity in the horizontal direction is used to find the initial velocity because its value is always constant—not affected by the vertical force of gravity. Thus, we use charts $(t, x)$ to find the initial velocity. Meanwhile, the gravity force only affected the vertical movements, thus, we use charts $(t, y)$ to determine the gravity acceleration. Both determinations are described in the subsections below.

**Initial Velocity Determination by Tracker**
The results of data analysis from the Tracker using Eqs. (3), (8) – (9) are shown in Table 5 – 7.

Table 5. *Analysis results of initial velocity data on marbles*

| | Ejection angle | | | | | |
|---|---|---|---|---|---|---|
| | $\theta = 30°$ | | $\theta = 45°$ | | $\theta = 60°$ | |
| Trials Number | $(t, x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ | $(t, x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ | $(t, x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ |
| 1 | y = 3.213x + 0.0825 | 3.71 | y = 2.2707x − 0.0530 | 3.21 | y = 1.546x − 0.0255 | 3.09 |
| 2 | y = 3.278x + 0.0475 | 3.78 | y = 2.2579x − 0.0674 | 3.19 | y = 1.602x − 0.0325 | 3.20 |
| 3 | y = 3.152x + 0.0204 | 3.64 | y = 2.2672x − 0.0306 | 3.21 | y = 1.566x − 0.0550 | 3.13 |
| Average | | $\bar{v}_0 = 3.71$ | | $\bar{v}_0 = 3.20$ | | $\bar{v}_0 = 3.14$ |
| Relative uncertainty | | $\Delta v_0 = 0.04$ | | $\Delta v_0 = 0.01$ | | $\Delta v_0 = 0.03$ |

Table 6. *Analysis results of initial velocity data on plasticine*

| | Ejection angle | | | | | |
|---|---|---|---|---|---|---|
| | $\theta = 30°$ | | $\theta = 45°$ | | $\theta = 60°$ | |
| Trials Number | $(t, x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ | $(t, x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ | $(t, x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ |
| 1 | y = 3.3617x − 0.0175 | 3.88 | y = 2.4678x + 0.0161 | 3.49 | y = 1.6005x + 0.0113 | 3.20 |
| 2 | y = 3.2396x − 0.0549 | 3.74 | y = 2.3577x − 0.1025 | 3.33 | y = 1.5918x − 0.0134 | 3.18 |
| 3 | y = 3.2130x + 0.0825 | 3.71 | y = 2.4705x − 0.0246 | 3.49 | y = 1.6150x − 0.0262 | 3.23 |
| Average | | $\bar{v}_0 = 3.78$ | | $\bar{v}_0 = 3.44$ | | $\bar{v}_0 = 3.20$ |
| Relative uncertainty | | $\Delta v_0 = 0.05$ | | $\Delta v_0 = 0.05$ | | $\Delta v_0 = 0.01$ |

Table 7. *Analysis results of initial velocity data on stone*

| | Ejection angle | | | | | |
|---|---|---|---|---|---|---|
| | $\theta = 30°$ | | $\theta = 45°$ | | $\theta = 60°$ | |
| Trials Number | $(t,x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ | $(t,x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ | $(t,x)$ chart equation | $v_0 \left(\frac{m}{s}\right)$ |
| 1 | y = 3.1656x + 0.0218 | 3.66 | y = 2.587x + 0.0049 | 3.66 | y = 1.6753x + 0.0299 | 3.35 |
| 2 | y = 3.2810x + 0.0325 | 3.79 | y = 2.787x + 0.0050 | 3.94 | y = 1.6280x − 0.0246 | 3.26 |
| 3 | y = 3.2252x − 0.0162 | 3.72 | y = 2.652x − 0.0024 | 3.75 | y = 1.5890x − 0.0270 | 3.18 |
| Average | | $\bar{v}_0 = 3.72$ | | $\bar{v}_0 = 3.78$ | | $\bar{v}_0 = 3.26$ |
| Relative uncertainty | | $\Delta v_0 = 0.04$ | | $\Delta v_0 = 0.08$ | | $\Delta v_0 = 0.05$ |

Tables (5) – (7) show that the initial velocity value tends to be the same as the theoretical calculation results, that the greater the ejection angle of the object, the smaller its $\bar{v}_0$. An anomaly occurs in the case of rocks, where the 45° ejection angle produces a higher initial velocity than the 60°. This may occur because the determination of the initial velocity with the Tracker relies heavily on the obtained chart equation, which is a linear approximation with the $R^2$ values not precisely equal to 1. In addition, the results of the Tracker analysis also produce greater uncertainty than the theoretical calculation, with the greatest uncertainty value of 0.08.

To compare the results of the theoretical calculations and the Tracker analysis quantitatively, the error calculation for each test case is carried out using Eq. (10). The results of this calculation can be seen in Table 8.

Table 8. *Comparison of the initial velocity values of tests' results and Tracker analysis*

| Ejection angle ($\theta$) | object | Initial velocity ($v_0$) manually | Initial velocity ($v_0$) of Tracker analysis | Error | Average of error |
|---|---|---|---|---|---|
| 30° | Marbles | 3.80 | 3.71 | 2.37% | |
| | plasticine | 3.77 | 3.78 | 0.26% | 1.41% |
| | Stone | 3.78 | 3.72 | 1.59% | |
| 45° | Marbles | 3.13 | 3.20 | 2.24% | |
| | plasticine | 3.44 | 3.44 | 0.00% | 1.35% |
| | Stone | 3.85 | 3.78 | 1.81% | |
| 60° | Marbles | 3.16 | 3.14 | 0.63% | |
| | plasticine | 3.12 | 3.20 | 2.56% | 4.20% |
| | Stone | 3.60 | 3.26 | 9.40% | |

The comparison of the initial velocity values obtained from the theoretical results and the Tracker analysis shows that the results of both calculations tend to be the same, with an error range between 1.35 - 4.2%. This proves that the developed props can be used to find the initial velocity value in parabolic motion by the theory of physics and the concepts supporting it. Even if the teachers or students have difficulty and/or cannot use the Tracker, the determination of initial velocity can still be done by taking data of the horizontal mileage and travel time, then calculating it using Eq. (1). It produces reliable data, with two to ten times smaller errors than the props developed by Wijaya R, et al., (Wijaya et al., 2014), as we expected.

**The Gravity Acceleration**

The initial velocity results prove that the props perform nicely and give consistent results. However, we must compare the results' validity with exact theoretical values. Here, the Tracker analysis results of $(t,y)$ charts are analyzed to determine the gravity acceleration value and then compared with the gravity

constants provided by (Giancoli, 2005). Tables 9 – 11 are the analysis results of marbles, plasticine, and stone, respectively, while Table 12 shows their comparison with theory.

Table 9. *Analysis results of gravity data on marbles*

| | Ejection angle | | | | | |
|---|---|---|---|---|---|---|
| | $\theta = 30°$ | | $\theta = 45°$ | | $\theta = 60°$ | |
| Trials Number | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ |
| 1 | y = -5.1407x$^2$ + 2.7573x + 0.0619 | 10.28 | y = -5.3892x$^2$ + 4.3007x + 0.018 | 10.78 | y = -4.8775x$^2$ + 4.2781x + 0.0303 | 9.76 |
| 2 | y = -5.2013x$^2$ + 2.9596x - 0.0249 | 10.40 | y = -5.2151x$^2$ + 4.3603x - 0.0443 | 10.43 | y = -4.9815x$^2$ + 4.0436x - 0.0492 | 9.96 |
| 3 | y = -5.0157x$^2$ + 2.8919x + 0.0062 | 10.03 | y = -5.3201x$^2$ + 4.4683x - 0.0234 | 10.64 | y = -5.0027x$^2$ + 4.2423x + 0.0268 | 10.01 |
| Average | $\bar{g} = 10.24$ | | $\bar{g} = 10.62$ | | $\bar{g} = 9.91$ | |
| Relative uncertainty | $\Delta g = 0.11$ | | $\Delta g = 0.10$ | | $\Delta g = 0.08$ | |

Table 10. *Analysis results of gravity data on plasticine*

| | Ejection angle | | | | | |
|---|---|---|---|---|---|---|
| | $\theta = 30°$ | | $\theta = 45°$ | | $\theta = 60°$ | |
| Trials Number | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ |
| 1 | y = -5.3243x$^2$ + 2.8978x + 0.0131 | 10.64 | y = -4.7957x$^2$ + 3.4239x + 0.0002 | 9.59 | y = -5.0307x$^2$ + 4.1325x + 0.0287 | 10.06 |
| 2 | y = -5.2013x$^2$ + 2.9596x - 0.0249 | 10.40 | y = -4.7198x$^2$ + 3.626x - 0.0979 | 9.44 | y = -5.0272x$^2$ + 4.0303x + 0.0661 | 10.05 |
| 3 | y = -5.1407x$^2$ + 2.7573x + 0.0619 | 10.28 | y = -5.049x$^2$ + 3.6294x - 0.0352 | 10.10 | y = -5.1772x$^2$ + 4.2407x + 0.0168 | 10.35 |
| Average | $\bar{g} = 10.44$ | | $\bar{g} = 9.71$ | | $\bar{g} = 10.15$ | |
| Relative uncertainty | $\Delta g = 0.11$ | | $\Delta g = 0.20$ | | $\Delta g = 0.10$ | |

Table 11. *Analysis results of gravity data on stone*

| | Ejection angle | | | | | |
|---|---|---|---|---|---|---|
| | $\theta = 30°$ | | $\theta = 45°$ | | $\theta = 60°$ | |
| Trials Number | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ | $(t, y)$ chart equation | $g\left(\dfrac{m}{s^2}\right)$ |
| 1 | y = -5.0125x$^2$ + 2.7864x + 0.0304 | 10.03 | y = -4.932x$^2$ + 3.1265x + 0.024 | 9.86 | y = -5.4189x$^2$ + 4.1068x + 0.0736 | 10.84 |
| 2 | y = -5.1123x$^2$ + 2.8563x − 0.0124 | 10.22 | y = -4.959x$^2$ + 3.1177x + 0.017 | 9.92 | y = -5.4028x$^2$ + 4.2024x + 0.0526 | 10.81 |
| 3 | y = -5.0906x$^2$ + 2.7625x + 0.0146 | 10.18 | y = -4.945x$^2$ + 3.0188x + 0.045 | 9.89 | y = -5.2266x$^2$ + 4.0628x + 0.0318 | 10.45 |
| Average | $\bar{g} = 10.14$ | | $\bar{g} = 9.89$ | | $\bar{g} = 10.70$ | |
| Relative uncertainty | $\Delta g = 0.06$ | | $\Delta g = 0.02$ | | $\Delta g = 0.13$ | |

Table 12. *Gravity comparison*

| Ejection angle $(\theta)$ | Object | Acceleration due to gravity $\left(\dfrac{m}{s^2}\right)$ theoretically | Acceleration due to gravity $\left(\dfrac{m}{s^2}\right)$ experiment | Error | Average of error |
|---|---|---|---|---|---|
| 30° | Marbles | | 10.24 | 4.49% | 4.83% |
| | Plasticine | | 10.44 | 6.53% | |
| | Stone | | 10.14 | 3.47% | |
| 45° | Marbles | | 10.62 | 8.37% | 3.40% |
| | Plasticine | 9.80 | 9.71 | 0.92% | |
| | Stone | | 9.89 | 0.92% | |
| 60° | Marbles | | 9.91 | 1.12% | 4.62% |
| | Plasticine | | 10.15 | 3.57% | |
| | Stone | | 10.70 | 9.18% | |

The above Tables show that the props resulted in overestimated gravity acceleration values, ranging from $9.71 - 10.62 \ m/s^2$. The small relative uncertainty values indicate that the tests carried out by these props are highly reproducible—although its highest value of 0.13 is higher than that of the initial velocity data. As expected, the results are independent of the object's mass; thus, we see similar results for all object types. It is exciting to see that the $45°$ ejection angle produces the smallest average of error for both initial velocity and gravity acceleration results. Other studies by (Yulkifli et al., 2018) and (Hariyono et al., 2020) give better accuracy of gravity acceleration value, but those studies use sensor and electronic-strong-dependencies in their measurement tools. Thus, for simple and easy-to-make props, the results given by the developed props are pretty satisfactory.

## Conclusion

This research has succeeded in making a parabolic motion prop with tools and materials that are cheap and easy to obtain. These props are designed to throw objects from various angles between $0°$ to $75°$ with a more accurate angle measuring tool using protractors, initial heights, and various objects with mass with a maximum diameter of 2 cm. To verify the ability of the developed props, a series of repeated tests with the initial mass and angle of the object has been carried out. Test data was processed manually and compared with the tests' video analysis results using Tracker. This tool can be used to determine the initial velocity and acceleration due to gravity. The initial velocity obtained from manual experiments on marbles, plasticine, and stone with angles of 30°, 45°, and 60° respectively are (3.80 ± 0.03) m/s, (3.13 ± 0.01) m/s, (3.16 ± 0.02) m/s; (3.77 ± 0.03) m/s, (3.44 ± 0.02) m/s, (3.12 ± 0.02) m/s; (3.78 ± 0.03) m/s, (3.85 ± 0.01) m/s, (3.60 ± 0.06) m/s. While the initial velocity of the tracker analysis results obtained for marbles, plasticine, and stone with angles of 30°, 45°, and 60° respectively are: (3.71 ± 0.04) m/s, (3.20 ± 0.01) m/s, (3.14 ± 0.03) m/s; (3.78 ± 0.05) m/s, (3.44 ± 0.05) m/s, (3.20 ± 0.01) m/s; (3.72 ± 0.04) m/s, (3.78 ± 0.08) m/s, (3.26 ± 0.05) m/s.

The magnitudes of the acceleration due to gravity on marbles, plasticine, and stone at angles of 30°, 45°, and 60° are (10.24 ± 0.11) ms$^{-2}$, (10.62 ± 0.10) ms$^{-2}$, (9.91 ± 0.08) ms$^{-2}$; (10.44 ± 0.11) ms$^{-2}$, (9.71 ± 0.20) ms$^{-2}$, (10.15 ± 0.10) ms$^{-2}$; (10.14 ± 0.06) ms$^{-2}$, (9.89 ± 0.02) ms$^{-2}$, (10.70 ± 0.13) ms$^{-2}$. The analysis results show that this teaching aid test resulted in consistent data from several data collections, with uncertainties ranging from 0.01 to 0.13. The comparison of initial velocity and gravity acceleration values between theoretical data and analysis with Tracker gives a relatively small error, with the most significant error being 4.20% and 4.83% for initial velocity and gravity acceleration, respectively. Those errors are nine times smaller than in the previous study. Thus, it can be concluded that, although made with simple and uncomplicated designs, tools, and materials, these teaching aids can assist students and teachers in accurately explaining the concept of parabolic motion.

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