KONSTAN
JURNAL FISIKA DAN PENDIDIKAN FISIKA
Volume 10, Number 1, June 2025
E-ISSN : 2460-9129 dan P-ISSN : 2460-9110
http://jurnalkonstan.ac.id/index.php/jurnal

Effect of Elevation Angle on Range, Maximum Height, and Travel Time in Parabolic Motion: A PhET Simulation Approach

Yanto[1], Azmar[2,*)], Adam Malik[3]

[1,3)] Physics education study programme, State Islamic University Sunan Gunung Djati Bandung, Jl. A.H. Nasution No. 105A, Cibiru, Bandung, West Java, Indonesia

[2)] Faculty of Teacher Training, University of Balikpapan Jl.Pupuk Raya Gn. Bahagia Balikpapan

*E-mail korespondensi: azmat@uniba-bpn.ac.id

Article Info:

Sent:
December 25, 2023

Revision:
July 21, 2025

Accepted:
July 21, 2025

Keywords:

Elevation angle, Parabolic motion, PhET simulation, Physics learning, Virtual laboratory

Abstract

A virtual laboratory is one of the innovative solutions in physics learning, especially to overcome the limitations of space, time, and conventional practical tools. This study aims to analyse the effect of elevation angle on the characteristics of parabolic motion, namely the highest point, farthest range, and maximum travel time. The research method used is a simulation-based quantitative experiment using the PhET Projectile Motion platform. The simulation was conducted with a fixed initial velocity of 10 m/s at three elevation angle variations: 30°, 45°, and 60°, with each angle tested 15 times. Results show that the elevation angle significantly affects all observed variables. The maximum height was reached at an angle of 60°, the furthest horizontal reach was obtained at an angle of 45°, and the longest time to peak occurred at an angle of 60°. However, the relationship between elevation angle and parabolic motion outcomes was not linear. These findings strengthen the theoretical understanding of bullet motion and show that virtual simulation can be a valid and effective alternative medium for the exploration of physics concepts. The integration of virtual laboratories such as PhET into the learning process is recommended to improve the quality of students' understanding of two-dimensional motion phenomena.

INTRODUCTION

Science is one of the branches of science that focuses on various aquatic phenomena that occur. One of the main categories is called Physics. Physics is a basic science; that is, a science that is fundamental and has many contributions to other sciences, such as chemistry, biology, cosmology, and geology [1]. Physics is a branch of knowledge or science that has the same nature as science itself. Science can be seen as a collection of knowledge, as a method of observation, and as a method of elimination [2]. In particular, physics can learn about the properties of matter and the phenomena it contains through experimentation, mathematical analysis, and observation. In addition, the study of physics teaches us about energy, gravity, force, temperature, electricity, magnetism, and other concepts that help us understand how to work in the open air [3]. Science skills are needed in physics.

According to [19], science process skills refer to the skills needed to understand, extend, and apply legal concepts, principles, laws, and theories. These include mental, physical (manual), and social skills [20]. Physics is the study of physical phenomena in the surrounding environment. Physical science requires observation and investigation to identify aquatic anomalies emerging from sedimentary rocks [8].

Physics is a branch of science that studies natural phenomena and interactions. One of the current components of physical science that requires careful consideration and timely development of certain concepts is static fluids (liquids) [5]. Scientific research requires a laboratory, which is why it is called a laboratory. A laboratory is a special room equipped with tools and materials used to conduct experiments, practices, or research in fields related to science, such as biology, chemistry, and physical science, among others. The ability of laboratories to support scientific research and teaching by providing facilities for data analysis, observation, and experimentation is essential [14].

Laboratories are places of practical practice, research, and analysis of scientific topics that can bridge theory and practice. Laboratories are divided into two categories: real labs and virtual labs. When there are virtual labs, they tend to be rarely used in practical lab exercises [14]. Since virtual labs can be done anywhere by using software technology, they are more convenient and practical. This technology is based on interactive multimedia computer technology and can be used as a virtual laboratory. It supports audio, text, graphics, video, animation, and hypertext formats. The effectiveness of PhET virtual labs as a teaching tool has been demonstrated in several studies, showing that it can create a stimulating environment.

Virtual media are attractive multimedia objects consisting of several formats such as text, hypertext, images, graphics, video, and animation [16]. One of the virtual laboratory applications is called Physics Education Technology (PhET) simulation. According to [17], PhET is a website that provides free simulations of science, biology, chemistry, and maths lessons. It is provided by the University of Colorado for classroom teaching purposes or can be used for individual learning purposes [15].

PhET virtual labs used in science classes can help students become more proficient in representation, making it easier for them to understand concepts and solve problems [12]. The implementation of PhET can reduce the incidence of delays in work, which can cause problems with practice tools [11]. (Through the PhET virtual lab, students can independently conduct explorations and develop a mathematical understanding of experimental results slowly and silently using interactive simulations. Utilising this application to enhance learning activities can result in a more engaging learning experience [13].

Utilising PhET Virtual Lab organizes practice that is not bound by time and freedom in choosing a place, which can increase the absorption of material much higher than in class, and can be applied in real life [9]. The interactive and visually stimulating features in PhET Virtual Lab can lead to more effective learning, improving students' understanding of physical principles [13]. In the PhET simulation, practicums exist ranging from biology, chemistry, physics, and other fields. One of the materials in physics is a parabolic graph.

Parabola-based motion is motion that is based on a parabola. A parabola is a two-dimensional motion that represents two quantities, namely the horizontal sum (x) and the vertical sum (y), on a given curve drawn sideways and then drawn back to the origin in a straight line. Earth's gravity and air resistance affect parabolic motion. The coefficient of determination of a parabola has a downward vertical velocity of magnitude = 9.8 m/s2. The horizontal and vertical components of this motion are very weak. One type of graph based on a parabola is a parabolic graph. A parabolic graph is a two-dimensional graph that combines two quantities, horizontal (x sum) and vertical (y sum) [2].

Parabolic Trajectory refers to the trajectory caused by a parabolic graph. A rope that is given an initial velocity and is useful for following a parabolic path determined by the gravitational force that affects the point. For example, a bullet extracted from a rifle, a rocket after the raw material is broken, and an object extracted from an aeroplane. Stars experience a straight, regular motion when viewed against the x-axis (vertical), and threads will experience a straight, regularly changing motion when viewed from the y-axis (horizontal). Parabolic motion is the limit in the presence of initial velocity and the influence of gravitational force, which will form a two-dimensional motion [6]. Parabolic motion, also known as bullet motion, is a curve in which the motion is given an initial acceleration and then rises to the point where the tangential gravitational field of the curve is affected (linatasan is a parabola). The components of the parabola are the height of the object and the distance of the object [3].

The purpose of this study is to determine how changes in the elevation angle will affect the highest point reached by the object, the farthest distance of the object from the launcher, and the time taken by the object to reach the highest point.

RESEARCH METHOD

This research method is an experimental method, where experimentation is a type of study that looks for relationships between dependent and independent variables, where the dependent variable is analysed and interpreted. Research, also known as experimentation, is the process of conducting experiments to understand any anomalies or changes that arise as a result of certain events. This research discusses the practicum of parabolic motion that uses the PHET simulation to generate data. In this practicum, it can be done easily.

The following tools and materials are needed:

1. A set of computers or PCs
2. Virtual laboratory software (https//phet.colouredo.edu/sims/html/projectile-motion/lates/projectile-motionen-html)

After knowing the tools and materials used, here are some rare steps that can be done:

1. Open the PhET Simulation Virtual Laboratory on the desktop PC.
2. Select the Projectile Motion simulation.
3. Arrange the experiment sketch as follows.

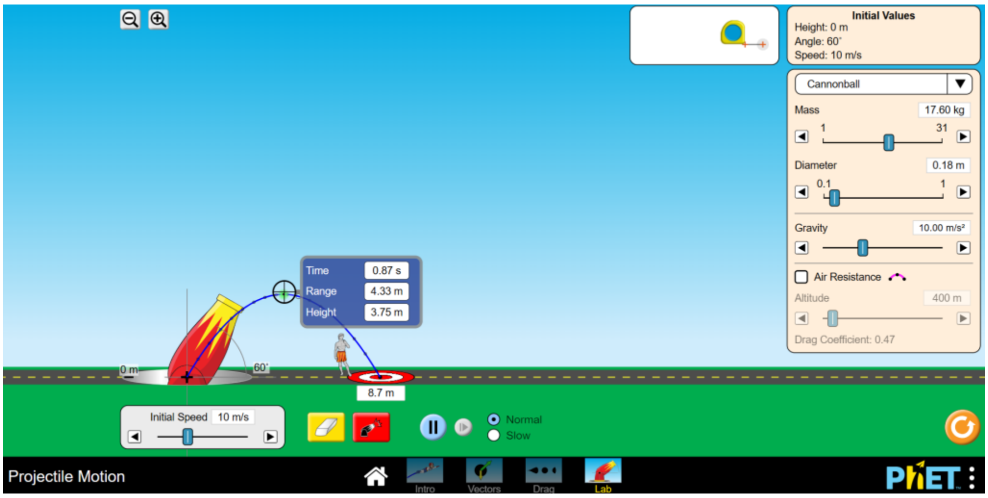

Figure 1. Phet Simulation

4. Set the elevation angle used on the cannon.
5. Set the acceleration used on the cannon.
6. Click the red cannon button to throw the ball from the cannon.
7. Observe the parabolic motion that occurs.
8. Record the time taken, the highest point, and the furthest distance travelled by the ball.
9. Experiment 15 times with a fixed speed of different elevation angles and different speeds of fixed elevation angles.
10. Repeat Rare 6 to 8 with fixed speed and different elevation angles.
11. Record the results of the experiment (in Microsoft Word).

After the research steps are carried out, the data obtained will be processed using data processing and calculations.

The following is the calculation formula:

- To find the highest point

$$\Delta Y_{max} = \left|\frac{\partial Y_{max}}{\partial Vo}\right| \Delta\ vo + \left|\frac{\partial Y_{max}}{\partial \theta}\right| \Delta\ \theta + \left|\frac{\partial Y_{max}}{\partial g}\right| \Delta\ g$$

$$= \left|\frac{VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin\ 2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005 \qquad (1)$$

To find the furthest reach

$$\Delta x_{max} = \left|\frac{\partial x_{max}}{\partial Vo}\right| \Delta \text{ vo} + \left|\frac{\partial x_{max}}{\partial \theta}\right| \Delta \theta + \left|\frac{\partial x_{max}}{\partial g}\right| \Delta \text{ g}$$

$$= \left|\frac{2VO \sin^2 \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\, 2\cos 2\,\theta}{g}\right| 0.5 + \left|\frac{v_0{}^2 \sin^2 \theta}{2g}\right| 0.005 \qquad (2)$$

To find the highest point time

$$\Delta tx = \left|\frac{\partial\, tx}{2Vo}\right| \Delta \text{ vo} + \left|\frac{\partial\, tx}{\partial \theta}\right| \Delta \theta + \left|\frac{\partial\, tx}{\partial g}\right| \Delta \text{ g}$$

$$= \left|\frac{2 \sin\theta}{g}\right| 0.5 + \left|\frac{2vocos\,\theta}{g}\right| 0.5 + \left|\frac{-2\, v_0 \sin\,\theta}{2g}\right| 0.005 \qquad (3)$$

RESULTS AND DISCUSSION

This study uses the PhET Projectile Motion simulation to analyse the effect of elevation angle on parabolic motion characteristics. The experiment was conducted with a fixed initial velocity of 10 m/s and three elevation angle variations: 30°, 45°, and 60°. The three main parameters measured were maximum height, furthest range, and travelling time to the highest point.

Experiment 1

In the first experiment, 15 trials were conducted with an elevation angle of 30°, velocity = 10 m/s, gravitational velocity = 10 m/s^2, mass = 17.60 kg, diameter = 0.18 m to determine the furthest reach the object could travel, the maximum height of the object and the time taken by the object to the highest point. The following data is obtained after doing the lab work.

Table 1. Effect of the elevation angle of 30° on the farthest reach, maximum height, and time

Experiment 1	Initial velocity (m/s)	Angle (°)	Peak point time (s)	Maximum distance (m)	Maximum height (m)
1	10 m/s	30°	0,5 s	8,7 m	1,25 m
2	10 m/s	30°	0,5 s	8,7 m	1,25 m
3	10 m/s	30°	0,5 s	8,7 m	1,25 m
4	10 m/s	30°	0,5 s	8,7 m	1,25 m
5	10 m/s	30°	0,5 s	8,7 m	1,25 m
6	10 m/s	30°	0,5 s	8,7 m	1,25 m
7	10 m/s	30°	0,5 s	8,7 m	1,25 m
8	10 m/s	30°	0,5 s	8,7 m	1,25 m
9	10 m/s	30°	0,5 s	8,7 m	1,25 m
10	10 m/s	30°	0,5 s	8,7 m	1,25 m
11	10 m/s	30°	0,5 s	8,7 m	1,25 m
13	10 m/s	30°	0,5 s	8,7 m	1,25 m
14	10 m/s	30°	0,5 s	8,7 m	1,25 m
15	10 m/s	30°	0,5 s	8,7 m	1,25 m

2nd Experiment

In the first experiment, 15 experiments were carried out with an elevation angle of 45 °, speed = 10 m / s, speed of gravity = 10 m / s ^{2}, mass = 17.60 kg, diameter = 0.18 m which is the same to determine the furthest range that can be travelled by objects, the maximum height of objects and the time taken by objects to the top point. The following data is obtained after doing the lab work.

Table 2. Effect of 45° elevation angle on the furthest reach, maximum height, and time

Experiment 1	Initial velocity (m/s)	Angle (°)	Peak point time (s)	Maximum distance (m)	Maximum height (m)
1	10 m/s	45°	0,71 s	10 m	2,5 m
2	10 m/s	45°	0,71 s	10 m	2,5 m
3	10 m/s	45°	0,71 s	10 m	2,5 m
4	10 m/s	45°	0,71 s	10 m	2,5 m
5	10 m/s	45°	0,71 s	10 m	2,5 m
6	10 m/s	45°	0,71 s	10 m	2,5 m
7	10 m/s	45°	0,71 s	10 m	2,5 m
8	10 m/s	45°	0,71 s	10 m	2,5 m
9	10 m/s	45°	0,71 s	10 m	2,5 m
11	10 m/s	45°	0,71 s	10 m	2,5 m
12	10 m/s	45°	0,71 s	10 m	2,5 m
13	10 m/s	45°	0,71 s	10 m	2,5 m
14	10 m/s	45°	0,71 s	10 m	2,5 m
15	10 m/s	45°	0,71 s	10 m	2,5 m

3rd Experiment

In the first experiment, 15 experiments were carried out with an elevation angle of 60 °, speed = 10 m / s, speed of gravity = 10 m / s ^{2}, mass = 17.60 kg, diameter = 0.18 m which is the same to determine the furthest range that can be travelled by objects, the maximum height of objects and the time taken by objects to the top point. The following data is obtained after doing the lab work.

Table 3. Effect of 45° elevation angle on the furthest reach, maximum height, and time

Experiment 1	Initial velocity (m/s)	Angle (°)	Peak point time (s)	Maximum distance (m)	Maximum height (m)
1	10 m/s	60°	0,87 s	8,7 m	3,75 m
2	10 m/s	60°	0,87 s	8,7 m	3,75 m
3	10 m/s	60°	0,87 s	8,7 m	3,75 m
4	10 m/s	60°	0,87 s	8,7 m	3,75 m
5	10 m/s	60°	0,87 s	8,7 m	3,75 m
6	10 m/s	60°	0,87 s	8,7 m	3,75 m
7	10 m/s	60°	0,87 s	8,7 m	3,75 m
8	10 m/s	60°	0,87 s	8,7 m	3,75 m
9	10 m/s	60°	0,87 s	8,7 m	3,75 m
11	10 m/s	60°	0,87 s	8,7 m	3,75 m
12	10 m/s	60°	0,87 s	8,7 m	3,75 m
13	10 m/s	60°	0,87 s	8,7 m	3,75 m
14	10 m/s	60°	0,87 s	8,7 m	3,75 m
15	10 m/s	60°	0,87 s	8,7 m	3,75 m

After taking the data, the data will then be processed to determine changes in acceleration (Δv_0), changes in angle ($\Delta\theta$), and changes in object gravity (Δ g). Then get the results through the following calculations:

Data processing:

Angle 30° (1st experiment)

Maximum distance (Y_{max})

P = 8.7 m = 8.7 x10^{-1} = 0.87

Travelling time

P = 0.71 m = 0.71 x10^{-1} = 0.071

Δp= $\frac{1}{2}$ Nst =$\frac{1}{2}$ x (0.001 m) = 0.005

$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}87}$ X 100%
= 0,0005 X 100%
= 0,0005
KTP = (0.87 x 0.005)10^{-2}
Maximum height (X_{max})
P = 1.25 m = 1.25 x10^{-1} = 0.125
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}125}$ X 100%
= 0,04 X 100%
= 0,04
KTP = (0.125 x 0.005)10^{-2}

Travelling time
P = 0.05 m = 0.05 x10^{-1} = 0.05
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}05}$ X 100%
= 0,1 X 100%
= 0,1
KTP = (0.05 X 0.005)10^{-2}

45° angle (2nd trial)
Maximum distance (Y_{max})
P = 10 m = 10 x10^{-1} = 0.10
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}10}$ X 100%
= 0,10 X 100%
= 0,05
KTP = (0.10 X 0.005)10^{-2}
Maximum height (X_{max})
P = 2.5 m = 2.5 x10^{-1} = 0.25
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}25}$ X 100%
= 0,02 X 100%
= 0,02
KTP = (0.25 X 0.005)10^{-2}

KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}071}$ X 100%
= 0,07 x 100%
= 0,07
KTP = (0.071 X 0.005)10^{-2}

60° angle (3rd trial)
Maximum distance (Y_{max})
P = 8.7 m = 8.7 x10^{-1} = 0.87
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}87}$ X 100%
= 0,005 X 100%
= 0,005
KTP = (0.87 X 0.005)10^{-2}
Maximum height (X_{max})
P = 3.75 m = 3.75 x10^{-1} = 0.375
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}375}$ X 100%
= 0,013 X 100%
= 0,013
KTP = (0.375 X 0.005)10^{-2}

Travelling time
P = 0.87 m = 0.87 x10^{-1} = 0.087
$\Delta p = \frac{1}{2}$ Nst $= \frac{1}{2}$ x (0.001 m) = 0.005
KRS $= \frac{\Delta p}{P}$ X 100% $= \frac{0{,}005}{0{,}087}$ X 100%
= 0,05 X 100%
= 0,05
KTP = (0.087 X 0.005)10^{-2}

Gravitational acceleration
Gravity = 10 m/s^2
NST = 0.01 m/s^2Asked:Δ g, KRS, KTP?
$\Delta g = \frac{1}{2}$ x (0.01 m) = 0.05 m/s^2
KRS $= \frac{\Delta g}{g}$ X 100% $= \frac{0{,}005}{0{,}10}$ X 100%
= 0,05 X 100%
= 0,05
KTP = (0.05 X 0.005)10^{-2}

°After processing, calculations are then carried out. The first calculation is to get the highest point, the second calculation is to get the furthest range, and the third calculation is to get the time at each angle of 30 °, 45 °, and 60 °. So that the following results are obtained:

1. Calculation of determining the highest point
   a. Elevation angle to the highest point: 30°
      Vo =10 m/s θ = 30° g = 9.8 m/s^2 Δvo = 0.5 $/ms$ $\Delta\theta$ = 0.5°
      Δg = 0.05 m/s^2
      $Y_{max} = \frac{VO^2 sin^2}{2g} = \frac{10^2 sin^2 30°}{2.(10)} = \frac{100.\frac{1}{2}\sqrt{3}}{20} = \frac{100.\frac{1}{4}}{20} = \frac{25}{20} = 1{,}25$

$$\Delta Y_{max} = \left|\frac{\partial Y_{max}}{\partial Vo}\right|\Delta vo + \left|\frac{\partial Y_{max}}{\partial \theta}\right|\Delta \theta + \left|\frac{\partial Y_{max}}{\partial g}\right|\Delta g$$
$$= \left|\frac{VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin\ 2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005$$
$$= \left|\frac{10\ sin^2\ (30°)}{10}\right| 0.5 + \left|\frac{10^2\ sin2(30°)}{g}\right| 0.5 + \left|\frac{10^2\ sin^2\ (30°)}{2g}\right| 0.005$$
$$= \left|\frac{10\ (\frac{1}{4})}{10}\right| 0.5 + \left|\frac{100\ \sin 60°}{10}\right| 0.5 + \left|\frac{100\ (\frac{1}{4})}{2.10}\right| 0.005$$
$$= \left|\frac{2,5}{10}\right| 0.5 + \left|\frac{100\ (\frac{1}{2}\sqrt{3}}{10}\right| 0.5 + \left|\frac{200}{2g}\right| 0.005$$
$$= 0,125 + 0,043 + 0,000625$$
$$= 0,168\ m$$

b. Elevation angle to the highest point: 45°

$$Y_{max} = \frac{VO^2 sin^2}{2g} = \frac{10^2 sin^2 30°}{2.10} = \frac{100.(\frac{1}{2}\sqrt{2})}{2.10} = \frac{100(\frac{1}{2})}{20} = 2,5\ m$$
$$\Delta Y_{max} = \left|\frac{\partial Y_{max}}{\partial Vo}\right|\Delta vo + \left|\frac{\partial Y_{max}}{\partial \theta}\right|\Delta \theta + \left|\frac{\partial Y_{max}}{\partial g}\right|\Delta g$$
$$= \left|\frac{VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin\ 2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005$$
$$= \left|\frac{10\ sin^2\ (45°)}{9,8}\right| 0.5 + \left|\frac{10^2\ sin2(45°)}{g}\right| 0.5 + \left|\frac{10^2\ sin^2\ (45°)}{2g}\right| 0.005$$
$$= \left|\frac{10\ (\frac{1}{4})}{10}\right| 0.5 + \left|\frac{100\ \sin 45°}{10}\right| 0.5 + \left|\frac{100\ (\frac{1}{2})}{2.10}\right| 0.005$$
$$= 0,125 + 7,07 + 0,001$$
$$= 7,196\ m$$

c. Elevation angle to the highest point: 45°

$$Y_{max} = \frac{VO^2 sin^2}{2g} = \frac{10^2 sin^2 30°}{2.10} = \frac{100.(\frac{1}{2}\sqrt{2})}{2.10} = \frac{100(\frac{1}{2})}{20} = 2,5\ m$$
$$\Delta Y_{max} = \left|\frac{\partial Y_{max}}{\partial Vo}\right|\Delta vo + \left|\frac{\partial Y_{max}}{\partial \theta}\right|\Delta \theta + \left|\frac{\partial Y_{max}}{\partial g}\right|\Delta g$$
$$= \left|\frac{VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin\ 2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005$$
$$= \left|\frac{10\ sin^2\ (45°)}{9,8}\right| 0.5 + \left|\frac{10^2\ sin2(45°)}{g}\right| 0.5 + \left|\frac{10^2\ sin^2\ (45°)}{2g}\right| 0.005$$
$$= \left|\frac{10\ (\frac{1}{4})}{10}\right| 0.5 + \left|\frac{100\ \sin 45°}{10}\right| 0.5 + \left|\frac{100\ (\frac{1}{2})}{2.10}\right| 0.005$$
$$= 0,125 + 7,07 + 0,001$$
$$= 7,196\ m$$

2. Calculation to determine the furthest reach

a. Elevation angle to furthest reach 30°

Vo =10 m/s θ = 30° g = 9.8 m/s² Δvo = 0.5 $/ms$ $\Delta\theta$ = 0.5°

Δg = 0.05 m/s²

$$x_{max} = \frac{VO^2 sin^2}{2g} = \frac{10^2\ \sin 2(30°)}{2.(10)} = 8,6\ m$$
$$\Delta x_{max} = \left|\frac{\partial x_{max}}{\partial Vo}\right|\Delta vo + \left|\frac{\partial x_{max}}{\partial \theta}\right|\Delta \theta + \left|\frac{\partial x_{max}}{\partial g}\right|\Delta g$$
$$= \left|\frac{2VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ 2cos2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005$$
$$= \left|\frac{2(10)\ sin^2\ (30°)}{10}\right| 0.5 + \left|\frac{10^2\ 2cos2(30°)}{10}\right| 0.5 + \left|\frac{10^2\ sin^2\ (30°)}{10^2}\right| 0.005$$
$$= 0,86 + 5 + 0,004$$
$$= 5,864\ m$$

b. Elevation angle concerning the farthest range is 45°

$$x_{max} = \frac{VO^2 sin^2}{2g} = \frac{10^2\ \sin 2(30°)}{2.(10)} = 8,6\ m$$

$$\Delta x_{max} = \left|\frac{\partial x_{max}}{\partial Vo}\right| \Delta\ vo + \left|\frac{\partial x_{max}}{\partial \theta}\right| \Delta\ \theta + \left|\frac{\partial x_{max}}{\partial g}\right| \Delta\ g$$

$$= \left|\frac{2VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ 2cos2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005$$

$$= \left|\frac{2(10)\ sin^2\ (45°)}{10}\right| 0.5 + \left|\frac{10^2\ 2cos2(45°)}{10}\right| 0.5 + \left|\frac{10^2\ sin^2\ (45°)}{10^2}\right| 0.005$$

= 1+ 0 + 0,005

= 1,005 m

c. Elevation angle concerning the farthest range is 45°

$$x_{max} = \frac{VO^2 sin^2}{2g} = \frac{10^2\ sin\ 2(30°)}{2.(10)} = 8{,}6\ m$$

$$\Delta x_{max} = \left|\frac{\partial x_{max}}{\partial Vo}\right| \Delta\ vo + \left|\frac{\partial x_{max}}{\partial \theta}\right| \Delta\ \theta + \left|\frac{\partial x_{max}}{\partial g}\right| \Delta\ g$$

$$= \left|\frac{2VO\ sin^2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ 2cos2\ \theta}{g}\right| 0.5 + \left|\frac{v_0{}^2\ sin^2\ \theta}{2g}\right| 0.005$$

$$= \left|\frac{2(10)\ sin^2\ (45°)}{10}\right| 0.5 + \left|\frac{10^2\ 2cos2(45°)}{10}\right| 0.5 + \left|\frac{10^2\ sin^2\ (45°)}{10^2}\right| 0.005$$

= 1+ 0 + 0,005

= 1,005 m

3. Calculation of determining travel time

a. Elevation angle 30° to peak point travel time

Vo =10 m/s θ = 30° g = 9.8 m/s² Δvo = 0.5 $/ms$ $\Delta\theta$ = 0.5°

Δg = 0.05 m/s²

$$t_x = \frac{2Vosin}{g} = \frac{2.10\ sin(30°)}{10} = \frac{2.\frac{1}{2}}{10} = 1\ s$$

$$\Delta tx = \left|\frac{\partial\ tx}{2Vo}\right| \Delta\ vo + \left|\frac{\partial\ tx}{\partial \theta}\right| \Delta\ \theta + \left|\frac{\partial\ tx}{\partial g}\right| \Delta\ g$$

$$= \left|\frac{2\ sin\theta}{g}\right| 0.5 + \left|\frac{2vocos\ \theta}{g}\right| 0.5 + \left|\frac{-2\ v_0\ sin\ \theta}{2g}\right| 0.005$$

$$= \left|\frac{2\ sin\ (30°)}{10}\right| 0.5 + \left|\frac{2(10)\ cos(30°)}{10}\right| 0.5 + \left|\frac{2(10)\ sin\ (30°)}{10^2}\right| 0.005$$

= 0,05+ 0,86 + 0,0005

= 0.91 seconds

b. Elevation angle 45° to the highest point, travel time

$$t_x = \frac{2Vosin}{g} = \frac{2.10\ sin(45°)}{10} = 1{,}4\ sekon$$

$$\Delta tx = \left|\frac{\partial\ tx}{2Vo}\right| \Delta\ vo + \left|\frac{\partial\ tx}{\partial \theta}\right| \Delta\ \theta + \left|\frac{\partial\ tx}{\partial g}\right| \Delta\ g$$

$$= \left|\frac{2\ sin\theta}{g}\right| 0.5 + \left|\frac{2vocos\ \theta}{g}\right| 0.5 + \left|\frac{-2\ v_0\ sin\ \theta}{2g}\right| 0.005$$

$$= \left|\frac{2\ sin\ (45°)}{10}\right| 0.5 + \left|\frac{2(10)\ cos(45°)}{10}\right| 0.5 + \left|\frac{2(10)\ sin\ (45°)}{10^2}\right| 0.005$$

= 0,07+ 0,7 + 0,0007

= 0.77 seconds

c. Elevation angle 30° to the highest point, travel time

$$t_x = \frac{2Vosin}{g} = \frac{2.10\ sin(60°)}{10} = 1{,}7\ sekon$$

$$\Delta tx = \left|\frac{\partial\ tx}{2Vo}\right| \Delta\ vo + \left|\frac{\partial\ tx}{\partial \theta}\right| \Delta\ \theta + \left|\frac{\partial\ tx}{\partial g}\right| \Delta\ g$$

$$= \left|\frac{2\ sin\theta}{g}\right| 0.5 + \left|\frac{2vocos\ \theta}{g}\right| 0.5 + \left|\frac{-2\ v_0\ sin\ \theta}{2g}\right| 0.005$$

$$= \left|\frac{2\ sin\ (60°)}{10}\right| 0.5 + \left|\frac{2(10)\ cos(60°)}{10}\right| 0.5 + \left|\frac{2(10)\ sin\ (60°)}{10^2}\right| 0.005$$

= 0,086+ 0,5 + 0,0008

= 1.36 seconds

Based on the results of the calculations carried out to determine the highest point, the farthest range, and travel time of the farthest point to the angles of 30°, 45°, and 60° can be seen in the following table:

Table 4. Elevation angle to the highest point

No	Elevation angle (°)	Highest point (m)
1	30°	0,618
2	45°	7, 196
3	60°	4,67

Based on the results of the experiments carried out for the elevation angle to the highest point, it shows that the elevation angle is very influential on the highest point, but does not show a linear between the angle and the highest point at an angle of 45° with a height of 4.67 m, while decreasing at 60° with 4.67 m, and the lowest at 30° with 0.618m.

Table 5. Elevation angle versus furthest reach

No	Elevation angle (°)	Farthest range (m)
1	30°	5,864
2	45°	1,005
3	60°	5,864

Based on the results of the experiments carried out for the elevation angle to the farthest range shows that the elevation angle is very influential on the farthest range, but does not show a linear between the angle and the highest range at an angle of 30° and 60° which is 5.864 m while at an angle of 45° with 1.005 m, and the difference is very far.

Table 6. Elevation angle to the highest point at time

No	Elevation angle (°)	Highest point time (s)
1	30°	0,91
2	45°	0,77
3	60°	1,36

Based on the results of the experiments conducted for the elevation angle against the highest point time, it shows that the elevation angle is very influential on the highest point, but does not show a linear between the angle and the highest point at an angle of 60° with 1.36, at 30° with 0.91 and 45° with a time of 0.77 s. The data shows that the maximum height increases as the elevation angle increases. The 60° angle produced the highest height (3.75 m), while the 30° angle had the lowest height (1.25 m). This is in line with the theory of parabolic motion, where the vertical component of velocity (V_0sin ϴ) increases at larger angles, resulting in longer rise times and higher heights [6].

This result is reinforced by research [12], which shows that the use of PhET simulation can improve students' understanding of the relationship between throw angle and maximum height in parabolic motion. Similarly, a study by Fauzia and [5] noted students' misconceptions about the role of angle in determining the height of the throw, which can be corrected by visualization through simulation.

Theoretically, a 45° angle produces the maximum range because it is a compromise point between horizontal and vertical velocities. The experimental results support this theory, with the 45° angle producing the furthest range of 10 metres. In contrast, 30° and 60° angles produce the same range (8.70 m) because the sin (2θ) values for 30° and 60° are the same (sin 60° = sin 120°). This phenomenon was also reported by [2], who used Matlab GUI for parabolic motion simulation and found that the farthest range was achieved at an elevation angle of 45°. [3] Also confirmed that the relationship between angle and range is not linear and is symmetrical about the 45° axis, which is also seen in the results of this study.

The travelling time to the highest point is directly affected by the vertical velocity component. $(V_0\ Sin\ \theta\ )$. The simulation results show that the longest time occurs at an angle of 60° (0.87 s), followed by 45° (0.71 s), and the shortest at an angle of 30° (0.50 s). This is consistent with the formula$t = \frac{V_0\ Sin\ \theta}{g}$ Where the greater the elevation angle, the greater the vertical velocity component and travel time.

This result supports the findings of [13], which states that the visualization of velocity and time in PhET simulations helps students understand the dynamics of parabolic trajectories more concretely. Research [15] also concluded that the travel time to the top of the trajectory is the easiest indicator to observe through simulation if the throwing angle is varied. Although the elevation angle affects all three main parameters, the relationship is not linear. Each angle makes an optimal contribution to different parameters: a 60° angle is optimal for height, a 45° angle for maximum range, 30° angle for shorter time. This confirms that there is no one ideal elevation angle for all parameters, and the choice of angle is highly dependent on the specific goals of the trajectory.

This finding suggests that PhET simulations are not only theoretically valid but also pedagogically relevant. PhET allows students to independently explore physics variables and observe their impact directly. The effectiveness of PhET as a visual aid has also been reported by [8], who stated that the interactive features and quantitative visualization in PhET enhance engagement and understanding of abstract physics concepts at both high school and college levels.

CONCLUSION

Based on the results of the research using the PhET Projectile Motion simulation, it can be concluded that the elevation angle has a significant influence on the characteristics of parabolic motion, which include the highest point, furthest range, and travel time to the maximum point. Firstly, the most optimal elevation angle to reach the maximum height is 60°, while the lowest height occurs at an angle of 30°. Secondly, the furthest horizontal reach was achieved at 30° and 60° with equivalent results, while 45° showed a shorter reach. Thirdly, the travel time to the highest point was longest at 60°, and shortest at 45°. In general, although the elevation angle affects all three main parameters of parabolic motion, the relationship between the angle and the measurement results is not linear. These results reinforce the understanding that each angle has a specific contribution to certain aspects of motion and needs to be analyzed separately in the context of physics learning.

REFERENCES

[1] N. K. M. Arini and N. W. S. Darmayanti, "Analisis kebutuhan guru terhadap panduan praktikum IPA," *Jurnal Pendidikan dan Pembelajaran Sains Indonesia (JPPSI)*, vol. 5, no. 1, pp. 12–19, 2022.

[2] J. Rajagukguk and C. S. Sarumaha, *Pemodelan dan analisis gerak parabola dua dimensi dengan menggunakan aplikasi GUI Matlab*, Medan: Program Studi Fisika, Universitas Negeri Medan, 2018.

[3] P. Artawan, *Fisika Dasar*, Jakarta: Graha Ilmu, 2014.

[4] N. Febriana, "Pengaruh Pembelajaran Berbentuk Simulasi Modellus Terhadap Peningkatan Pemahaman Konsep Gerak Parabola," *Jurnal Pendidikan Madrasah*, vol. 8, no. 2, pp. 227–234.

[5] A. Fauziah and Y. Darvina, "Analisis miskonsepsi peserta didik dalam memahami materi gerak lurus dan gerak parabola pada kelas X SMAN 1 Padang," *Pillar of Physics Education*, vol. 12, no. 1, 2019.

[6] H. D. Young and R. A. Freedman, *Fisika Universitas*, Jilid 1, Jakarta: Erlangga, 2002.

[7] I. Diraya, A. Budiyono, and M. Triastutik, "Kontribusi Virtual Lab Phet Simulation untuk Membantu Praktikum Fisika Dasar," *Phenomenon: Jurnal Pendidikan MIPA*, vol. 11, no. 1, pp. 45–56, 2021.

[8] M. Ulfah, S. Suyidno, and R. Efendi, "Efektivitas laboratorium virtual berbasis simulasi PhET dalam meningkatkan pemahaman konsep fisika siswa," *Jurnal Pendidikan Fisika dan Teknologi*, vol. 6, no. 1, pp. 38–44, 2020.

[9] G. Martínez Borreguero, F. Naranjo-Correa, Á. Pérez, M. Suero, and P. Pardo, "Comparative Study Of The Effectiveness Of Three Learning Environments: Hyper-Realistic Virtual

Simulations, Traditional Schematic Simulations And Traditional Laboratory," *Phys. Rev. ST Phys. Educ. Res.*, vol. 7, p. 020111, 2011.

[10] A. A. Rahma, "Efektivitas penggunaan virtual lab phet sebagai media pembelajaran fisika terhadap hasil belajar siswa," *Pedagogy: Jurnal Ilmiah Ilmu Pendidikan*, vol. 8, no. 2, pp. 47–51, 2021.

[11] S. W. Widyaningsih and I. Yusuf, "Penerapan Simulasi PhET pada Mata Kuliah Fisika II di Program Studi Ilmu Kelautan Universitas Papua," *Berkala Ilmiah Pendidikan Fisika*, vol. 6, no. 2, p. 180, 2018.

[12] J. Siswanto, "Implementasi Model IBMR Berbantu PhET Simulation untuk Meningkatkan Kemampuan Representasi pada Pembelajaran Fisika," *Jurnal Penelitian Pembelajaran Fisika*, vol. 10, no. 2, pp. 96–100, 2019.

[13] E. M. E. Putri, I. Koto, and D. H. Putri, "Peningkatan Keterampilan Proses Sains dan Penguasaan Konsep Gelombang Cahaya dengan Penerapan Model Inkuiri Berbantuan Simulasi PhET di Kelas XI MIPA E SMAN 2 Kota Bengkulu," *Jurnal Kumparan Fisika*, vol. 1, no. 2, pp. 46–52, 2018.

[14] E. Elisa, A. Mardiyah, and R. Ariaji, "Peningkatan Pemahaman Konsep Fisika Dan Aktivitas Mahasiswa Melalui Phet Simulation," *Peteka*, vol. 1, no. 1, pp. 15–20, 2017.

[15] E. Dewa, M. U. J. Mukin, and O. Pandango, "Pengaruh pembelajaran daring berbantuan laboratorium virtual terhadap minat dan hasil belajar kognitif fisika," *Jurnal Riset Teknologi dan Inovasi Pendidikan (JARTIKA)*, vol. 3, no. 2, pp. 351–359, 2020.

[16] G. Gunawan, A. Setiawan, and D. Widyantoro, "Model Virtual Laboratory Fisika Modern Untuk Meningkatkan Keterampilan Generik Sains Calon Guru," *Jurnal Pendidikan dan Pembelajaran Universitas Negeri Malang*, vol. 20, no. 1, pp. 25–32, 2013.

[17] PhET Team, *PhET Interactive Simulations*, University of Colorado Boulder, 2014. [Online]. Available: http://phet.colorado.edu

[18] Y. F. Istinganah and M. Syam, "Pemanfaatan Laboratorium Fisika dan Kontribusinya dalam Pembelajaran Fisika, Studi Kasus di SMA Negeri 1 Sendawar dan SMA Negeri 1 Liggang Bigung Kabupaten Kutai Barat," *Jurnal Literasi Pendidikan Fisika (JLPF)*, vol. 2, no. 1, pp. 23–33, 2021.

[19] Y. N. Rustaman, *Strategi Belajar Mengajar Biologi*, Malang: UN PRESS, 2005.

[20] A. Lepiyanto, "Analisis keterampilan proses sains pada pembelajaran berbasis praktikum," *BIOEDUKASI*, vol. 5, no. 2, pp. 156–161, 2017.