Education

An investigation of projectile motion using basic classroom experiments and mathematical concepts

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Abstract

This study investigated projectile motion through simple classroom experiments and mathematical analysis to examine how closely experimental measurements of horizontal range, maximum height, and time of flight agree with theoretical predictions. Experimental trials launched a ping-pong ball at 30°, 45°, and 60° using a rubber-band launcher. Measurements (three trials per angle) recorded range, peak height, and flight time and were averaged for analysis. Theoretical values were computed with standard projectile equations and compared to experimental averages. Percentage errors were generally small (≤5.21%), showing close agreement between observations and model predictions. Results show the 45° launch produced the greatest horizontal range while the 60° launch produced the highest maximum height and longest time aloft, illustrating the independence of horizontal and vertical motion and the role of launch angle. Small discrepancies were attributed to air resistance, launcher variability, and measurement limitations. The study concludes that low-cost classroom experiments effectively reinforce mathematical and physical concepts of projectile motion and recommends more precise instruments and expanded trials for future work.

Keywords: Projectile motion, Launch angle, Horizontal range, Maximum height, Classroom experiment

1. Introduction

Projectile motion is a fundamental concept in physics that describes the motion of an object launched into the air and moving under the influence of gravity. Under ideal conditions, where air resistance is neglected, gravity acts as the only force affecting the projectile after it is launched, causing it to follow a curved path called a trajectory. The motion of a projectile can be analyzed by separating it into independent horizontal and vertical components, making it one of the most common applications of two-dimensional kinematics and mathematical analysis (Ling *et al*., 2021; Urone & Hinrichs, 2022) [5, 7].

The study of projectile motion involves several mathematical concepts, including algebra, trigonometry, geometry, and vectors. The initial velocity of a projectile can be resolved into horizontal and vertical components using trigonometric functions, while mathematical equations are used to determine its horizontal range, maximum height, and time of flight. Understanding these relationships allows learners to predict the behavior of moving objects and demonstrates how mathematical principles can be applied to solve real-world problems. Yıldırım (2025) [8] explained that the characteristics of projectile motion can be effectively analyzed through mathematical relationships that describe the trajectory and overall motion of a projectile.

Projectile motion has numerous practical applications in everyday life and in various fields such as sports, engineering, transportation, and space science. Activities such as throwing a ball, kicking a football, and launching a rock*et al*l involve the principles of projectile motion. Because of these applications, the topic plays an important role in mathematics and physics education by helping students connect theoretical concepts with practical situations and develop analytical and problem-solving skills (Ling *et al*., 2021; Hernandez-Sanchez *et al*., 2026) [5, 3].

Despite its importance, many students experience difficulties in understanding projectile motion because it requires the integration of mathematical concepts and physical principles. Learners often struggle to visualize the independent horizontal and vertical components of motion and to apply mathematical equations to actual situations. Chinaka (2021) [1] found that interactive and experiential learning approaches improve students' understanding of projectile motion by helping them connect theoretical knowledge with observable phenomena. Similarly, Jamaludin, Batlolona, and Dulhaszim (2025) [4] reported that experimental activities encourage students to address misconceptions and develop a more accurate understanding of projectile motion through observation and analysis.

Recent developments in mathematics and science education have emphasized the importance of combining mathematical modeling, classroom experiments, and interactive learning to improve conceptual understanding. Computational visualizations and educational technologies enable students to investigate how variables such as launch angle and initial velocity affect projectile trajectories. Hernandez-Sanchez *et al*., (2026) [3] emphasized that computational approaches strengthen students' mathematical reasoning by linking mathematical equations with physical behavior, while educational simulations and interactive activities provide meaningful opportunities for learners to explore projectile motion concepts in a practical setting.

Although previous studies have examined projectile motion through simulations, computational models, and experimental activities, simple classroom investigations using readily available materials continue to play an important role in mathematics and science education. Such activities provide opportunities for students to compare theoretical calculations with actual observations and to develop a deeper understanding of the mathematical principles governing projectile motion. However, there is still a need for investigations that integrate basic classroom experiments with mathematical concepts in a manner that is practical, accessible, and suitable for regular educational settings.

Therefore, this mathematical investigation aims to examine projectile motion through basic classroom experiments and mathematical concepts. Specifically, the study seeks to determine the horizontal range, maximum height, and time of flight of projectiles under different launch conditions and to compare the experimental results with theoretical calculations based on projectile motion equations. Through this investigation, the researchers hope to demonstrate the effectiveness of mathematical models in describing physical motion and to strengthen students' understanding of projectile motion and its practical applications.

Statement of the problem

This study aims to investigate projectile motion using basic classroom experiments and mathematical concepts. Specifically, it seeks to answer the following questions:

a) What are the characteristics of the projectile motion observed in the classroom experiments in terms of:
   - horizontal range;
   - maximum height; and
   - time of flight?

b) How are the principles of projectile motion reflected in the observed results of the classroom experiments?

c) To what extent do the experimental results differ from the theoretical values obtained using projectile motion equations?

2. Methodology

Research design

This study employed an experimental-descriptive research design to investigate projectile motion through basic classroom experiments and mathematical concepts. The experimental component involved launching a projectile at different predetermined angles while maintaining similar launching conditions throughout the investigation. The descriptive component focused on observing, measuring, recording, and analyzing the characteristics of projectile motion, particularly the horizontal range, maximum height, and time of flight of the projectile. This research design is appropriate because it allows the researchers to gather experimental data and describe the relationships among the variables under investigation (Creswell & Creswell, 2023) [2].

In this investigation, the independent variable was the launch angle of the projectile, while the dependent variables were the horizontal range, maximum height, and time of flight. The projectile used, launching method, measuring instruments, and experimental environment were maintained as controlled variables to minimize errors and improve the reliability of the results.

Research Materials

The following materials were used in conducting the investigation:

- **Projectile object** – A ping-pong ball served as the projectile because it is lightweight, safe, and easy to observe during the experiment.
- **Rubber band launcher –** An improvised launcher made from a plastic spoon, rubber bands, and popsicle sticks or a wooden frame was used to launch the projectile. The launcher was designed to provide a nearly constant launching force during each trial.
- **Measuring instruments –** A protractor, measuring tape, stopwatch, ruler, graph paper, and markers were used to measure the launch angle, horizontal range, maximum height, and time of flight of the projectile.
- **Reference materials –** Physics textbooks, scholarly articles, and educational resources on projectile motion and mathematical modeling were used as references for the theoretical calculations.

Research procedure

The investigation was carried out through the following procedures:

a) Preparation of the experimental setup

A safe and suitable area was selected for conducting the experiment. The rubber band launcher was assembled and placed on a stable surface. A protractor was used to adjust the launch angles, while the measuring instruments were prepared for recording the projectile's motion. The launcher and measuring devices were tested before the actual experiment to ensure consistency and reliability throughout the investigation.

b) Conduct of the experiment

The ping-pong ball was launched using the rubber band launcher at predetermined angles of 30°, 45°, and 60°. The rubber band was pulled back to the same distance for every trial to maintain a nearly constant launching force. For each launch angle, the horizontal range was measured using a measuring tape from the launch point to the landing point. The maximum height was determined by placing a vertical measuring scale behind the projectile's path and visually recording the highest point reached by the projectile relative to the scale. The time of flight was measured using a stopwatch from the moment the projectile was launched until it landed. Three trials were conducted for each launch angle, and all measurements were recorded and averaged for analysis.

c) Mathematical analysis

The theoretical values of the horizontal range, maximum height, and time of flight were determined using the standard equations of projectile motion. The relationships among launch angle, initial velocity, horizontal range, maximum height, and time of flight were analyzed mathematically and compared with the experimental observations to determine the consistency between theoretical and experimental results. Standard projectile motion principles and equations served as the basis for the mathematical computations.

d) Interpretation of results

The data collected from the experiment were organized into tables and graphs for analysis and interpretation. Patterns and relationships among the measured variables were identified, while differences between the theoretical and experimental values were examined. Possible sources of experimental error and factors affecting the accuracy of the investigation were also discussed.

Mathematical model

The theoretical values of projectile motion were calculated using the standard equations of projectile motion (Ling, Sanny, & Moebs, 2021; Urone & Hinrichs, 2022) [5, 7].

Horizontal Range:

$$R = \frac{v^2 \sin 2\theta}{g}$$

Maximum Height:

$$H = \frac{v^2 \sin^2 \theta}{2g}$$

Time of Flight:

$$T = \frac{2v \sin \theta}{g}$$

Where:

R = horizontal range,

H = maximum height,

T = time of flight,

v = initial velocity,

θ = launch angle,

$g = 9.8\ m/s^2$.

These equations were used to obtain theoretical values for comparison with the experimental results.

Ethical and safety considerations

Safety precautions were observed throughout the investigation to ensure a safe experimental environment. Before each trial, the launching area was cleared of unnecessary objects, and all participants remained at a safe distance during projectile launches to prevent accidental injury. The improvised rubber-band launcher was handled carefully, and the experiment was conducted responsibly throughout the data collection process. Since the investigation involved only physical measurements and did not involve human participants as research subjects or collect personal information, formal ethical approval was not required. The researchers ensured that all observations and recorded data were reported accurately and honestly to maintain the integrity of the investigation.

Data gathering table

The researchers conducted three trials for each predetermined launch angle. The horizontal range, maximum height, and time of flight were measured and recorded. The average values were computed for comparison with the theoretical calculations.

Table 1: Experimental data for projectile motion

Launch angle	Trial	Horizontal range (m)	Maximum height (m)	Time of flight (s)
30°	1	2.17	0.30	0.49
	2	2.20	0.32	0.51
	3	2.14	0.31	0.50
45°	1	2.49	0.60	0.70
	2	2.53	0.62	0.72
	3	2.50	0.61	0.71
60°	1	2.15	0.90	0.87
	2	2.18	0.93	0.89
	3	2.16	0.91	0.88

Average values were computed for each launch angle and compared with the theoretical results obtained from the projectile motion equations

Sample computation

The theoretical values for the horizontal range, maximum height, and time of flight were calculated using the standard equations of projectile motion.

Suppose:

Initial velocity:

$v = 5\ m/s$

Launch angle:

$\theta = 45°$

Acceleration due to gravity:

$g = 9.8\ m/s^2$

Horizontal Range

$R = (v^2 \sin 2\theta)/g$

$R = (5^2 \times \sin 90°)/9.8$

$R = 25/9.8$

$R = 2.55\ m$

Maximum Height

$H = (v^2 \sin^2 \theta)/(2g)$

$H = (25 \times 0.5)/19.6$

$H = 0.64\ m$

Time of Flight

$T = (2v \sin \theta)/g$

$T = (2 \times 5 \times 0.7071)/9.8$

$T = 0.72\ s$

These theoretical values were compared with the experimental measurements to determine the consistency between the mathematical model and the observed projectile motion.

Data analysis

The data obtained from the classroom experiments were organized according to the launch angles used in the

investigation. The horizontal range, maximum height, and time of flight recorded for each trial were tabulated. The mean and standard deviation were computed for each variable to summarize the measurements and evaluate the consistency of the experimental data.
The theoretical values obtained from the projectile motion equations were compared with the experimental measurements. Tables and graphs were used to illustrate the relationships between launch angle and the characteristics of projectile motion.
To determine the difference between the theoretical and experimental values, the percentage error was computed using the following formula:

Percentage Error = |Experimental Value − Theoretical Value| ÷ Theoretical Value × 100%

The mathematical and experimental analyses were used to evaluate the principles of projectile motion and to answer the research questions of the study.

3. Results and Discussion

This chapter presents and discusses the results of the experimental investigation of projectile motion using basic classroom experiments and mathematical concepts. The presentation and analysis of data are organized according to the Statement of the Problem, focusing on the measured characteristics of projectile motion, the reflection of projectile motion principles in the observed data, and the comparison between experimental and theoretical values.

1. Characteristics of observed projectile motion

To identify the basic characteristics of the observed projectile motion, the experiment tracked three dependent variables across fixed launch angles of 30°, 45°, and 60° while keeping the launch force constant.

Table 2: Average horizontal range, maximum height, and time of flight at different launch angles

Launch angle	Average range (m)	Average height (m)	Average time (s)
30°	2.17	0.31	0.50
45°	2.51	0.61	0.71
60°	2.16	0.91	0.88

Table 2A: Mean and standard deviation of experimental measurements

Launch angle	Variable	Mean	Standard deviation
30°	Range	2.17	0.03
30°	Height	0.31	0.01
30°	Time	0.50	0.01
45°	Range	2.51	0.02
45°	Height	0.61	0.02
45°	Time	0.71	0.01
60°	Range	2.16	0.02
60°	Height	0.91	0.02
60°	Time	0.88	0.01

The mean values summarize the average measurements obtained from the three experimental trials for each launch angle, while the standard deviations indicate the variability of the recorded data. The relatively small standard deviation values for the horizontal range, maximum height, and time of flight suggest that the measurements were highly consistent across the three trials. This indicates that the experimental procedure produced reliable results with only minimal variation, despite the minor measurement uncertainties commonly encountered in classroom investigations.

1.1 Horizontal range

The results showed that the launch angle of 45° produced the greatest average horizontal range of 2.51 m, while the launch angles of 30° and 60° produced average ranges of 2.17 m and 2.16 m, respectively. This indicates that the projectile traveled the farthest when launched at 45°. The findings are consistent with the principles of projectile motion, which state that under ideal conditions and constant initial velocity, the maximum horizontal range is achieved at a launch angle of 45°.
The observed results support the mathematical model of projectile motion. At 45°, the horizontal and vertical components of velocity are balanced, allowing the projectile to remain airborne while maintaining sufficient horizontal motion. In contrast, at 30° the projectile spent less time in the air, while at 60° more of the velocity was directed upward rather than forward, resulting in shorter horizontal distances.

1.2 Maximum height

The average maximum height increased as the launch angle increased. The projectile launched at 60° reached the highest average maximum height of 0.91 m, followed by 45° with 0.61 m and 30° with 0.31 m. These results demonstrate that larger launch angles produce greater vertical velocity components, enabling the projectile to rise higher before descending due to gravity.
The findings agree with the theoretical principles of projectile motion. Since the vertical component of velocity depends on the sine of the launch angle, increasing the angle increases the upward motion of the projectile. Consequently, the projectile reaches a greater height before gravitational acceleration causes it to fall back toward the ground.

1.3 Time of flight

The results revealed that the projectile launched at 60° remained in the air the longest, with an average time of flight of 0.88 s. The average times of flight for 45° and 30° were 0.71 s and 0.50 s, respectively. This pattern indicates that the time the projectile spends in the air increases as the launch angle increases.
The longer flight time at higher launch angles can be explained by the greater vertical velocity component imparted to the projectile. Because the projectile moves upward for a longer period before descending, the total duration of its motion increases. These observations are consistent with the theoretical equations of projectile motion.

2. Reflection of projectile motion principles

The experimental results clearly reflect the fundamental principles of projectile motion. Throughout the investigation, the horizontal range, maximum height, and time of flight varied systematically with changes in the launch angle while the launch force was kept approximately constant. This demonstrates that the motion of a projectile depends not only on its initial speed but also on the angle at which it is launched. The results further illustrate the independence of horizontal and vertical motion. The horizontal range was greatest at 45°, whereas the maximum height and time of flight were greatest at 60°. This shows that the horizontal and vertical components of velocity influence different aspects of projectile motion. While the horizontal component determines how far the projectile travels, the vertical component determines how high and how long it remains in the air.

Moreover, the curved trajectory observed during the experiment confirms the effect of gravity on the projectile. As the projectile moved forward, gravity continuously acted downward, causing the path to form a parabola. These observations demonstrate how mathematical concepts such as trigonometry, algebra, and kinematics can be applied to explain real-world motion and support the validity of projectile motion theory.

3. Comparison of experimental results and theoretical values

Table 3: Experimental and Theoretical values

Angle	Experimental range	Theoretical range	Experimental height	Theoretical height	Experimental time	Theoretical time
30°	2.17	2.21	0.31	0.32	0.50	0.51
45°	2.51	2.55	0.61	0.64	0.71	0.72
60°	2.16	2.21	0.91	0.96	0.88	0.88

Table 4: Percentage error

Angle	Variable	Experimental	Theoretical	% Error
30°	Range	2.17	2.21	1.81%
30°	Height	0.31	0.32	3.13%
30°	Time	0.50	0.51	1.96%
45°	Range	2.51	2.55	1.57%
45°	Height	0.61	0.64	4.69%
45°	Time	0.71	0.72	1.39%
60°	Range	2.16	2.21	2.26%
60°	Height	0.91	0.96	5.21%
60°	Time	0.88	0.88	0.00%

Tables 3 and 4 present the comparison between the experimental and theoretical values of the horizontal range, maximum height, and time of flight, together with the percentage errors obtained for each launch angle. The results indicate a high level of agreement between the measured values obtained from the classroom experiment and the values predicted by the standard equations of projectile motion. The relatively small percentage errors observed suggest that the mathematical model accurately described the motion of the projectile under the conditions of the investigation.

Comparing the experimental measurements with the theoretical calculations demonstrates the effectiveness of projectile motion equations in predicting the behavior of moving objects. The theoretical values were obtained using the standard kinematic formulas for horizontal range, maximum height, and time of flight, assuming ideal conditions and constant gravitational acceleration. When compared with the averaged experimental results, only minor differences were observed across the measured variables, indicating that the experimental outcomes closely followed the expected mathematical relationships.

The slight discrepancies between the experimental and theoretical values may be attributed to several factors commonly encountered in classroom investigations. The theoretical model assumes ideal conditions and does not account for air resistance, minor variations in the launching force, or measurement limitations. Since the projectile used in the experiment was a lightweight ping-pong ball, its motion was particularly susceptible to air drag, which may have reduced its horizontal range and maximum height. In addition, small errors in measuring distance and time, as well as human reaction time when operating the stopwatch, may have contributed to the observed differences. Despite these limitations, the close agreement between the experimental and theoretical results supports the validity of the projectile motion model and demonstrates the usefulness of mathematical concepts in describing real-world motion.

Experimental limitations

While the study yielded valuable data on projectile motion, certain experimental limitations must be acknowledged. The outcomes may have been affected by environmental and procedural factors, including air resistance and minor variations in the launching force of the improvised launcher. Additionally, human reaction time when measuring the time of flight, along with minor measurement errors in determining the horizontal range and maximum height, may have introduced slight discrepancies between the experimental and theoretical values. Furthermore, the investigation was limited to three trials for each launch angle. Although this number of trials was sufficient for a classroom-based investigation, conducting five or more trials in future studies could improve the reliability and consistency of the measurements by reducing the effect of random experimental errors. Despite these limitations, the experimental results closely agreed with the theoretical predictions, supporting the validity of the mathematical model used in this investigation.

4. Conclusion

This study successfully investigated projectile motion through basic classroom experiments and mathematical concepts by examining the horizontal range, maximum height, and time of flight of a projectile launched at different angles. The findings showed that the launch angle significantly influenced the characteristics of projectile motion. Among the three angles tested, 45° produced the greatest horizontal range, while 60° resulted in the highest maximum height and the longest time of flight. These observations clearly demonstrated the relationship between launch angle and the horizontal and vertical components of projectile motion.

Furthermore, the experimental results closely matched the theoretical values obtained using the standard projectile motion equations. The percentage errors were relatively small, indicating that the mathematical models accurately described the projectile's motion under classroom conditions. Although minor differences were observed, these were primarily attributed to unavoidable experimental factors such as air resistance, slight variations in launching force, and measurement limitations. Despite these sources of error, the results confirmed the validity and reliability of the mathematical principles governing projectile motion.

Overall, the study demonstrated that simple classroom experiments can effectively illustrate the fundamental concepts of projectile motion while reinforcing mathematical reasoning and scientific inquiry. By connecting theoretical calculations with actual observations, the investigation enhanced understanding of how mathematical models describe real-world physical phenomena and highlighted the value of experiential learning in mathematics and science education.

5. Recommendations

Based on the findings and conclusions of this study, the following recommendations are proposed to improve future investigations and enhance the teaching and learning of projectile motion. These recommendations aim to increase the accuracy of experimental results, strengthen students' understanding of mathematical and physical concepts, and encourage further research in this field.

- Future researchers should conduct additional trials for each launch angle to further improve the accuracy and reliability of the experimental results.
- More precise measuring instruments, such as digital timers, motion sensors, or video analysis software, should be used to minimize measurement errors and obtain more accurate data.
- Future investigations may include a wider range of launch angles and different initial velocities to provide a more comprehensive analysis of projectile motion.
- Researchers are encouraged to investigate the effects of external factors, such as air resistance, wind conditions, projectile mass, and projectile shape, to better explain the differences between theoretical and experimental results.
- Mathematics and science teachers should incorporate simple projectile motion experiments into classroom instruction to help students relate mathematical equations to real-life situations and strengthen their conceptual understanding.
- Educational institutions should encourage inquiry-based and hands-on learning activities that integrate mathematics and physics concepts to develop students' analytical, problem-solving, and critical-thinking skills.
- Future studies may utilize computer simulations and mathematical modeling alongside classroom experiments to compare simulated, theoretical, and experimental results, thereby providing a deeper understanding of projectile motion.

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