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Design of Parabolic Motion Simulation Using R for Physics Learning

Lisnawati Lisnawati[1], Nurhayati Nurhayati[2*]
[1]Physics Education Study Program, Faculty of Tarbiyah and Teacher Training, Universitas Islam Negeri Ar-Raniry, Banda Aceh, Indonesia
[2]Engineering Physics Study Program , Faculty of Science and Technology, Universitas Islam Negeri Ar-Raniry, Banda Aceh, Indonesia

Correspondence E-mail: nurhayati.sururi@ar-raniry.ac.id

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ABSTRACT

Students' understanding of parabolic motion remains low due to the abstract nature of the concept and the limited use of effective visualization media in learning. This study aims to develop an interactive learning medium in the form of a parabolic motion simulation using the R programming language with the R-Shiny framework, as well as to evaluate its feasibility through expert validation. This research adopts the Research and Development (R&D) method with the Alessi and Trollip model, which includes planning, design, and development stages. The novelty of this study lies in the integration of the R-Shiny framework into physics learning, which is still rarely utilized, particularly for developing interactive simulations at the higher education level. The developed simulation enables dynamic visualization of projectile motion and facilitates exploration of relationships between key variables. The validation results show an Aiken's V value of 0.99 from media experts and 0.94 from subject matter experts, both categorized as highly valid. These findings indicate that the developed simulation is feasible and effective as an interactive learning medium. It contributes to physics education by enhancing conceptual understanding, promoting active learning, and providing an accessible platform for visualizing two-dimensional kinematics.

1. INTRODUCTION

Parabolic motion is a fundamental concept in physics that describes the motion of an object along a curved trajectory resulting from the combination of horizontal and vertical components. A solid understanding of this concept is essential for learning more advanced topics such as projectile motion and related physical phenomena. However, in educational practice, parabolic motion is often perceived as difficult because it is abstract and requires the ability to visualize motion in two dimensions (Widowati & Kurniawan, 2021).

Previous studies indicate that students still experience significant difficulties in understanding parabolic motion. A large proportion of students perceive this topic as one of the most challenging in physics due to its abstract nature and the need to simultaneously analyze two-dimensional motion components (Purwaningsih et al., 2023; Boller-Aying & Villegas-Mendaño, 2024). Students often struggle to distinguish between horizontal and vertical motion and to relate these components to the resulting trajectory (Maharani & Perdana, n.d.). These difficulties are further exacerbated by the limited use of interactive visualization media in traditional teaching, which tends to emphasize theoretical explanations (Villavelez et al., 2025).

Based on the researcher's observations, conducted by distributing a questionnaire containing a list of questions regarding the needs for physics learning materials on April 28, 2025, it was found that the majority of Physics and Physics Education students experienced difficulty in understanding physics concepts due to a lack of adequate visual aids (40.9%), followed by material deemed too abstract (27.3%), limited availability of learning media (22.7%), and teaching methods that lack variety (9.1%). These conditions indicate that teaching methods still focus on a theoretical approach without the support of media capable of providing clear visual representations.

Simulation-based learning media offer a potential solution by enabling students to explore the relationship between variables such as initial velocity, angle, and time through interactive visualization. Previous studies have demonstrated that simulation media can improve conceptual understanding and learning motivation (Wulansari et al., 2023; Mahmuda et al., 2022; Faradila & Perdana, 2024).

In this context, the R programming language, particularly through the R-Shiny framework, provides a promising platform for developing interactive simulations. Compared to other tools such as PhET, Scratch, or VBA-based applications, R-Shiny offers advantages in terms of flexibility in numerical computation, integration with advanced visualization libraries (e.g., ggplot2 and gganimate), and the ability to create fully interactive web-based applications without requiring extensive programming expertise (Heinsberg et al., 2023; Kasprzak et al., 2020). These features make R-Shiny particularly suitable for developing dynamic and customizable physics simulations.

Various studies have shown the effectiveness of simulation media in improving understanding of the concept of parabolic motion: Slingshot Simulation shows a very high level of validity (94.53%) and is considered suitable as a learning medium (Wulansari et al., 2023). The development of bullet motion simulation based on VBA (Visual Basic for Applications) Excel also received a score of 85% (excellent category) (Mahmuda et al., 2022). Scratch-based media on the same topic received an average feasibility score of 3.45 (very feasible) and was proven to increase interest and motivation to learn (Faradila & Perdana, 2024). On the other hand, in the field of mathematics/statistics, R has proven to be effective as a simulation medium for improving conceptual understanding (Wulandari et al., 2021), R–Shiny is a framework of the R programming language that is widely used to develop interactive web applications that make it easier for users to visualize abstract concepts dynamically, thereby supporting exploration-based learning and deeper understanding (Simarmata et al., 2025).

However, despite its potential, the use of R-Shiny in physics education—especially for developing interactive simulations of parabolic motion at the university level—remains limited. Furthermore, existing studies rarely integrate systematic instructional design models, such as the Alessi and Trollip model, into the development of R-based learning media. This indicates a clear research gap in combining R-Shiny technology with a structured development approach to produce validated and pedagogically sound learning media.

Therefore, this study aims to fill this gap by developing an interactive parabolic motion simulation using the R programming language with the R-Shiny framework, based on the Alessi and Trollip development model. The novelty of this study lies in the integration of R-Shiny technology with a systematic instructional design framework to produce a validated simulation that supports conceptual understanding through interactive visualization.

This study aims to design a parabolic motion simulation using the R programming language as a medium for physics learning and to evaluate its feasibility through validation by media and subject matter experts.

2. METHODS

2.1 Type of Research

This study applied the Research and Development (R&D) method using the Alessi & Trolip development model (Sugiyono, 2019), which emphasizes three main stages: planning, design, and development, as well as continuous evaluation at each stage (Yaniawati et al., 2021). The final outcome of this study is an R-Shiny-based parabolic motion simulation developed as a physics learning tool. Product feasibility was assessed through an alpha test involving validators who are experts in media as well as subject matter experts. There were 3 media expert validators, who assessed the media's visual presentation, interactivity, and functionality, while there were also 3 subject matter expert validators, who assessed the alignment of the simulation's content with the concept of parabolic motion in physics. The analysis of the research results was conducted using Aiken's V formula, which is used to evaluate the strength of content validity in each aspect assessed by the experts; thus, the focus of the research results lies on the product's feasibility based on the assessments of the media and subject matter experts.

2.2 Development Procedure

Procedures for developing parabolic motion simulations using the R programming language as a medium for teaching physics using the Alessi & Trollip model. Researchers chose this model because it was in line with the research design to produce a simulation-based learning medium. (Wati et al., 2022). The Alessi & Trollip development model has three stages in its research procedure, namely:

1. Planning
   The planning stage began with a needs analysis through literature studies and questionnaires distributed to students. This analysis was intended to reveal the various difficulties faced by students, particularly in visualizing parabolic motion trajectories and understanding the relationship between the variables of elevation angle, initial velocity, and motion trajectory. In addition, at this stage, learning objectives are formulated in line with the learning outcomes of the physics course, while also compiling the functional specifications of the R-Shiny-based parabolic motion simulation designed as a physics learning tool (Sugiyono, 2019).
2. Design
   The design phase focused on creating a simulation structure design that included the usage process flow, UI (User Interface) display, and a storyboard illustrating how the parabolic motion simulation would be run. The visualization design was created using R programming packages such as ggplot2, plotly, and gganimate (Asmarianti et al., n.d.), in order to present static and interactive animated graphics. At this stage, research instruments were also developed, consisting of validation sheets for media experts and validation sheets for subject matter experts, using a 1-5 Likert scale.
3. Development
   The development stage was carried out by applying the design that had been compiled into an R-Shiny-based simulation. At this stage, the parabolic motion formula was integrated to calculate the horizontal position $x(t)$ and vertical position $y(t)$ based on the elevation angle (θ), initial velocity (v_0), and acceleration due to gravity (g) parameters. The calculation results were then visualized in the form of trajectory graphs and interactive animations. The simulation is also equipped with input controls, such as sliders and input boxes, so that users can easily change variables directly and see how these changes affect the trajectory. After the simulation was completed, the researchers performed internal checks (debugging) to ensure that all functions,

from the calculation of the parabolic motion formula to the display of graphs and animations, ran correctly without errors. (Widyatmojo & Muhtadi, 2017).

After the internal testing phase was complete, the simulation that had been developed was then implemented in the form of an interactive web application using ShinyApps.io. This platform functions as a cloud-based hosting medium that allows R-Shiny applications to run online without requiring R to be installed on the user's device (Moschidis et al., 2023). Thus, students can access web browser simulations with only an internet connection, thereby increasing the ease of distribution and accessibility of learning media. Through the use of ShinyApps.io, researchers can update or improve application versions directly without requiring reinstallation on user devices. This makes the process of developing web-based learning media more efficient and sustainable (Kasprzak et al., 2020). In addition, the implementation of ShinyApps.io is also in line with the development of cloud-based learning environments that emphasize efficiency, scalability, and ease of integration of digital media in modern learning processes.

2.3 Data Analysis Techniques

The technique for analyzing validation data of parabolic motion simulation media using the R programming language is carried out by measuring the content of the research instruments of media experts and material experts using Aiken's V formula (Tajuddin et al., 2025) as follows:

$$V = \frac{\sum s}{n(c-1)} \tag{1}$$

Description:

s = r-lo

lo = lowest score on the rating scale

c = number of rating scale categories

r = score given by each validator

n = number of validators

The Aiken’s V index was selected in this study because it is specifically designed to quantify content validity based on expert judgments using rating scales. Compared to other validity indices, Aiken’s V is more appropriate for small numbers of experts and provides a clear coefficient that reflects the degree of agreement among experts regarding the relevance of each item. Therefore, it is widely used in educational research to assess the validity of learning media and instruments.The analysis of the validation results was conducted using the validity criteria of Aiken's V index shown in Table 1.

Table 1. Validity Criteria for Aiken's V Index

Validity Index	Criteria
0 ≤ V ≤ 0,4	Less Valid
0,4 < V ≤ 0,8	Valid
0,8 < V ≤ 1	Highly Valid

(Restyayulita et al., 2023)

3 RESULT AND DISCUSSION

3.1 Development Results

The final result of this research is an R-Shiny-based parabolic motion simulation medium developed to visualize projectile trajectories interactively in the form of static graphics and dynamic animations. This medium is designed so that users can understand the relationship between parabolic motion variables directly through digital exploration (Simarmata et al., 2025). The main features in this simulation include several key components, namely:

1. Control variables in the form of sliders and numeric input boxes to set the initial velocity (v_0), elevation angle(θ), and acceleration due to gravity (g).
2. Visualization of trajectories in the form of static graphics and dynamic animations, complete with markers for the starting point, peak point, and end point.
3. Track comparison feature, which allows users to compare two different tracks based on speed or angle variations.
4. Calculation results output, displaying maximum height, maximum distance, and total movement time. Appears automatically after the simulation is run.
5. The export feature allows users to download plots in PNG format and trajectory animations in GIF format, so that simulation results can be used as learning materials or digital lab reports.

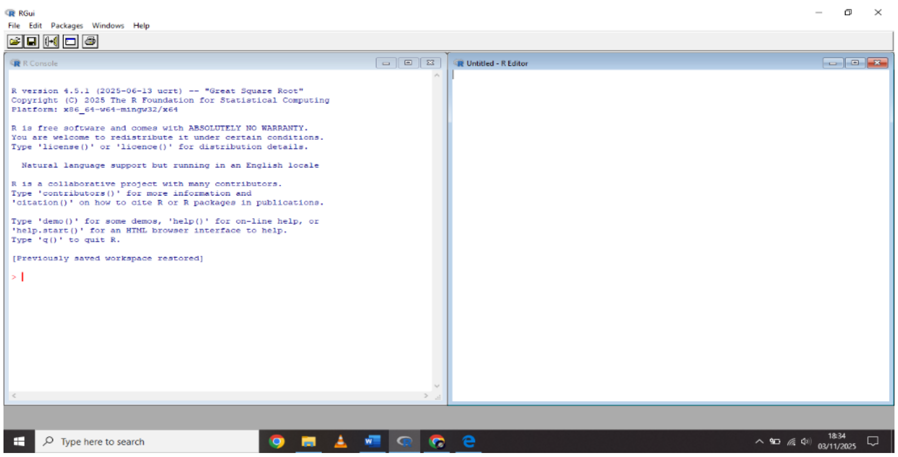

Figure 1. Initial display of R programming and the Rstudio console

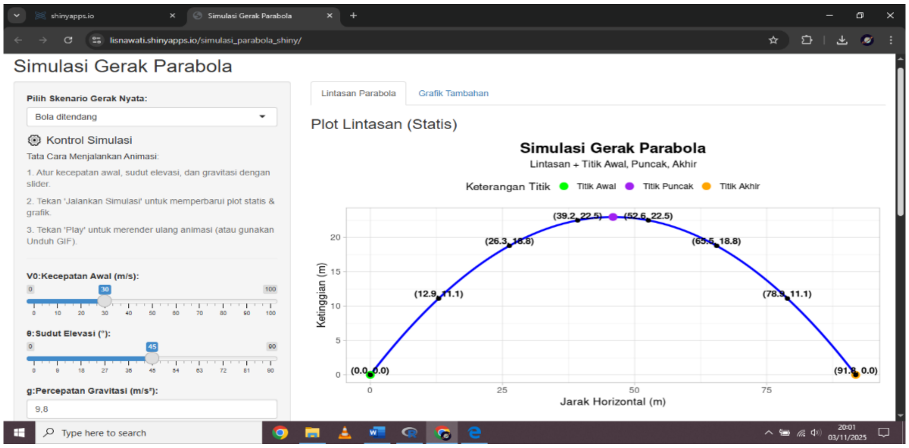

Figure 2. Parabolic Trajectory Simulation Display (Static)

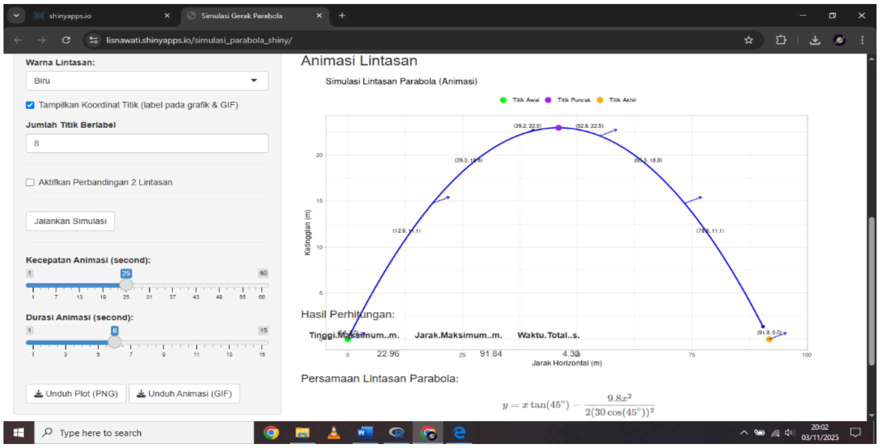

Figure 3. Parabolic Trajectory Simulation Display (Dynamic Animation)

The implementation of this simulation utilizes the parabolic motion formula with separation of horizontal and vertical components, namely:

$$x(t) = v_0 \cos(\theta) \, . \, t \tag{2}$$

$$y(t) = v_0 \sin(\theta) \, . \, t - \frac{1}{2} g t^2 \tag{3}$$

The simulation can display a parabolic trajectory along with the coordinates of important points (start, peak, end). The resulting trajectory visualization shows that the greater the angle of elevation, the higher the trajectory will be, but the horizontal distance traveled will be shorter. Conversely, a smaller angle results in a lower trajectory with a longer horizontal distance. At an angle of approximately 45°, the trajectory reaches its maximum distance in accordance with the theory of parabolic motion in classical physics. As also shown in research (Wulansari et al., 2023) that visual simulations of parabolic trajectories effectively help students understand the relationship between the angle of elevation and the horizontal distance of a projectile.

This simulation also displays the speed profile of the object at various points along the trajectory in real time. When the object reaches its highest point, its vertical velocity (v_y) becomes zero because its direction of motion momentarily stops before changing direction downward, while its horizontal component ($v_x = v_0 \cos(\theta)$) remains constant throughout the trajectory. This shows that the horizontal velocity is not affected by gravity, so the object continues to move horizontally at a constant velocity in the horizontal direction. The maximum total velocity occurs at launch and before the object hits the ground, when both velocity components (v_x, v_y) are at their maximum values.

In addition, this simulation provides a more concrete visual understanding of the relationship between variables. This feature allows students to independently study how changes in physical parameters such as initial velocity and gravity affect the shape of the trajectory and travel time. This simulation medium not only serves as a tool for visualizing the concept of parabolic motion, but also as a virtual experiment learning medium that can improve students' conceptual understanding of two-dimensional kinematics (Villavelez et al., 2025)

3.2 Expert Validation Results

The validation results were analyzed using Aiken's V index, which was selected because it is appropriate for measuring content validity based on expert judgment, particularly with a limited number of validators, and provides a clear quantitative measure of agreement.

Media expert validation was conducted to evaluate the interface design, interactivity, and system functionality of the developed parabolic motion simulation. The analysis resulted in an average Aiken's V value of 0.99, which falls into the very valid category (V > 0.8). All assessment items obtained values above 0.90, indicating a high level of consistency in the evaluation.

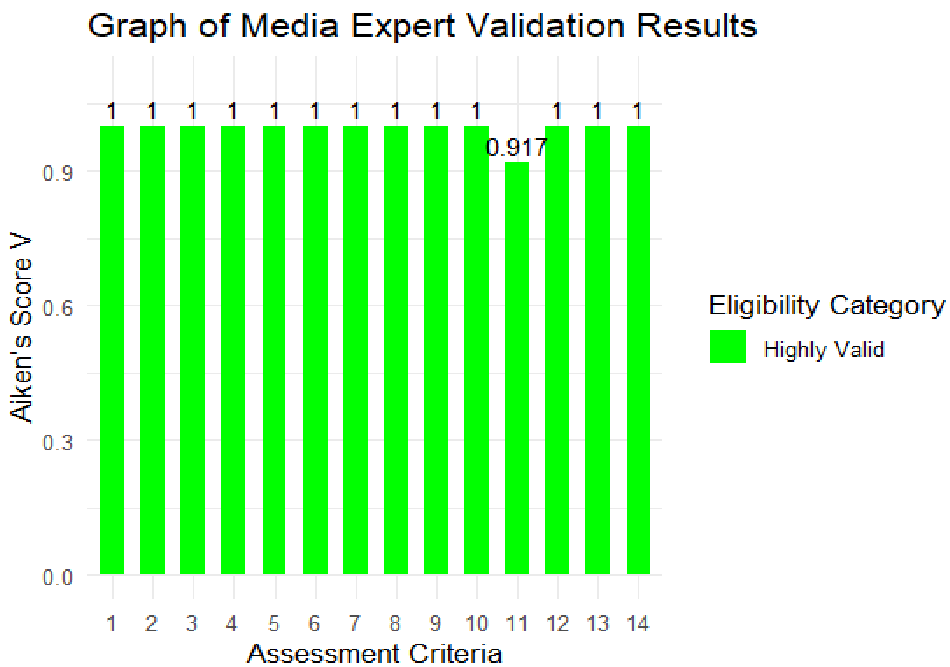

Figure 4. Media Expert Validation Results Chart

These results suggest that the developed simulation has a well-designed interface, effective navigation, and fully functional features without technical issues. The high validity score reflects that the media successfully meets usability and visual communication standards required for interactive learning media. This finding implies that the simulation is not only technically feasible but also capable of supporting independent learning by providing an intuitive and engaging user experience.

Material expert validation was conducted to assess the accuracy of physics concepts, alignment with learning objectives, and the integration of simulation features with theoretical content. The results showed an average Aiken's V value of 0.94, categorized as very valid (V > 0.8). Most items scored above 0.90, indicating strong agreement among experts regarding the conceptual accuracy of the simulation.

The results demonstrate that the simulation effectively represents key variables in parabolic motion, such as initial velocity, launch angle, time of flight, and horizontal range. The integration of graphical visualization and animation supports deeper conceptual understanding by allowing students to observe the relationships between these variables dynamically.

Although one item obtained a slightly lower score (V = 0.75), it still falls within the valid category, indicating minor aspects that can be improved without affecting the overall quality of the material.

Overall, these findings confirm that the simulation meets the standards of conceptual accuracy and instructional relevance, making it suitable for use in higher education physics learning.

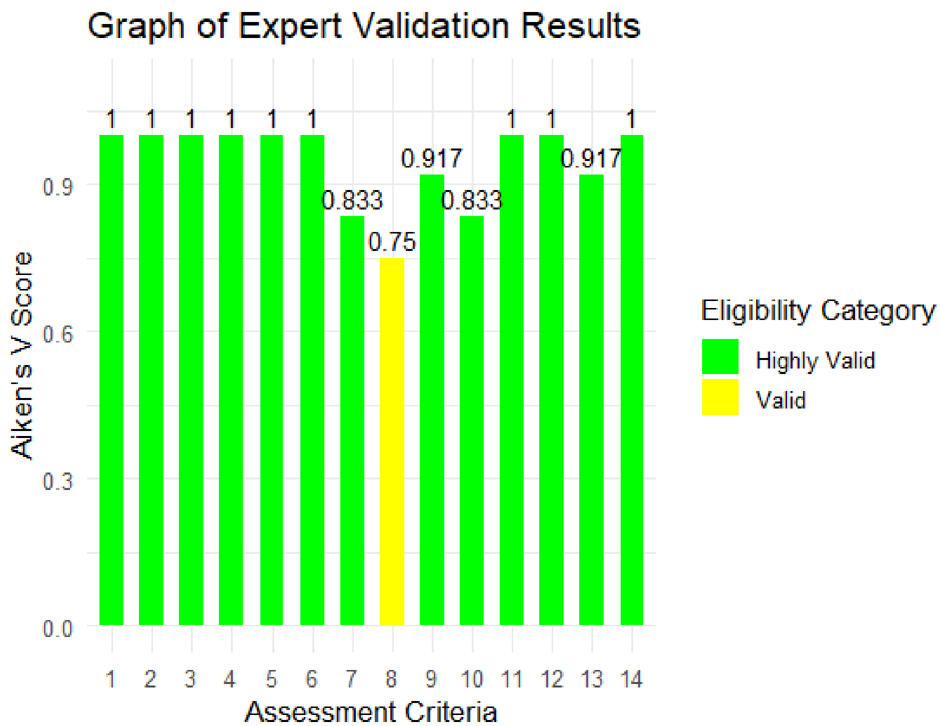

Figure 5. Material Expert Validation Results Chart

Based on the validation results from both media and material experts, the developed parabolic motion simulation using the R programming language is categorized as highly feasible. The high Aiken's V scores indicate that the media successfully integrates technical quality with conceptual accuracy.

3.3 Discussion

Based on the results of the validation test conducted by media experts and subject matter experts, it was found that the parabolic motion simulation media using the R programming language has a very high level of feasibility, both in terms of appearance and content. The average Aiken's V value for media experts was 0.994, while for subject matter experts it was 0.946, both of which are in the highly valid category. These results indicate that the developed media is not only visually appealing and easy to use, but also has content that is in line with the basic principles of physics regarding parabolic motion. The simulation allows students to adjust physics variables such as initial velocity, elevation angle, and gravity to see changes in the projectile's trajectory directly. This supports exploration-based learning, where students can discover relationships between variables through interactive experiences.

The results indicate that the developed interactive simulation media has high validity and strong potential to support students' conceptual understanding and engagement in physics learning. These findings are consistent with previous studies showing that simulation-based learning enhances understanding of abstract concepts through visualization and interactive exploration (Wulansari et al., 2023; Mahmuda et al., 2022; Faradila & Perdana, 2024). The use of the R programming language offers a distinct advantage by enabling data-driven exploration, allowing students to directly observe relationships between variables (Rizal et al., 2025). This supports a more meaningful learning process in which students actively construct their understanding through interaction with dynamic representations.

From an instructional perspective, the simulation facilitates inquiry-based learning by enabling students to manipulate key variables and observe their effects in real time. This process encourages experimentation and helps reduce the cognitive load associated with abstract concepts, thereby supporting the development of students' mental models. From a pedagogical perspective, the integration of interactive technology with the Alessi and Trollip model ensures that the media is both technically functional and pedagogically appropriate, promoting student-centered and exploratory learning. However, this study is limited to validity testing, and further empirical research is needed to examine its effectiveness in improving learning outcomes. Overall, the findings suggest that R-Shiny-based simulation has strong potential as an innovative instructional tool for teaching abstract physics concepts such as parabolic motion.

4 CONCLUSION

This This study developed an interactive R-Shiny-based simulation for parabolic motion that visualizes projectile trajectories through dynamic and user-controlled representations. The validation results (Aiken's V = 0.99 for media experts and 0.94 for subject matter experts) indicate that the media is highly valid and suitable for physics learning. The main contribution of this study is the integration of the R programming language with the R-Shiny framework and the Alessi and Trollip model, providing a novel, data-driven, and interactive approach to learning abstract physics concepts. This media supports instructional practices by facilitating visualization, exploration, and active learning in two-dimensional motion topics. However, this study is limited to expert validation. Future research is recommended to implement the simulation in real classroom settings and to evaluate its effectiveness through experimental studies on students' conceptual understanding.

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