3D-Printed Projectile Demonstrator and Its Implications on Students' Conceptual Understanding and Attitudes toward Physics

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ABSTRACT

Purpose of the study: This study aimed to develop, evaluate, and implement a 3D-printed Projectile Demonstrator (3D-PPD) as an instructional tool for projectile motion, and analyze its implications on students' conceptual understanding of projectile motion (CUPM) and attitudes toward physics (ATP).

Methodology: The study employed a developmental and quasi-experimental research design. The 3D-PPD was designed using AutoCAD for 3D modeling and printed using a Bambu Lab X1 Carbon with AMS multicolor 3D printer. Research tools included survey and test questionnaires, an evaluation rating sheet, and a weekly learning plan. Statistical tests such as inferential statistics were performed using Jamovi software.

Main Findings: The 3D-PPD received "very satisfactory" ratings in design *($M = 3.62$, $SD = 0.27$)*, instructional quality *($M = 3.53$, $SD = 0.36$)*, and cost-benefit *($M = 3.40$, $SD = 0.38$)*. It significantly improved students' CUPM *($p < 0.05$, $d = 0.90$)* but showed no significant improvement in ATP *($p = 0.294$, $d = 0.43$)*. Furthermore, the correlation analysis between CUPM and ATP after exposure to the 3D-PPD yielded a p-value of *0.818*, indicating a statistically insignificant relationship.

Novelty/Originality of this study: This study pioneers the development of an instructional tool through 3D printing, recognizing how modern fabrication technologies can concretize abstract physics concepts and offer scalable solutions to instructional material gaps in physics education. It also offers a significant insight into distinct students' learning dimensions which emphasizes the need for contextualized support to inform future instructional design and research.

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1. INTRODUCTION

A solid grasp of scientific principles is deemed vital for fostering innovation and achieving sustainable development worldwide. The United Nations Educational, Scientific and Cultural Organization (UNESCO), within its Education for Sustainable Development (ESD) framework, acknowledges the role of science education in cultivating the skills and values essential for a sustainable future. The importance of quality education (Goal 4) and the promotion of scientific literacy for all is also emphasized in the United Nations' Sustainable Development Goals (SDGs). However, UNESCO's High-Level Reflection Group, in its October 2020 meeting, noted that Science is in crisis, highlighting the need to strengthen science education as a core intervention.

This crisis is characterized by several challenges, including declining student interest in science-related fields, gaps in scientific literacy, and the inability of many educational systems to equip students with skills to apply scientific knowledge. Moreover, disparities in access to quality science education persist, particularly in developing countries, where inadequate resources, outdated curricula, and ineffective teaching strategies contribute to poor learning outcomes.

In the Philippines, the K to 12 Science Curriculum was established with the objective of developing scientifically literate learners who can utilize scientific knowledge in addressing real-world problems. Nevertheless, despite this reform, the nation continues to trail behind other countries in terms of science education quality. According to the 2018 World Economic Forum report, the Philippines ranked 76th out of 137 countries regarding the quality of its science education system. Further research has identified various factors influencing the perceived quality of science education in the Philippines. A key factor contributing to this concern is the insufficiency of instructional materials and teaching resources that align with the learning competencies set by the Department of Education (DepEd). Many teachers encounter difficulties in effectively delivering complex scientific concepts due to the limited availability of relevant, research-based, and responsive learning materials. This challenge is evident in the low science achievement scores of Filipino students in international large-scale assessments such as the Programme for International Student Assessment (PISA).

The latest PISA results conducted by the Organization for Economic Cooperation and Development (OECD) revealed that the Philippines ranked last among participating countries, with science as one of the tested subjects [1]. The average scientific literacy of Filipino students score falls under Proficiency Level 1a, indicating that a typical 15-year-old in the country can only apply basic scientific knowledge to recognize or identify explanations for scientific phenomena but struggles to use complex scientific concepts to explain familiar situations independently.

Physics, a branch of the natural sciences, focuses on the study of nonliving natural phenomena and matter within the dimensions of space and time [2]. Its contributions to the advancement of science and technology are substantial, offering numerous benefits that enhance human life [3]. Fortunately, physics education continues to evolve through ongoing research aimed at improving instructional methods and student learning outcomes [4]. But despite efforts, significant gaps remain in students' understanding of fundamental physics concepts [5].

Research has shown that many students struggle with mastering physics due to the abstract nature of its concepts, inadequate teaching methods, and a lack of effective instructional materials. Data gathered from pre- and post-assessments indicate that a significant proportion of students enrolled in introductory physics courses struggle to develop a meaningful understanding of core concepts. Additionally, many exhibit difficulties in engaging with scientific inquiry processes and in applying scientific reasoning [6]. These challenges are further magnified in developing countries where access to quality science education is limited. A review of the state of physics education in the Philippines reveals that Filipino students struggle, particularly when they lack direct experiences related to the topics [7], [8]. They also struggle due to inadequate resources and ineffective teaching strategies. Given these challenges, an even more concerning problem emerges.

A study revelead that weak conceptual understanding hinders students' ability to absorb new knowledge, thereby disrupting the learning process [9]. Many students develop a negative attitudes toward physics due to the subject’s perceived difficulty and the effort required to solve numerical problems [10]. With this, student attitude becomes a significant factor influencing academic performance, as those with low motivation are less likely to engage actively in learning [11]. These challenges highlight the importance of both conceptual understanding and attitudes toward physics as key dimensions of students' learning.

One of the topics in the area of physics being taught for grade 9 students is projectile motion. Despite decades of instructional innovation, many learners continue to struggle with persistent misconceptions, fragmented understanding, and limited engagement in lessons on this topic [12]. Traditional classroom strategies often rely on textbook illustrations or static demonstrations, which can fail to capture the dynamic and visual pertains to the movement of an object launched into the air under the influence of gravity. In many cases, the improvised instructional tools used by teachers are limited in terms of accuracy, durability, and their ability to accurately reflect essential physical relationships.

Despite various efforts to enhance projectile motion instruction, previous studies have either focused on lesson delivery without incorporating physical materials Abatayo et al. [13], developed print-based interventions lacking hands-on engagement Malabana-Paredes [14], or introduced demonstrator tools without empirical classroom testing Basagre et al. [15]. Moreover, it has been recognized that there is a need to explore the interplay between students’ conceptions of learning, problem-solving ability, motivation, and self-regulation, particularly when situated in diverse learning environments. This underscores the importance of designing interventions that are not only conceptually sound but also motivational and engaging for learners [16].

In light of these challenges, there is growing interest in rethinking the development of instructional materials. In recent years, three-dimensional (3D) printing has gained increasing attention for its ability to concretize complex scientific concepts through the production of tangible, interactive models [17]. Beyond visualization, 3D printing fosters 21st century skills by allowing students to interact with customized, real-world models designed for exploration and experimentation. The urgency of integrating 3D printing technology in physics education stems from its unique capacity to produce durable, customizable, and easily reproducible instructional materials. Unlike traditional laboratory tools, 3D-printed models can be tailored to specific learning goals, allowing educators to address particular misconceptions or curricular needs with precision. Their cost-effectiveness and replicability make them especially valuable in under-resourced schools, where access to standard equipment is limited.

To maximize the potential of 3D printing in educational settings, however, it is not enough to simply introduce the technology. Effective implementation requires thoughtful integration into the curriculum and the development of instructional tools that are pedagogically sound, technically accurate, and engaging for learners. Addressing long-standing challenges in physics instruction, this study presents an innovative approach to developing teaching materials that combine modern fabrication techniques with instructional best practices.

The primary objective of this study is to develop and evaluate an instructional material on projectile motion and analyze its effect on students. Specifically, this study aimed to design and develop a 3D-Printed Projectile Demonstrator (3D-PPD), which will be evaluated according to design, instructional quality, and cost-benefit. It also seeks to determine if the use of the 3D-PPD has a significant effect on students in the experimental group compared to those in the control group in terms of their conceptual understanding of projectile motion and attitude towards physics. Lastly, the study aims to analyze the relationship of students' attitude towards physics to their conceptual understanding of projectile motion when exposed to the 3D-PPD. Through addressing these objectives, the study aims to contribute a scalable and innovative solution to current gaps in physics instruction which can empower teachers, engage learners, and elevate the quality of physics education.

2. RESEARCH METHOD

2.1. Research Design and Research Method

In this study, developmental and quasi-experimental research designs were utilized to address the objectives related to the development, evaluation, and implementation of the 3D-Printed Projectile Demonstrator (3D-PPD). First, developmental research design was utilized to design, develop, and evaluate the 3D-PPD, which served as the instructional intervention. This study followed Type 1 developmental research (Description or Analysis of Product or Program Design, Development & Evaluation), focusing on analyzing and describing the 3D-PPD's development process and evaluation. This method supports the iterative creation and refinement of educational tools in authentic settings, enabling researchers to generate both practical solutions and theoretical insights [18].

Second, a quasi-experimental design using a two-group pretest-posttest format was employed to determine the cause-and-effect relationship among the study variables. Both experimental and control groups took pretests and posttests, but only the experimental group received the intervention. The design assessed whether the intervention led to greater improvement in the experimental group compared to the control group. It can be noted that the adoption of quasi-experimental methods across the field of education was largely influenced by the broader credibility revolution in the social sciences. These methods have proven especially promising in evaluating the effects of educational policies and instructional interventions when random assignment is not feasible [19].

To address the objectives of the study, appropriate research methods were employed corresponding to the two research phases. or the development phase, document analysis and survey methods were utilized. In this study, document analysis was used to examine curriculum guides, existing instructional tools, and relevant literature to guide the design of the 3D-PPD. Meanwhile, the survey method was applied to gather expert feedback and learner responses essential to the iterative improvement of the material. These methods were selected based on their suitability in addressing the goals of the study, particularly in developing and evaluating a context-specific instructional innovation. The integration of these methods reflects the growing emphasis on aligning research methodology with education quality standards and learning outcomes, as advocated in contemporary instructional design literature and reflects quality-driven instructional practices that emphasize evidence-based development and stakeholder input [20].

Furthermore, a quantitative research method was utilized to obtain numerical data on the evaluation results, effects of the 3D-PPD on students' conceptual understanding on projectile motion (CUPM) and attitude towards physics (ATP), as well as the relationship between these learning dimensions. Statistical analysis included descriptive statistics to summarize and analyze the evaluation results, and inferential statistics to determine the initial comparability of participants, assess the intervention's effect, and analyze the relationship between CUPM and ATP when students were exposed to the 3D-PPD.

2.2. Participants

The study involved two groups of participants, identified as the experimental group (EG) and control group (CG). Each group corresponded to one section of Grade 9 students from the Computer Science High School of Bicolandia (CSHB). Total enumeration was employed; hence, all students from the two sections were included as respondents. A comparability test was conducted to ensure the reliable assignment of groups.

To identify the population of evaluators for the 3D-PPD, expert sampling was used to select individuals based on their specialized knowledge in the field. This qualified body of experts was composed of five secondary school teachers with specialization in Science. Likewise, there were student validators, composed of Grade 10 students from Central Bicol State University of Agriculture – College of Development Education (CBSUA-CDE) Laboratory High School, where total enumeration was employed.

2.3. Research Instruments

The researcher utilized four primary research instruments in this study. These instruments includes questionnaires to determine students' CUPM and ATP, evaluation rating sheet to evaluate the developed instructional tool, and a weekly learning plan to guide the implementation of the 3D-PPD.

To determine students' CUPM, the researcher adapted a validated test questionnaire used in the study of Gainsan [21]. This 30-item multiple-choice questionnaire aims to assess students' knowledge and understanding of concepts related to projectile motion. This instrument was applicable to the study as it aligns with the learning competencies outlined in the K to 12 Science Curriculum. In terms of students' ATP, the researcher adapted a 22-item attitude scale used in the study of Mbonyiryivuze [10] which was validated and tested for reliability. These two questionnaires mentioned were administered as before and after the implementation of the 3D-PPD. The pretest was conducted to ensure the initial comparability. In contrast, the posttest helped determine whether the use of the 3D-PPD has a significant effect on students' CUPM and ATP.

To evaluate the 3D-PPD, the researcher adapted a validated evaluation rating sheet used in the study of Basagre et al. [22], which is aligned on the guidelines provided in the DepEd Learning Resources Management and Development System (LRMDS). The evaluation rating sheet used a 4-point Likert scale to assess the 3D-PPD in terms of design, instructional quality, and cost-benefit. Lastly, this study utilized a researcher-made Weekly Learning Plan (WLP), which was reviewed by the Science teacher who handles the CG and EG. The learning plan aligned with the prescribed 240-minute weekly instructional time, as stated in DepEd Order No. 021, series of 2019. Since the study covers two learning competencies, the instructional time for each group spanned eight hours in total.

2.4. Procedures

The data gathering procedure focused on the development, evaluation, and implementation of the 3D-PPD, and it was divided into two phases: (1) the development phase, which consisted of four stages, and (2) the implementation phase.

Development Phase

This phase involved the use a 4D model by Thiagarajan in 1974 to develop the 3D-PPD, which served as the intervention. The 4D Model was chosen for its systematic and iterative approach to instructional development, particularly in creating effective educational tools that are grounded in learner needs and instructional goals [23]. It is divided into four stages as follows:

Define Stage

The define phase began with a preliminary analysis to guide the development of the 3D-PPD. The researcher reviewed related literature and studies to gain overview of the facts and the fundamental problems in learning science and physics. Local and international assessment results were also reviewed to determine common misconceptions and learning gaps. Next, the DepEd K to 12 Science Curriculum Guide and Most Essential Learning Competencies (MELCs) were used as a basis for identifying the key concepts students must learn and learning competencies in projectile motion.

Design Stage

The design of the 3D-PPD was planned in this stage, which included identifying design parameters, sketching the initial design, and creating a 3D model. The process began with specifying the projectile motion concepts that the 3D-PPD should demonstrate. After identification, the initial design was sketched with consideration of three design parameters: design, instructional quality, and cost-benefit. Design included the shape, size, and components needed to build the 3D-PPD. Instructional quality focused on the interactive elements that can allow students to manipulate the device for a hands-on learning experience. After finalizing the sketch, it was converted into a 3D digital model in consultation with a licensed mechanical engineer using AutoCAD, a computer-aided design software. This step ensured precision in design and accurate component specifications, aligning the 3D-PPD with the established parameters.

Develop Stage

This stage included the 3D-PPD development and evaluation. The physical model was constructed based on the finalized design. Some components of the 3D-PPD that are already available in the local market was purchased, while the main components undergone 3D printing at BISCAST Manufacturing and Testing Laboratory and a 3D printing laboratory based in Metro Manila, and printed using a Bambu Lab X1 Carbon with AMS multicolor 3D printer. The specifications for 3D printing was customized based on the desired durability and functionality of the components. The 3D printing process enabled the customization of component size and color, making the model more suitable and visually engaging for classroom instruction. This flexibility also enabled the production of parts optimized for ease of handling and clear visual distinction, which are essential for effective student interaction and learning. Labels, instructions for use, and safety precautions were also integrated into the developed 3D-PPD to ensure efficient and safe utilization. After assembly, the evaluation process was conducted. To assess the 3D-PPD, teacher and student evaluators evaluated its instructional and technical quality using the evaluation rating sheet. The researcher presented the device, explained its features and its relation to projectile motion, and facilitated a discussion. An appointment was set with the evaluators to facilitate a face-to-face demonstration of the 3D-PPD, during which they were provided with hard copies of the evaluation forms. The duration of the demonstration and evaluation varied depending on the evaluators' questions and requests for clarification. After evaluation, the responses was compiled through data presentation in tables and statistical analysis to determine the overall evaluation results of the 3D-PPD.

Disseminate Stage

After the evaluation, the 3D-PPD was implemented and used as an instructional intervention in teaching projectile motion. It was the primary instructional material used to achieve the two learning competencies identified. This was followed by the implementation phase.

Implementation Phase

To examine the effect of the 3D-PPD on students, the implementation was conducted. The researcher first administered a pretest in hard copy to determine comparability between the CG and EG before proceeding with the intervention. After determining the comparability, the researcher implemented the intervention using the WLP as a guide. The plan for the experimental group focused on the use of the 3D-PPD, while the control group will receive conventional instruction. Afterward, posttest was administered to both groups. The pretest and posttest results were then compiled and statistically analyzed to determine the effect of the 3D-PPD on students' CUPM and ATP. Additionally, the data obtained were used to analyze the relationship between the two learning dimensions after exposure to the intervention. These steps ensured that necessary improvements or recommendations were identified and addressed.

2.5. Data Analysis

A range of statistical techniques was utilized in this study to analyze the data systematically and to derive meaningful interpretations from the results. Descriptive statistics, including frequency counts, means, and standard deviations, were employed to quantify occurrences. These methods facilitated the evaluation of the 3D-PPD and the synthesis of pretest and posttest outcomes. To evaluate data distribution and guide the choice of statistical tests, the Shapiro-Wilk test was administered to assess normality, while Levene's test was used to test the homogeneity of variances between the CG and EG. For inferential analysis, a combination of parametric and non-parametric tests was applied. The Mann-Whitney U-test was utilized as a non-parametric counterpart to the independent samples t-test in cases where the assumptions of normality or equal variances were not satisfied. The independent samples t-test was conducted to compare pretest and posttest scores across the groups, and Cohen’s d was computed to determine the effect size, indicating the magnitude of differences in posttest outcomes. Cohen’s d was selected because it provides a standardized metric to assess how meaningful the observed differences are, and enables educational researchers to go beyond statistical significance [24]. Additionally, Pearson correlation analysis was performed to explore the relationship between students' CUPM and ATP following the implementation of the 3D-PPD. It was employed to identify whether changes in one variable are associated with changes in another, thus revealing the extent to which students’ cognitive understanding may be linked to their affective responses [25]. All statistical analyses were carried out using Jamovi software.

3. RESULTS AND DISCUSSION

3.1. Developed 3D-Printed Projectile Demonstrator (3D-PPD)

The instructional tool developed in this study, called the 3D-PPD, was designed to visually demonstrate key concepts in projectile motion, including horizontal and vertical motion, launch angle, maximum height, and range of a projectile. As shown in figure 1, the main components of the 3D-PPD include the launch angle protractor which mainly functions to measure launch angles, and serves as the supporting and housing structure of the other internal components.

Figure 1. 3D-Printed Projectile Demonstrator (3D-PPD)

Another component of the 3D-PPD is the launcher which functions to launch projectiles. It can be adjusted and aligned with a preferred launch angle by tilting it against the reference measurements in the protractor frame. The launcher features a stainless steel compression spring inside it and a lever that sets the launch position and triggers projectile's launch. The third components are the two retractable rulers for measuring maximum height and range of a projectile during and after launch, respectively. The fourth and final main component is the projectiles for the 3D-PPD, which are small chalk balls inserted into the launcher one at a time per launch. These are stored in a transparent acrylic box. The 3D-PPD also features a protective case that can be used to cover the components when not in use, thereby preventing further damage. The components of the 3D-PPD are properly labeled to facilitate ease of use and understanding. Further, the parts include the lever, which is used to launch projectiles, and the bracket hinge, which is used to connect the launcher and support it in place of the protractor frame.

The 3D-PPD functions by manipulating its mechanical components during setup and operation. The launcher operates through a spring compression mechanism. It is mounted on a bracket hinge and secured with a lock nut, allowing easy adjustment of the launch angle. To set up a launch, the lever is positioned within a designated gap in the launcher, compressing the internal spring. When the lever is pulled or released from the gap, the spring decompresses, generating the force needed to propel the projectile forward. This mechanism ensures controlled and consistent launches while allowing for angle adjustments based on the protractor frame's reference measurements.

Figure 2 shows the 3D model of the 3D-PPD. This model served as a guide and reference in constructing the 3D-PPD, including the assembly of its components. It was primarily utilized during the development phase, which involved 3D printing of some of the components and parts. The 3D printing process was configured with specific settings to ensure durability, as well as resistance to heat and impact, making the parts suitable for enduring stress during use. The printing parameters were as follows: a layer height of 0.20mm, 15% rectilinear infill, two wall loops, and the use of acrylonitrile butadiene styrene (ABS) filament.

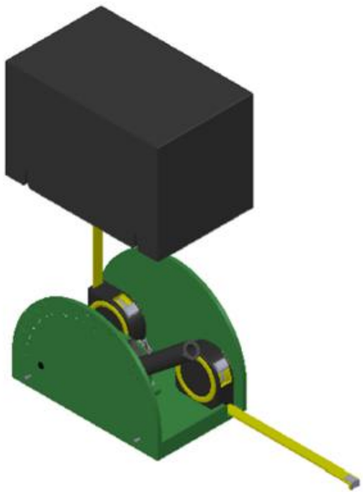
Figure 2. 3 D Model of the 3D-PPD

The chosen printing parameters strike a balance between print quality, mechanical strength, and cost-effectiveness. In reference to the study by Popovski et al. [26], which explored the infill print design's impact on fabrication cost for 3D printed ABS parts, a 0.20 mm layer height provides sufficient surface resolution for functional prototypes without significantly increasing print time. The 15% rectilinear infill offers a lightweight internal structure that delivers substantial cost savings while maintaining adequate strength for bending and tensile loads. The study revealed that low-density infill can achieve mechanical performance comparable to higher-density options but at a reduced production cost, especially important for mechanical applications like classroom instructional tools. Similarly, Kefalis et al. [27] emphasized how 3D printing enhances STEM education by enabling the development of customized, interactive materials that foster engagement, problem-solving, and inclusivity.

This development of 3D-PPD through 3D-printing as an instructional tool for projectile motion contributes to the field by demonstrating how optimized 3D printing parameters can be applied to fabricate functional, low-cost instructional tools for physics education. It offers a practical model for integrating modern fabrication into curriculum-aligned teaching aids. The findings imply that scalable, durable, and pedagogically effective tools can be developed even in resource-limited settings. However, limitations include the reliance on a single material (ABS) and performance assessments conducted under controlled conditions which may suggest the need for further field testing across diverse educational environments.

3.2. Evaluation of the 3D-printed Projectile Demonstrator (3D-PPD) in terms of Design, Instructional Quality, and Cost-Benefit

Table 1 presents the obtained weighted mean and the respective standard deviations from students' and teachers' evaluation of the 3D-PPD in terms of design. The average weighted mean for students' evaluation was *M = 3.62 (SD = 0.24)*, while the average weighted mean from the teachers' evaluation was *M = 3.54 (SD = 0.44)*. Additionally, the total weighted mean for each indicator ranged from *M = 3.46 (SD = 51)* to *M = 3.72 (0.44)*, with an overall average mean of *M = 3.62 (SD = 0.27)*. Both groups of evaluators consistently rated the instructional tool as very satisfactory, based on the scale range provided in the legend.

In terms of total weighted mean for each indicator, the organization of components obtained the highest mean, *M = 3.72 (SD = 0.44)*. This was followed closely by the total weighted mean for observed safety and precautionary measures, which was *M = 3.69 (SD = 0.41)*, and the mean for clarity and proper labeling of visuals and representations, which was *M = 3.67 (SD = 0.54)*. Other indicators, such as the design's alignment with expected classroom time commitment, ease of use and durability, and user-friendliness, also received high ratings within the same descriptive category, with weighted means of *M = 3.66 (SD = 0.50)*, *M = 3.56 (SD = 0.50)*, and *M = 3.46 (0.51)*, respectively.

Table 1. Evaluation of the 3D-PPD in terms of Design

Indicators	Students		Teachers		Overall Mean		
	WM	SD	WM	SD	WM	SD	VI
1. The instructional tool is user-friendly.	3.41	0.51	3.8	0.45	3.46	0.51	VS
2. Size and composition are appropriate for use in school.	3.62	0.53	3.4	0.55	3.59	0.54	VS
3. The colors and the organization of components are appropriate.	3.76	0.41	3.4	0.55	3.72	0.44	VS
4. Design is reasonable regarding expected classroom time commitment.	3.62	0.50	3.4	0.55	3.66	0.50	VS
5. Observed safety and precautionary measures.	3.71	0.41	3.8	0.45	3.69	0.41	VS
6. Visuals and representation are clear and properly labelled.	3.68	0.53	3.4	0.55	3.67	0.54	VS
7. The design of the instructional tool is easy to use and durable.	3.56	0.50	3.6	0.55	3.56	0.50	VS
Average Weighted Mean	3.62	0.24	3.54	0.44	3.62	0.27	VS

In terms of design, the 3D-PPD was found to be well-structured, safe, and effective in its visual qualities. This indicates that it successfully achieved its intended purpose of being a reliable instructional tool for long-term classroom use, with safety features and sturdy materials incorporated into its design. Its proper labeling further supported ease of use and classroom appropriateness. In the study conducted by Acosta [28], a developed and validated Grade 10 Science learning material for secondary schools was also subjected to evaluation. The evaluators in Acosta's study rated the materials highly in terms of print clarity, illustrations, layout, and logical presentation. Based on these results, the proposed instructional tool was further recommended to be utilized. Building on this standard, the present study extends the concept of effective material design by integrating modern fabrication techniques, particularly 3D printing, into development of instructional tools. The 3D-PPD not only meets key instructional design criteria similar to Acosta's materials but also introduces enhanced features made possible by 3D-printing, such as customizable components and improved durability.

Table 2 presents the evaluation results of the 3D-PPD in terms of instructional quality, assessed by students and teachers. As shown in the table, the average weighted mean for students' and teachers' evaluation was *M = 3.55 (SD = 0.35)* and *M = 3.5 (SD = 0.48),* respectively. The total weighted mean for the nine indicators ranged from *M = 3.46* (SD = 0.56) to *M = 3.62 (SD = 0.50),* which all corresponded to a very satisfactory qualitative description and had an average weighted mean of *M = 3.53 (SD = 0.36),* with overall standard deviation for instructional quality indicating high reliability in the respondents' evaluations.

In terms of the total weighted mean for each indicator, the mean score for how well the 3D-PPD promotes creative thinking and advanced cognitive skills was *M = 3.62 (SD = 0.50)*, the highest among all indicators. This was followed by the total weighted mean for user control of the instructional content, which was *M = 3.59 (SD = 0.55)*. Additionally, the mean score for both the appropriateness of difficulty level for the intended users and the effective use of user feedback was *M = 3.56*. The lowest mean scores, both at *M = 3.46 (SD = 0.56)*, involved the clarity of the 3D-PPD purpose and the relevance of the content to the prior knowledge or experiences of the users. Despite this, all indicators corresponded within the same qualitative category of 'very satisfactory'.

Table 2. Evaluation of the 3D-PPD in terms of Instructional Quality

Indicators	Students		Teachers		Overall Mean		
	WM	SD	WM	SD	WM	SD	VI
The purpose of the material is well-defined.	3.47	0.56	3.4	0.55	3.46	0.56	VS
Instructional tool fosters an understanding of the subject.	3.53	0.61	3.6	0.55	3.54	0.60	VS
Learning objectives are clearly stated and measurable.	3.53	0.55	3.6	0.55	3.54	0.54	VS
Level of difficulty varies appropriately for the intended target user.	3.62	0.51	3.2	0.45	3.56	0.51	VS
Material is enjoyable, stimulating, challenging, and engaging.	3.53	0.56	3.6	0.55	3.54	0.55	VS
Material stimulates creativity and cultivates higher-order thinking skills.	3.62	0.50	3.6	0.55	3.62	0.50	VS
Target users can control the rate and sequence of presentation and review.	3.62	0.56	3.4	0.55	3.59	0.55	VS
Instruction is integrated with the target user's previous experience.	3.44	0.61	3.6	0.55	3.46	0.60	VS
Learning resources foster a deeper understanding of the subject.	3.5	0.56	3.6	0.55	3.51	0.55	VS
Feedback on the target users' responses is effectively employed.	3.59	0.55	3.4	0.55	3.56	0.55	VS
Average Weighted Mean	3.55	0.35	3.5	0.48	3.53	0.36	VS

Regarding instructional quality, the evaluation results show that the 3D-PPD successfully delivers key concepts related to projectile motion in a clear and structured manner. It not only meets the expected learning outcomes but also deepens students' understanding of the subject which fulfills its primary purpose of enhancing instruction in this specific physics topic. The results obtained is supported by the findings of Pineda in his study where a Teaching-Learning Package including a Computer-Aided Instructional (CAI) tool was developed and evaluated [29]. The instructional quality of the CAI tool reflected its alignment with learning objectives, educational value, and curriculum appropriateness. Similarly, the 3D-PPD upholds these qualities while further enhancing instructional effectiveness through the capabilities of 3D printing. Such use of innovation enables the production of accurately scaled instruction tools tailored to the curriculum, particularly in demonstrating concepts related to projectile motion.

Table 3 shows the results of the evaluation of the 3D-PPD in terms of cost-benefit based on the five indicators. As shown in the table, the average weighted mean for students' and teachers' evaluation was *M = 3.41 (SD = 0.38)* and *M = 3.4 (SD = 0.40)*, respectively. Meanwhile, the total mean across the five cost-benefit-related indicators ranged from *M = 3.00 (SD = 0.68) to M = 3.69 (SD = 0.51)*. Out of the five indicators, four received a very satisfactory rating, while one was interpreted as satisfactory. Despite this, the overall average, *M = 3.40 (SD = 0.38)*, still corresponded to a very satisfactory qualitative description, while the overall standard deviation indicated high reliability in the participants' responses.

In terms of total weighted mean for each indicator, adherence to established quality standards was *M = 3.69 (SD = 0.51),* the highest among all indicators. This was followed by the IPD's perceived cost-effectiveness, with a mean score of *M = 3.54 (SD = 0.64)*. The mean scores for availability of materials and sustainability of resources were both *M = 3.38 (SD = 0.58; SD = 0.70)*. Meanwhile, the weighted mean for maintenance cost, which was rated the lowest, was *M = 3.00 (SD = 0.68)*. In summary, the average weighted mean for the cost-benefit aspect was *M = 3.40 (SD = 0.38)*, corresponding to a very satisfactory evaluation.

Table 3. Evaluation of the 3D-PPD in terms of Cost-Benefit

Indicators	Students		Teachers		Overall Mean		
	WM	SD	WM	SD	WM	SD	VI
Materials are readily available in the mainstream market.	3.4	0.60	3.4	0.55	3.38	0.58	VS
Materials are based on the conformed quality standard of the product.	3.79	0.48	3.2	0.45	3.69	0.51	VS
Resources are sustainable.	3.38	0.73	3.4	0.55	3.38	0.70	VS
The cost of maintenance is/are not expensive.	2.94	0.67	3.4	0.55	3.0	0.68	S
The instructional tool's quality is justifiable by its overall cost.	3.53	0.66	3.6	0.55	3.54	0.64	VS
Average Weighted Mean	3.41	0.38	3.4	0.40	3.40	0.38	VS

In terms of cost-benefit, the 3D-PPD achieved a balance between affordability and functionality, proving its value as a practical educational investment. These results imply that the 3D-PPD offers very satisfactory cost-benefit value, showing that its cost is reasonable given the quality and functionality it provides. Although the use of 3D printing slightly increased the production cost, this was a worthwhile investment for ensuring durability and long-term usability in the classroom. These findings are supported by the study of Basagre et al., where a Physics Multifunctional Instrument (PMI) was developed and evaluated based on several aspects, including cost-benefit [22]. While their study focused on a different physics topic, the researchers emphasized the practicality and cost-efficiency of their tool by using accessible materials while maintaining quality standards. Similarly, the 3D-PPD achieved its objective of being a cost-beneficial instructional material, receiving very satisfactory ratings in key areas such as adherence to quality standards and perceived cost-effectiveness through the use of 3D printing. Custom fabrication made the parts more precise, durable, and reusable while keeping production cost-effective for classroom use. These results show that when combined with good teaching design, 3D printing can help create practical, affordable, and powerful learning tools for science education.

3.3. Implementation of the 3D-PPD on Students' Conceptual Understanding of Projectile Motion (CUPM) and Attitudes toward Physics (ATP)

Table 4 presents the normality and homogeneity of variances tests to determine the initial comparability of the CG and EG. These tests of assumptions were based on the groups' mean pretest scores in CUPM.

Table 4. Tests of Assumptions for Initial Comparability in terms of CUPM

Tests	Results	Interpretation
Shapiro-Wilk Statistics	W = 0.97; p = 0.173	Normally Distributed
Levene's test	F = 1.69; p = 0.199	Equal Variance

The Shapiro-Wilk test for normality yielded *W = 0.97; p = 0.173,* indicating that the data from both groups did not significantly deviate from a normal distribution. Additionally, Levene's Test for homogeneity of variances showed *F = 1.69, p = 0.199*, suggesting that the assumption of equal variances was also met. These results validate the use of parametric tests specifically the independent t-test, at the 0.05 level of significance. Table 5 shows the result of the analysis.

Table 5. Independent t-test Results for Initial Comparability in terms of CUPM

	Statistic	df	p
CUPM	1.66	54.00	0.102

The mean pretest score for CUPM of CG was *M* = 10.07 *(SD = 2.87),* while for EG, it was *M = 8.69* (*SD = 3.33*). Table 5 shows the results of the independent t-test, *t (54) = 1.66, p = 0.102,* indicating that the difference in mean scores between the two groups was not statistically significant, as the p-value is exceeds the 0.05 level of significance. This implies that both the CG and EG had comparable levels of CUPM prior to the intervention, supporting the assumption of initial equivalence between the two groups.

To determine if the use of 3D-PPD has a significant effect on students in the EG compared to those in the CG in terms of CUPM, the mean posttest scores of both groups were analyzed. Prior to conducting the analysis, tests of assumptions were carried out to ensure the appropriateness of the statistical procedures used. Table 6 presents the results of this preliminary analysis.

Table 6. Tests of Assumptions after the Intervention

Tests	Results	Interpretation
Shapiro-Wilk Statistics	W = 0.99; p = 0.922	Normally Distributed
Levene's test	F = 8.96; p < 0.05	Not Equal Variance

As shown in Table 6, the Shapiro-Wilk test revealed that the data were normally distributed, $W = 0.99, p = 0.922$. However, Levene's test indicated that the assumption of homogeneity of variances was violated because the p-value was less than the significant value, $F = 8.96$, $\boldsymbol{p} < 0.05$. Hence, the variances between the two groups were assumed to be not equal. Given this, a Mann-Whitney U-test, a non-parametric test, was employed to compare the posttest scores of the CG and EG. Table 7 shows the result of the statistical test.

Table 7. Mann-Whitney U-test and Cohen's d Results after the Intervention

	Statistic	df	p	Cohen's d	Interpretation
CUPM	91.00	56.00	0.033	0.90	Large

The mean posttest scores of the CG in terms of CUPM were $M = 15.71$ $(SD = 2.97)$, while the EG had a higher mean of $M = 20.67$ $(SD = 3.80)$. To determine if this observed difference in CUPM between the two groups was statistically significant, a Mann-Whitney U test was conducted due to the non-normal distribution of the data. As shown in Table 7, the results $U = 91.00, p < 0.05$ indicate a statistically significant difference in terms of CUPM between the two groups.

The findings indicate that the intervention using the 3D-PPD not only led to a statistically significant improvement in students' CUPM but the magnitude of the difference was also practically meaningful. The large effect size implies that the 3D-PPD had a substantial positive impact on students' knowledge of projectile motion concepts compared to conventional teaching. These results support the effectiveness of the 3D-PPD in enhancing CUPM and confirm that it successfully fulfilled its primary purpose of aiding in the understanding of key concepts and further improving students' CUPM.

These results are supported by the study of Basagre, which revealed that students showed a substantial mean gain in their posttest scores, indicating enhanced conceptual understanding after engaging with inquiry-based activities. Notably, even competencies with low pretest performance saw remarkable improvement, as students were given opportunities to explain concepts in their own words, observe investigations, and report findings [30].

The improvement in students' CUPM following the use of the 3D-PPD highlights the pedagogical value of integrating tangible and interactive tools in physics instruction. This result demonstrates that abstract concepts, such as parabolic trajectories, launch angles, and motion under gravity, can be more effectively understood when students are provided with opportunities to manipulate physical representations of these phenomena [31].

Table 8 shows the normality and homogeneity of variances tests to determine the initial comparability of the CG and EG in terms of ATP. These tests of assumptions were based on the groups' mean pretest scores in ATP.

Table 8. Test of Assumptions for Initial Comparability in terms of ATP

Tests	Results	Interpretation
Shapiro-Wilk Statistics	W = 0.64; p = 0.051	Normally Distributed
Levene's test	F = 0.49; p = 0.487	Equal Variance

The Shapiro-Wilk test for normality yielded $W = 0.64, p = 0.051$, indicating that the data did not significantly deviate from a normal distribution. Additionally, Levene's Test for homogeneity of variances showed $F = 0.49, p = 0.487$, suggesting that the assumption of equal variances was met. These results justify the use of parametric tests, specifically the independent samples t-test, at the 0.05 level of significance.

Table 9. Independent t-test Results for Initial Comparability in terms of ATP

	Statistic	df	p
ATP	1.77	56.00	0.083

The mean pretest score of the CG was $M = 3.89$ ($SD = 0.38$), while for the EG, it was $M = 3.61$ ($SD = 0.73$). Independent t-test was conducted to compare these mean scores. Table 9 shows that the difference in means was not statistically significant, $t\ (56) = 1.77, p = 0.083$. Since the p-value is greater than 0.05, this suggests that there was no significant difference in ATP between the two groups. This supports the assumption that both groups had comparable levels of ATP prior to any intervention.

To determine whether the use of the 3D-PPD significantly influenced the ATP of students in the EG compared to those in the CG, the mean posttest scores of both groups were analyzed. Prior to the primary analysis, assumption testing was performed to ensure that the chosen statistical procedures were appropriate. The outcomes of these preliminary tests are summarized in Table 10 which served as the basis for selecting the suitable method of analysis.

Table 10. Test of Assumptions after the Intervention

Tests	Results	Interpretation
Shapiro-Wilk Statistics	*W = 0.98; p = 0.708*	Normally Distributed
Levene's test	*F = 0.00; p = 0.075*	Equal Variance

The Shapiro-Wilk test yielded a result of *W = 0.98, p = 0.708*, indicating that the distribution of scores did not significantly deviate from normality. Additionally, Levene's test for equality of variances was *F = 0.00, p = 0.075*, suggesting that the assumption of homogeneity of variances was also met. These results confirm that the data met the necessary assumptions for the use of parametric statistical tests, such as the independent t-test.

Table 11. Independent t-test and Cohen's d Results after the Intervention

	Statistic	df	p	Cohen's d	Interpretation
ATP	-1.07	34.00	0.294	0.43	Small effect

The mean posttest score of the CG in terms of ATP was *M = 3.89 (SD = 0.25),* while the EG had a higher mean of *M = 4.00 (SD = 0.27).* To determine whether this observed difference in ATP between the two groups was statistically significant, an independent samples t-test was conducted. As shown Table 11, the results were *t (34) = -1.07, p = 0.294*, indicating that the difference was not statistically significant. This finding is further supported by the small effect size, with Cohen's d calculated at *d = 0.43*, suggesting that the practical significance of the difference was limited.

As for students' ATP, the results imply that while the 3D-PPD as an intervention may have had some effect, it was not strong enough to create a noticeable change in students' attitudes. Alternatively, it might suggest that changes in attitude toward physics may require a longer or more intensive intervention to become apparent. This finding contrasts with the study by Okit et al. where the implementation of Electronic Learning Activity Sheets (e-LAS) led to an affirmative shift in students' attitudes toward Science [30]. However, it must be noted that in such study, attitude was anticipated to undergo significant change as a direct result of the intervention. This suggests that although the difference in ATP between groups was not statistically significant, the result remains relevant within the framework of the present study. Rather than being disregarded, attitude is recognized as a secondary yet important construct that contributes to shaping the learning environment. This aligns with the broader aim of understanding how students' ATP may influence their learning processes, particularly in relation to their CUPM.

The observed significant effect of the 3D-PPD on students' CUPM but not on their ATP may be explained through constructivist learning theory. Constructivism, particularly as articulated by Piaget and Vygotsky and further extended in contemporary educational literature, posits that learners construct knowledge actively through interaction with their environment [33]. The 3D-PPD provided a concrete, hands-on, and visually engaging learning experience, which likely helped students form stronger mental models and conceptual frameworks regarding projectile motion. Recent studies [34], [35] support that manipulative and visual tools improve students' conceptual understanding in physics because they allow learners to test hypotheses, observe real-world applications, and self-correct misconceptions, core processes in constructivist learning.

In contrast, motivational theories such as the Expectancy-Value Theory (EVT) by Eccles and Wigfield suggest that students' attitudes are shaped by broader factors including prior experiences, self-efficacy, perceived value of the subject, and social influences [36]. Interventions like the 3D-PPD, while cognitively stimulating, may not be sufficient on their own to alter long-standing perceptions about physics, especially if students already harbor negative attitudes. Changes in science attitudes often require sustained exposure, emotionally supportive learning environments, and repeated experiences of success [37], [38]. Therefore, a single short-term intervention, even one as engaging as the 3D-PPD, may fall short of impacting the deeper motivational dimensions that influence ATP, thereby supporting that while the 3D-PPD contributed to improved understanding of projectile motion, its effect on attitudes was limited by the short intervention window and the absence of broader motivational scaffolds.

3.4. Relationship of Conceptual Understanding of Projectile Motion (CUPM) and Attitudes toward Physics (ATP) after Exposure to 3D-PPD

The mean posttest score of the EG in terms of CUPM was *M = 20.67 (SD = 3.80),* while the mean posttest score in terms of ATP was *M = 4.00 (SD = 0.27)*. To determine the relationship between students' ATP and their CUPM after exposure to the 3D-PPD, a Pearson correlation analysis was conducted using the data obtained. Prior to this, a test of normality was performed using the Shapiro-Wilk test to ensure that the assumptions for parametric testing was met. Table 12 shows the results of the test.

Table 12. Test of Assumptions before Pearson Correlation Analysis

	Tests	Results	Interpretation
CUPM	Shapiro-Wilk Statistics	$W = 0.92; p = 0.260$	Normally Distributed
ATP	Shapiro-Wilk Statistics	$W = 0.93; p = 0.363$	Normally Distributed

As shown in Table 12, the Shapiro-Wilk statistic for CUPM was $W = 0.92, p = 0.260$, and for ATP, the result was $W = 0.93, p = 0.363$. Since the p-values for both variables are greater than 0.05, this indicates that the data do not significantly deviate from a normal distribution. Therefore, the assumption of normality is satisfied for both CUPM and ATP. Given this, it is appropriate to proceed with Pearson's r correlation analysis, which assumes that the variables under study are approximately normally distributed in order to yield valid and reliable results.

Table 13 presents the results of the Pearson correlation analysis between students' CUPM and ATP after the intervention. The results yielded a correlation coefficient of $r = 0.07, p = 0.818$. This result indicates a very low correlation between the two variables after being exposed to the 3D-PPD. Although students might have developed slightly more positive attitudes or a better understanding individually, these two outcomes were not directly connected.

Table 13. Relationship between Experimental Group's CUPM and ATP after the Intervention

Variables Compared	r	df	p-value	Interpretation
CUPM & ATP	.07	10	.818	Very low correlation level

This result implies that students' ATP were not linked to their ability to understand projectile motion concepts. While positive attitudes are often thought to enhance learning outcomes, this weak correlation suggests that a positive attitude alone may not be enough to improve conceptual understanding, and conversely, a better understanding of the concepts does not necessarily lead to a more positive attitude.

This result also highlights the complex role of attitude in the overall effectiveness of the 3D-PPD, suggesting that while attitude is an important factor in shaping the learning experience [39], the weak correlation observed suggests that a positive attitude alone may not suffice to significantly improve conceptual understanding. The strength of the 3D-PPD may lie in improving conceptual understanding through its structured, innovative approach, while attitude serves more as a supporting factor that enhances the learning environment rather than as a direct driver of performance outcomes. A similar result was observed in the study by Mutya et al., which examined how students' attitudes relate to their academic performance in Science when using self-learning modules [40]. In their study, although students demonstrated positive attitudes toward science, no significant correlation was found between their performance academically attitudes towards learning.

These results suggest that the cognitive and affective learning domains, while both essential to the educational experience, may operate independently. While affective factors like attitude contribute to shaping the learning environment and sustaining student motivation, they do not necessarily translate into measurable cognitive gains, such as improved conceptual understanding. Further support for this disconnect between these domains comes from recent studies that reveal attitude does not reliably predict conceptual gains. Doucette et al. [41] found that in inquiry-based physics labs, improvements in students' conceptual understanding did not consistently align with positive shifts in attitude—unless explicit reflective elements were included. Similarly, Mao et al. [42], through a meta-analysis involving over a million students, reported only a moderate correlation between attitude toward science and academic achievement, suggesting that while attitude can support engagement, it is not a strong standalone predictor of cognitive outcomes in science learning.

4. CONCLUSION

Physics education continues to face challenges, especially in teaching topics with abstract concepts. However, traditional methods often fail to address misconceptions and engage students effectively. While 3D printing is perceived as a useful technological breakthrough which can be beneficial to the educational landscape in materializing instructional tools, its classroom use remains limited and lacks strong research-based evidence. This study responds to that gap through the development and evaluation of the 3D-PPD which was tested for feasibility, instructional effectiveness, and design quality. Results showed that it significantly improved students' CUPM. This demonstrates that well-designed, tangible learning tools can enhance student learning in physics. However, the tool alone did not significantly improve students' ATP, suggesting that attitude change may require repeated use or additional strategies. Despite this, the 3D-PPD provides a strong foundation for future interventions that combine cognitive and affective goals. The study fills a critical gap in the literature by offering empirical evidence on the instructional value of 3D-printed tools in physics. To fully realize the tool's potential and address the observed limitations, follow-up studies must now shift focus toward enhancing its long-term impact on student attitudes. Future studies should examine the long-term use of the 3D-PPD, as improving students' ATP may require sustained and continuous exposure. Research should also determine the optimal timeframe for implementing such interventions to identify whether specific durations lead to measurable attitude changes. In addition, the integration of complementary instructional strategies should be explored to further enhance student attitudes. Developing contextualized learning activities using the 3D-PPD is also recommended to make physics lessons more relevant to students' real-life experiences and increase their engagement with the subject.

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