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RESEARCH ARTICLE

Design of Physics Bullet Motion Prototype: Improving Conceptual Understanding of Parabolic Motion in High School Physics

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Abstract

Physics is hard to learn even though it is based on math and is abstract. When students use interactive media less, they lose interest and understanding of ideas, especially projectile motion. To help students understand abstract ideas better, this study shows how important it is to give them technology-based learning tools. The goal of this project is to help students understand parabolic motion better by using a microcontroller to make a Physics Bullet Motion prototype. The research and development (R&D) strategy used in the study was based on the 4D model (Define, Design, Develop, Disseminate), with a focus on the design phase. The prototype moved on its own like a projectile thanks to an Arduino UNO, a servo motor, PVC pipe, a proximity sensor, and a compressor. When the button was pushed, the microcontroller let go of the rocket and changed the launch angle and air pressure. This design changes the way the classroom works by moving from passive observation to active inquiry. It also lets students use real-time data manipulation to bridge the gap between abstract mathematical models and the real world. This prototype lets teachers show that horizontal and vertical velocities are not related, which is a common misunderstanding, through accurate, repeatable trials that can't be done with regular manual launches.

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INTRODUCTION

Physics, a fundamental discipline of science, seeks to elucidate natural phenomena through methodical observation, experimentation, and scientific reasoning. It is made up of a network of related ideas, rules, and laws that help us understand the physical world (Nur & Affandi, (2022). Nonetheless, physics is frequently regarded as a challenging discipline due to its demand for advanced abstract reasoning and mathematical expertise (Yanti & Khasyyatillah (2017). This perception results in diminished learning motivation and inadequate conceptual comprehension, thereby obstructing the attainment of optimal learning outcomes (Fauziah et al., (2021).

Several studies have shown that students often have trouble understanding physics concepts when they are learning. Rohmah et al., (2025) found that students have a hard time understanding physics concepts because they don't use interactive learning methods and instructional media very often. In the same way, Ansya et al., (2024) and Murphy et al., (2021) found that teacher-centered learning makes students less interested and excited about learning. Mardatila et al., (2023) also said that not putting enough emphasis on basic ideas often makes students rely on rote memorization instead of understanding what they are learning. This problem is not limited to specific regions; it is a global phenomenon. Studies conducted by Kotsit, (2024) and González et al., (2024) reveal that numerous students globally continue to have difficulty linking physics concepts to real-world applications, leading to enduring misconceptions and inadequate conceptual transfer.

High school students often struggle with projectile (parabolic) motion because it combines both kinematic and dynamic principles. Research has shown that students often get the path of projectiles wrong, mix up the horizontal and vertical parts, and don't understand how gravity works (Hidayatulloh et al., 2024; Kusari et al., 2019). This abstract material is even harder to understand when it is only taught through lectures and formulas. As a result, students do not develop a comprehensive conceptual framework, despite the necessity of mastering fundamental concepts for meaningful learning outcomes (Wandi et al., 2024)

To deal with these problems, many people have suggested using interactive and experiment-based teaching tools. Students can use teaching aids and prototypes to help them see physical phenomena, test their ideas, and connect abstract ideas to real-life situations (Bigozi et al., 2018). These tools not only make lessons more interesting and real, but they also help students focus and be more creative, and they help teachers teach the material better.

With technology moving so quickly, microcontroller-based learning media have become a promising new way to teach physics. They provide adaptability, efficacy, and the capacity to surmount temporal and resource limitations (Sulimro et al., 2023; Boimalu & Mellu, 2019). In this case, the current study focuses on the design phase of the Physics Bullet Motion prototype, a new teaching tool that combines a pneumatic system with automated servo-controlled mechanisms to help students understand projectile motion. This design output is anticipated to establish a foundation for subsequent development phases and to facilitate the creation of innovative, technology-driven educational resources that improve conceptual comprehension and foster engagement in the study of physics.

METHOD

This study adheres to the Research and Development (R&D) framework established by Thiagarajan, (Sugiyono, 2019), focusing specifically on the Define, Design, and initial Develop stages. This research is confined to the design phase. During the Define stage, a Guttman scale was used to figure out what teachers and students at MAN 2 Deli Serdang needed. During the Design phase, the conceptual framework and technical specifications for the Physics Bullet Motion prototype were developed, incorporating an Arduino UNO, proximity sensors, and a pneumatic system.

The participants in this study include teachers and students from MAN 2 Deli Serdang, specifically Class XI MIA students in the first semester of the 2022/2023 academic year, along with two physics teachers. In this study, data collection entailed direct observation and the dissemination of questionnaires featuring needs assessment forms, which were administered directly to students and physics teachers. We used a measurement scale based on the Guttman scale to look at the results of the needs assessment questionnaire. The Guttman scale consists of multiple-choice questions or checklists. For positive statements, a score of 1 is given for "Yes" and 0 is given for "No." For negative statements, the scoring is reversed. The next step, design, is all about figuring out the overall look and feel of the teaching aid, including how the product will be made. We use the following equation to look at and show the results of each question.

This study mainly looks at the design phase, but it also includes the first stage of development, the design phase, and the expert validation phase to make sure the prototype is possible and useful for teaching.

$$P = \frac{\text{The ratio of respondents answers}}{\text{The maximum number of answers in the item}} \times 100\% \quad (1)$$

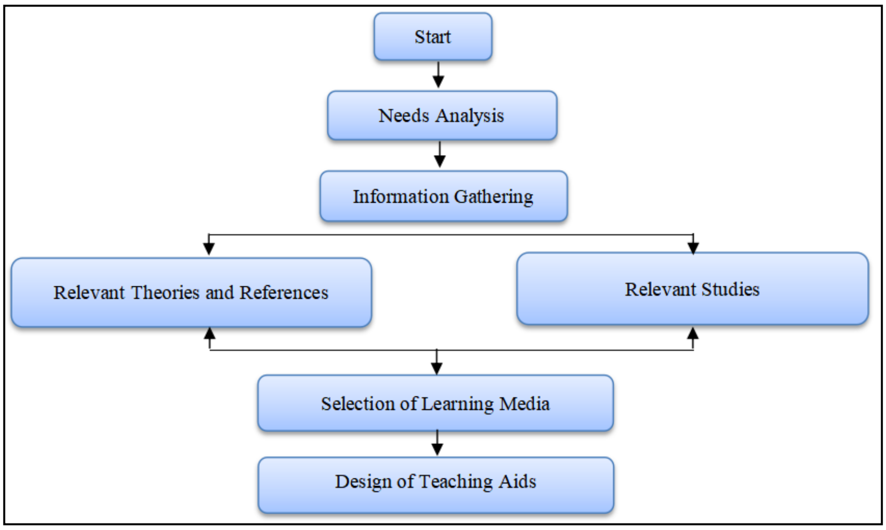

Figure 1. Research Flowchart

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Expert validation, to ensure the feasibility of the designed prototype, a formative evaluation through expert validation was conducted. Two experts in physics education and instructional technology assessed the design using a validation instrument covering aspect of pedagogical affordance, technical durability, and content accuracy. This step ensures that the transition from the 'Design' to the 'Develop' stage is grounded in professional instructional standards.

RESULT AND DISCUSSION

Define Stage

The questionnaire results from grade XI MIPA students led to several conclusions regarding their learning interests, conceptual comprehension, and classroom learning methodologies. The findings indicated that the students' comprehension score (75.07%) was moderate, whereas their interest in physics (36.30%) was relatively low. The statistics also showed that lecture-based methods were still the main way to teach physics (94.55%), and that the use of learning media, especially teaching aids, was still low (28.3%). This situation shows that there is no interactive involvement that helps people learn concepts. Consequently, students exhibited inadequate problem-solving abilities (39.6%), suggesting that their education has not yet facilitated higher-order thinking (Rizaldi et al., 2023).

These empirical findings align with prior research conducted by Ansya et al. (2024), which indicated that restricting media usage and emphasizing teacher-centered instruction diminishes students' motivation and conceptual understanding. They also support the broader claim made by Hidayatullah et al. (2024) that students worldwide often struggle to link theoretical knowledge to real-world facts, leading to errors and ineffective concept transfer. Consequently, the needs analysis for this stage underscores the imperative to develop innovative, technologically sophisticated teaching instruments that foster enhanced engagement and experiential learning in physics classrooms. Our findings corroborate research indicating that interactive learning materials can improve scientific literacy and reduce misconceptions (Andriyani et al., 2024).

Design Stage

The design stage is when you plan based on what you learned in the last stage. The main goal of this phase is to make sure that the process of making the instructional aids is well-organized, efficient, and planned. To help with the planning process, this method starts by getting information on the materials and equipment needed for the teaching aid prototype. Planning is based on coming up with ideas, which starts with using information from scientific articles and reference books to draw the basic design of the Physics Bullet Motion prototype. The prototype uses both mechanical and electronic systems to mimic projectile motion in real time. These systems include an air compressor, servo motors, and sensors that use microcontrollers (Arduino UNO). During the design phase, 3D visualization was done with SketchUp.

Using SketchUp for high-fidelity 3D visualization, mechanical and electronic systems were successfully combined during the design phase. This method cut down on mistakes in production by letting parts like the air compressor and servo motors be perfectly arranged in space before they were put together. This study demonstrates the transformation of inexpensive materials, such as PVC and Arduino, into sophisticated laboratory apparatus capable of simulating real-time projectile motion by integrating digital modeling with physical prototyping. This technical integration makes sure that the apparatus can be easily replicated by other researchers using the right parts.

The integration of SketchUp for 3D visualization before physical assembly serves as a crucial "pre-manufacturing" phase that ensures spatial efficiency of the electronic components. Theoretically, this device reinforces the 'Science Empathy' concept, where students do not just calculate variables but interact with the 'behavior' of the projectile. Unlike virtual simulations that can be perceived as 'pre-programmed' by students, the Physics Bullet Motion provides raw, tangible data that proves gravity's consistent effect, thereby neutralizing common misconceptions regarding the path of motion.

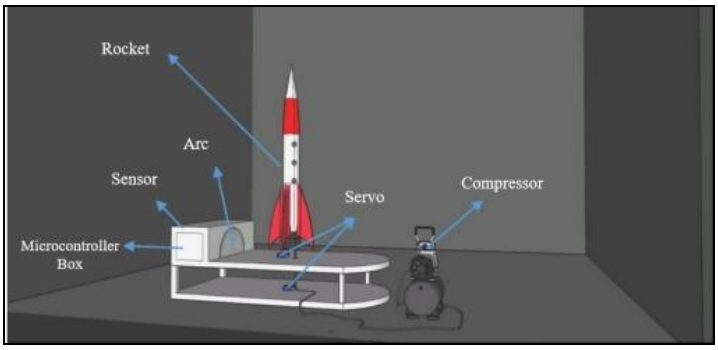

Figure 2. Components of the Physics Bullet Motion

Figure 3. Design of the Physics Bullet Motion

Upon pressing the push-button, the system activates: the microcontroller commands the compressor to fill the rocket with air; simultaneously Servo I adjust the rocket to a predetermined elevation angle. Once the air has reached the programmed level, the compressor deactivates. A proximity sensor then signals the microcontroller, which activates Servo II to retract the air hose and launch the rocket to a specified distance.

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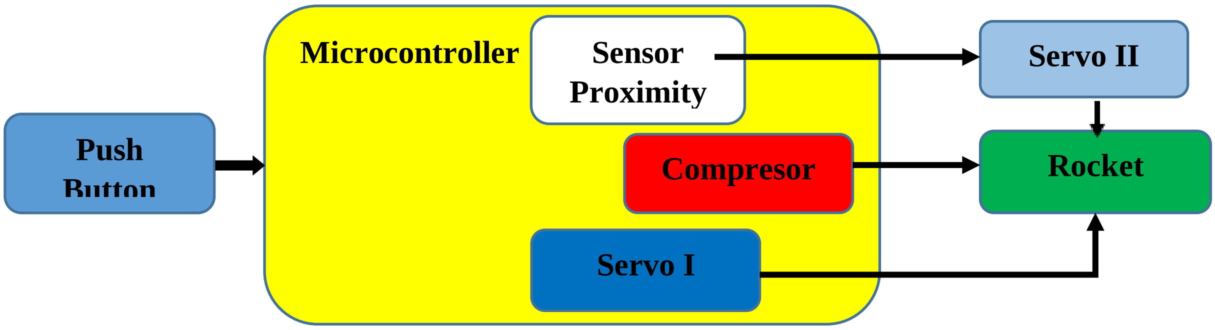

Figure 4. Techniques for Implementing Physics Bullet Motion

The use of such a prototype corresponds to constructivist learning theory, which emphasizes that students build their understanding through hands-on experiences and interaction with their learning environment (Piaget, 1972; Vygotsky, 1978). Through visual and kinesthetic experiences, students are expected to bridge the gap between abstract mathematical formulas and observable phenomena. As suggested by Waish & Magana, (2019) learning that involves visualization and direct manipulation of variables can significantly enhance students' conceptual understanding. Similarly, Faresta et al., (2024) demonstrated that integrating technology-based visualization tools helps learners comprehend projectile motion more effectively.

From a pedagogical perspective, this design also aligns with experiential learning theory, where learners engage in concrete experiences, reflective observation, and active experimentation. The Physics Bullet Motion prototype provides opportunities for students to observe, predict, test, and reflect, enabling them to internalize the underlying principles of parabolic motion. Moreover, by using digital sensors and microcontroller systems, the prototype offers measurable and reproducible data, which can stimulate scientific inquiry and data-driven reasoning—two essential competencies in modern physics education.

Implications & Future Directions

The study's findings and design outcomes have several implications for the future of physics education. The Physics Bullet Motion prototype can be the first step in making high-tech, interactive lab tools that help people understand abstract physics concepts. Second, the design process contributes to the growing body of research that integrates engineering design concepts into scientific education (STEM approach) by fostering creativity and problem-solving skills.

In the long run, this prototype could help create learning environments that are based on projects and questions, where students can change variables, gather information, and look at motion paths on their own. To evaluate the proposed design's effectiveness in improving students' conceptual understanding, engagement, and scientific reasoning, it can be further validated through implementation and testing in classroom environments. Consequently, our research propels both pedagogical innovation that links theoretical physics to practical applications and the design of instructional media.

CONCLUSION

This study successfully integrated digital sensors, pneumatic systems, and microcontrollers into a cohesive prototype of the Physics Bullet Motion tool. By transforming abstract mathematical formulas into tangible physical phenomena, this design facilitates a deeper visualization of parabolic motion concepts. The primary contribution of this work lies in providing a high-precision yet low-cost STEM framework, particularly beneficial for educational institutions with limited laboratory resources. Unlike pure virtual simulations, this prototype supports the paradigm that direct manipulation of physical variables with real-time data feedback is more effective in fostering conceptual understanding. While currently in the advanced design and initial validation stage, this tool demonstrates a significant shift from teacher-centered lectures toward evidence-based inquiry. Future research will focus on large-scale classroom implementation, utilizing metrics such as normalized gain (N-gain) to provide robust empirical evidence of its pedagogical effectiveness in reducing student misconceptions.

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