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Development and Limited Evaluation of an Air-Pressure Projectile Motion Teaching Aid for Senior High School Students

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Abstract

This study aimed to develop an air-pressure-based teaching aid for projectile motion and conduct a limited evaluation of its technical performance, expert-assessed validity, user responses, and student learning outcomes. The study employed a modified 4D development model restricted to the Define, Design, and Develop stages, without proceeding to Disseminate. The apparatus was designed to allow controlled variation of launch angle and applied air pressure and to enable direct measurement of horizontal range and maximum height. Technical testing showed that horizontal range increased toward a maximum at approximately 45° and subsequently decreased, whereas maximum height generally increased with elevation angle. Higher applied air pressure also produced greater measured range and height. Expert validation was conducted by four university lecturers and one physics teacher and yielded an overall score of 81.2% (mean item score = 4.06/5), meeting the predetermined "very valid" criterion. A limited classroom trial involved 18 Grade XI students and one physics teacher at SMA Plus Muhammadiyah Merauke during the 2023/2024 academic year. The teacher response was 43/50 (86%), categorized as "very effective" according to the predetermined response criteria, while the student response was 56.72/75 (75.6%), categorized as "effective." The post-instruction learning-outcome test produced a mean score of 83.33, with 17 of 18 students (94.4%) meeting the minimum mastery criterion of 70. These findings indicate that the developed apparatus is technically functional, judged suitable by experts, positively received during limited classroom implementation, and accompanied by high post-instruction mastery. Because the study did not include a pretest or comparison group, the findings should not be interpreted as causal evidence of improved learning outcomes.

Keywords: Air Pressure; Learning Media Development; Physics Education; Projectile Motion; Teaching Aid

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INTRODUCTION

Advances in science and instructional technology have increased the need for learning environments that connect scientific concepts with meaningful and observable experiences (Syaripudin et al., 2023; Raisal, 2025). In physics education, this need is particularly important because students are expected not only to apply mathematical expressions but also to interpret the physical phenomena represented by those expressions. Appropriate learning resources can support students' knowledge and understanding (Saraswati, 2020), while physics learning also contributes to the development of scientific thinking and problem-solving skills (Rusdiana & Juanda, 2019). Physics education therefore aims to build knowledge,

understanding, inquiry, and the capacity to engage with science and technology (Muhammad, 2019; Risamasu & Pieter, 2025). As a branch of natural science, physics requires students to connect explanations with observable phenomena rather than relying only on symbolic descriptions (R A R, 2021).

Projectile motion is a particularly challenging topic because students must coordinate two simultaneous but independent components of motion. Under the ideal model, horizontal motion occurs at constant velocity while vertical motion is uniformly accelerated by gravity; together, these components produce a parabolic trajectory. Understanding this relationship requires students to reason simultaneously about initial velocity, launch angle, gravity, horizontal range, maximum height, and the horizontal and vertical components of velocity. Previous studies have documented persistent difficulties in coordinating two-dimensional representations and understanding projectile-motion concepts (Sikhosana & Mudau, 2022; Uwayezu & Yadav, 2023). Misconceptions have also been reported in graphical and figural representations of projectile motion, particularly when adequate visualization is absent (Hidayatulloh et al., 2021). These difficulties reinforce concerns that projectile motion can remain abstract when students encounter it primarily through formulas and static representations (Rizaldi et al., 2023; Cabal & Basagre, 2025).

Visual, interactive, and experimental approaches can help address this difficulty by allowing students to relate mathematical representations to observable motion. Physics learning should connect abstract concepts with real-world applications and scientific practices (Wiyatmo, 2025). Practical activities and teaching aids allow students to interact directly with physical phenomena (Sipahutar, 2022), while adequate experimental equipment remains an important condition for laboratory-based physics instruction (Rahayu, 2023b). Experimental activities also provide opportunities to practice observation, measurement, and scientific reasoning (Azmi, 2023). Learning resources that are accessible, engaging, and understandable can further support participation in physics learning (Rahayu, 2023a; Usman, 2025).

Several approaches have been developed for teaching projectile motion, including physical launchers and virtual simulations. Simple physical launchers provide direct experience with projectile trajectories, although spring-based or manually operated systems can present difficulties in maintaining consistent launch conditions (Salam, 2019). Virtual environments such as PhET allow students to manipulate variables rapidly and visualize trajectories clearly, and simulation-based studies have reported improvements in students' understanding of projectile-motion graphs and concepts (Meka Jane C, 2025; Mohamad, 2025; Uwayezu & Yadav, 2023). Physical and virtual investigations offer different affordances: physical investigations provide interaction with tangible objects and real measurement variability, whereas virtual environments provide rapid, controlled exploration (Muilwijk & Lazonder, 2023). Thus, a physical apparatus can complement rather than replace simulation-based instruction.

Within this context, an air-pressure-based launcher offers a practical approach for creating a tangible projectile-motion experiment in which the elevation angle and applied air pressure can be varied systematically. Unlike a purely manual launch, the pressure-based mechanism provides a controllable launch input that can be reproduced across experimental conditions. Air pressure should, however, be regarded as a controllable launch parameter rather than a direct measurement of projectile initial velocity because pneumatic exit velocity depends on launcher

geometry and other mechanical factors (Sobczyk et al., 2021; Jastrzębski & Ułanowicz, 2022). The apparatus developed in this study was therefore designed primarily to enable investigation of observable relationships among applied pressure, elevation angle, horizontal range, and maximum height.

The local instructional context also supported the need for such an apparatus. A preliminary needs analysis conducted with Grade XI students at SMA Plus Muhammadiyah Merauke showed that 71% of students indicated a need for a teaching aid when learning projectile motion. Needs analysis can identify differences between existing instructional conditions and the resources required to support learning objectives (Arifin & Sani, 2021). At the time of the preliminary analysis, the school did not have a dedicated physical projectile-motion teaching aid. This local need is consistent with previous studies emphasizing that projectile motion benefits from media that make trajectories and related variables more directly observable (Rosita et al., 2020; Pineda, 2020). Developing an appropriate physical medium can therefore provide an additional resource for connecting mathematical descriptions with experimentally observable phenomena (Rahman et al., 2023).

Accordingly, this study developed an air-pressure-based projectile-motion teaching aid using a modified Define–Design–Develop process and conducted a limited evaluation of the product. Specifically, the study examined (1) technical performance through measurements of horizontal range and maximum height at different elevation angles and pressure conditions, (2) content and media validity based on expert judgment, (3) teacher and student responses during limited classroom implementation, and (4) students' post-instruction mastery of projectile-motion concepts. By integrating technical evaluation with expert and classroom-based evidence, the study sought to establish the preliminary feasibility of the apparatus without attributing causal improvements in learning outcomes beyond the scope of the research design.

METHOD

Research Design

This study employed a Research and Development (R&D) approach using a modified Four-D (4D) development model consisting of Define, Design, Develop, and Disseminate stages. In the present study, the model was intentionally limited to the first three stages—Define, Design, and Develop—because the research focused on product development, technical testing, expert validation, revision, and a limited classroom trial rather than large-scale dissemination. Related educational-development studies have similarly used 4D-based procedures to structure systematic product development and validation (Hartono et al., 2025; Kurnia et al., 2024; Mucti & Hermansyah, 2023). The omission of Disseminate was therefore treated as a limitation of developmental scope rather than completion of the full 4D cycle.

The Define stage included preliminary analysis, student analysis, analysis of the projectile-motion content, and specification of instructional objectives. The Design stage comprised media selection, identification of tools and materials, and preparation of the initial apparatus design. The Develop stage included product construction, technical performance testing, expert validation, revision, limited classroom implementation, user-response evaluation, and post-instruction learning assessment. The study did not employ a pretest, control group, or comparison with conventional instruction; therefore, learning outcomes were analyzed descriptively rather than

used to infer causal learning gains (Shepherd et al., 2024). The modified three-stage development procedure is summarized in Figure 1.

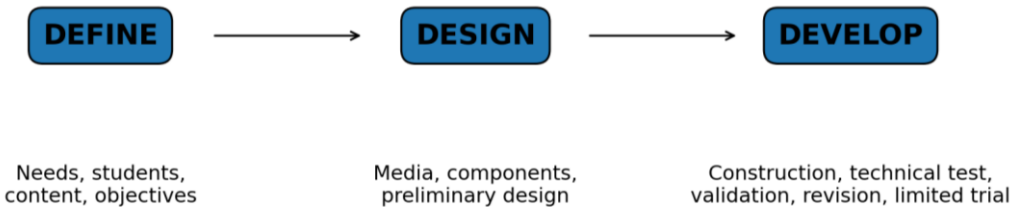
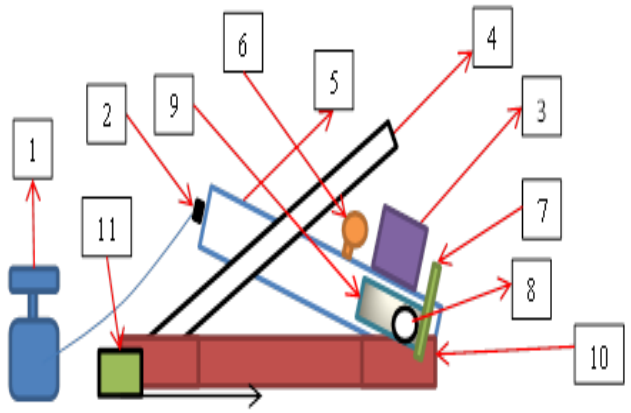


Figure 1. Development chart

Design and Components of the Teaching Aid

The developed product was an air-pressure-based projectile-motion teaching aid designed to allow controlled variation of elevation angle and applied air pressure. The apparatus incorporated a pressurized-air source, air-delivery tube, pressure gauge, angle meter, trigger mechanism, marble projectile, projectile holder, supporting structure, and measuring instrument for horizontal range. Figure 2 presents the initial design of the apparatus. The specifications, functions, materials, and estimated costs of the apparatus components are summarized in Table 1.



Information:
1. Length measuring instrument;
2. Vent hole;
3. Air pump;
4. Wind tube;
5. Pole;
6. Air pressure gauge;
7. Marble projectile;
8. Angle meter;
9. Projectile holder;
10. Trigger;
11. Base.

Figure 2. Design of the projectile-motion teaching aid.

Air pressure was treated as a controllable launch parameter rather than as a direct measurement of projectile initial velocity. Pneumatic-launcher studies show that exit velocity depends on supply pressure together with launcher geometry and flow characteristics (Sobczyk et al., 2021; Jastrzębski & Ułanowicz, 2022). Accordingly, the present study did not equate the pressure-gauge reading with v_0.

Table 1. Specifications and Estimated Costs of the Projectile-Motion Teaching-Aid Components

Component	Specification and Function	Material
Air pump	Provides compressed air for the launching system	Metal
Vent hole	Controls ventilation and airflow within the launching system	Metal
Angle meter	Measures the elevation angle of the launch	Stainless steel / metal
Pole	Supports the launcher and angle-adjustment mechanism	Wood

Component	Specification and Function	Material
Wind tube	Delivers pressurized air toward the projectile	Aluminium / steel
Air pressure gauge	Measures the applied air pressure in the system	Metal + glass / plastic
Trigger	Pneumatic trigger valve used to release the projectile	Plastic
Marble projectile	Projectile launched by the apparatus	Glass / plastic
Projectile holder	Holds the projectile before launch	Plastic / metal
Base	Supports and stabilizes the teaching aid	Wood
Length measuring instrument	Measures horizontal projectile range	Rubber / plastic tape measure

Participants and Research Setting

The limited classroom trial was conducted at SMA Plus Muhammadiyah Merauke during the 2023/2024 academic year. Five validators assessed the developed teaching aid: four lecturers from Universitas Musamus with expertise in physics education, physics teaching, learning evaluation, and educational technology, and one high-school physics teacher. The limited classroom trial involved 18 Grade XI students, comprising 10 female and eight male students aged 17–18 years, and one physics teacher. No control or comparison class was included. The characteristics of the validators and student participants are presented in Table 2.

Table 2. Characteristics of Validators and Student Participants

Participant	Institution	Expertise / Characteristics
Expert Lecturer 1	Universitas Musamus	Physics Education
Expert Lecturer 2	Universitas Musamus	Physics Teaching
Expert Lecturer 3	Universitas Musamus	Learning Evaluation
Expert Lecturer 4	Universitas Musamus	Educational Technology
Physics Teacher	SMA Plus Muhammadiyah Merauke	High-School Physics Teaching
Students	SMA Plus Muhammadiyah Merauke	18 Grade XI students: 10 female and 8 male, aged 17–18 years

Development and Evaluation Procedure

During the Define stage, the researchers conducted preliminary analysis, student analysis, subject-matter analysis, and specification of learning objectives. The needs analysis identified the requirement for a physical teaching aid capable of representing projectile motion through direct observation and measurement.

During the Design stage, the researchers selected the instructional medium, determined the required materials and components, prepared the apparatus configuration, and established the measurement variables. The design focused on manipulating elevation angle and applied air pressure and observing horizontal range and maximum height.

During the Develop stage, the apparatus was constructed and subjected to four sequential evaluation activities: (1) technical performance testing, (2) expert validation, (3) product revision based on validator feedback, and (4) limited classroom implementation followed by teacher and student response questionnaires and a post-instruction learning-outcome test. The product proceeded to the limited classroom trial only after meeting the predetermined expert-validation criterion.

Technical Performance Testing

Technical performance testing examined whether the apparatus produced systematic changes in horizontal range and maximum height under different launch conditions. Elevation angles from 15° to 90° were tested at applied pressures of 2.0 and 3.4 kPa. For each condition, horizontal range and maximum height were recorded. Repeatability was additionally examined under one fixed condition—45° and 2 kPa—using five repeated launches. The mean horizontal range and sample standard deviation were calculated to summarize the dispersion of repeated measurements.

Research Instruments

Expert-Validation Instrument

The expert-validation instrument comprised 20 items divided into content and media aspects. The content component addressed content suitability and conceptual compatibility, whereas the media component addressed suitability for instruction, durability, accuracy, efficiency, student safety, aesthetics, and completeness. This procedure was interpreted as expert validation of content and media suitability rather than psychometric construct validity. Validation in product-development research is intended to establish whether the media and material align with their instructional purpose (Febrianti & Prabowo, 2021). The distribution of the 20 validation items across the assessed domains is presented in Table 3.

Table 3. Product Validation Instrument

Domain	Aspect	Item Number
Content	Content suitability	1, 2
Content	Concept compatibility	3, 4, 5, 6, 7
Media	Suitability for instructional use	8, 9, 10
Media	Tool durability	11, 12
Media	Accuracy	13
Media	Tool efficiency	14, 15
Media	Safety for students	16, 17
Media	Aesthetics	18, 19
Media	Tool completeness	20

Teacher-Response Instrument

The teacher-response questionnaire was administered after limited classroom use of the apparatus. It consisted of 10 items covering content, perceived instructional effectiveness, and attractiveness. Although the original instrument uses the term "effectiveness," the response was interpreted primarily as perceived usefulness, usability, and classroom acceptability. Educational-media development studies commonly distinguish response-based practicality from objectively measured learning effects (Wulanningtyas et al., 2023). The questionnaire aspects and corresponding item numbers are summarized in Table 4.

Table 4. Teacher Response Questionnaire

Aspect	Item Number
Content	1, 2
Effectiveness	3, 4, 5, 6, 7, 8
Attractiveness	9, 10

Student-Response Instrument

The student-response questionnaire consisted of 15 items and was administered to the 18 participating students after classroom use of the teaching aid. The questionnaire assessed students' perceptions of content, effectiveness, and attractiveness. The resulting scores were used to describe student acceptance and perceived usefulness rather than to establish causal improvement in learning. The student-response aspects and item distribution are presented in Table 5.

Table 5. Student Response Questionnaire

Aspect	Item Number
Content	1, 2, 3, 4
Effectiveness	5, 6, 7, 8, 9, 10, 11, 12
Attractiveness	13, 14, 15

Scoring Scale for Validation and Response Instruments

The validation and response instruments used a five-point scoring scale. This five-point range is consistent with the maximum item scores recorded in the validator and teacher-response data. The exact verbal anchors should follow the wording of the original questionnaires used during data collection. The five-point scoring structure used for these instruments is shown in Table 6.

Table 6. Five-Point Scoring Scale

Score	Interpretation
1	Lowest level of suitability/agreement according to the original instrument
2	Low level of suitability/agreement according to the original instrument
3	Moderate level of suitability/agreement according to the original instrument
4	High level of suitability/agreement according to the original instrument
5	Highest level of suitability/agreement according to the original instrument

Student Learning-Outcome Test

Student learning outcomes were measured using a 15-item post-instruction test covering cognitive levels C2–C5. The test addressed definitions of projectile motion, decomposition of initial velocity, velocity calculations, elevation angle and range, total projectile velocity, special launch conditions, and the influence of gravity. Each assessment item can target particular content and cognitive processes, making blueprint alignment important for interpretation (Le et al., 2025). Because no pretest or comparison group was used, the resulting scores represented post-instruction achievement and mastery rather than measured learning gains. The test indicators, item distribution, question format, and cognitive levels are summarized in Table 7.

Table 7. Student Learning-Outcome Test Blueprint

Question Number	Test Item Indicator	Question Format	Cognitive Level
1, 2	Explain the definition of projectile motion	Explanation	C2
3, 4	Identify the initial velocity components on the x- and y-axes	Explanation	C2
5, 6, 7	Calculate velocity on the x- or y-axis after time t	Explanation	C3
8, 9	Determine the elevation angle for a given range	Explanation	C4
10, 11	Calculate the total velocity at a specific point along the trajectory	Explanation	C3

Question Number	Test Item Indicator	Question Format	Cognitive Level
12, 13	Apply special conditions, such as horizontal launch from a specified height	Explanation	C4
14, 15	Evaluate the effect of gravity on trajectory and velocity	Explanation	C5

Data Analysis

Expert-Validation Analysis

Scores from the five validators were aggregated and converted to percentages using the ratio between the obtained score and the maximum possible score. The product met the predetermined validation criterion when the percentage was at least 61%. The interpretation categories followed Sugiyono (2017). The percentage ranges and corresponding expert-validation categories are presented in Table 8.

$$\textit{Validity score (\%)} = (\textit{Total obtained score} / \textit{Maximum possible score}) \times 100$$

Table 8. Criteria for Expert-Validation Scores

Category	Average Value (%)
Very valid	81–100
Valid	61–80
Quite valid	41–60
Invalid	21–40
Very invalid	0–20

Teacher- and Student-Response Analysis

Teacher and student response scores were converted to percentages using the obtained score divided by the maximum possible score. The original category labels were retained for consistency with the study instrument, but the percentages were interpreted primarily as user-response indicators. The response-percentage categories used for teacher and student questionnaires are presented in Table 9.

$$\textit{Response (\%)} = (\textit{Obtained score} / \textit{Maximum possible score}) \times 100$$

Table 9. Criteria for Teacher and Student Response Scores

Category	Average Value (%)
Very ineffective	0–20
Ineffective	21–40
Quite effective	41–60
Effective	61–80
Very effective	81–100

Analysis of Student Learning Outcomes

Student post-instruction scores were analyzed descriptively using the mean, median, sample standard deviation, and percentage of students meeting the minimum mastery criterion. The minimum mastery criterion for Physics at the participating school was 70. Scores of 70 or higher were classified as mastery, while scores below 70 required remedial follow-up.

$$\textit{Mean: } \bar{X} = \Sigma Xi / n$$

$$\textit{Sample SD: } s = \sqrt{[\Sigma(Xi - \bar{X})^2 / (n - 1)]}$$

$$\textit{Mastery (\%)} = (\textit{Number of students scoring} \geq 70 / \textit{Total number of students}) \times 100$$

Analysis of Technical Measurements and Repeatability

Horizontal range and maximum height were analyzed descriptively across elevation angles and pressure conditions. Differences were described as observed patterns rather than statistically significant effects because no inferential hypothesis testing was conducted. For the five repeated launches at 45° and 2 kPa, repeatability was summarized using the mean and sample standard deviation.

RESULTS AND DISCUSSION

The development and limited evaluation of the air-pressure projectile-motion teaching aid comprised product development, technical performance testing, repeatability assessment, expert validation and revision, and limited classroom evaluation. To improve clarity and reduce redundancy, the Results section is organized around three principal evidence streams: technical performance, expert-assessed validity, and limited classroom evaluation.

Development and Final Product

The development process produced an air-pressure-based teaching aid designed to demonstrate projectile motion by allowing the elevation angle and applied air pressure to be varied. The final apparatus consisted of a pressurized-air launching system, angle-measurement device, pressure gauge, projectile holder, trigger mechanism, supporting structure, and length-measuring instrument. The final configuration and labeled components of the developed apparatus are shown in Figure 3.

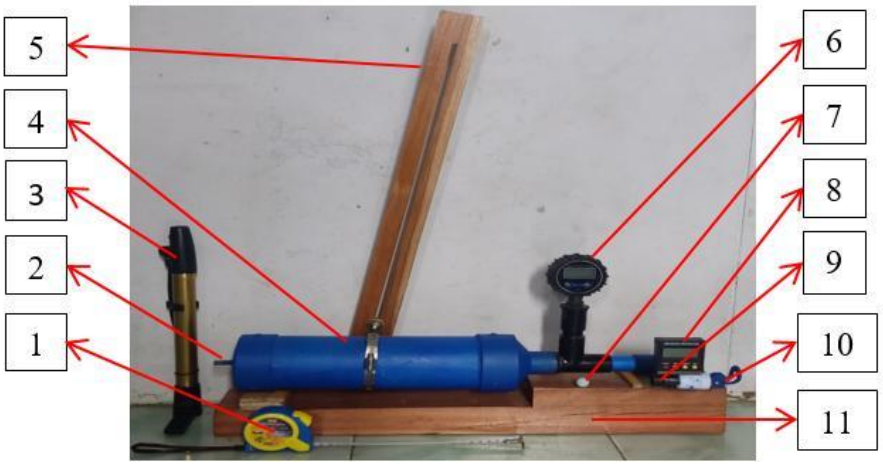


Figure 3. Air-Pressure Projectile-Motion Teaching Aid Product

Technical Performance of the Teaching Aid

Technical performance was evaluated at applied pressures of 2.0 and 3.4 kPa over elevation angles from 15° to 90°. Horizontal range and maximum height for each experimental condition are presented in Table 10.

Table 10. Technical Performance of the Projectile-Motion Teaching Aid

Elevation angle (°)	Horizontal range (m) 2.0 kPa	Maximum height (m) 2.0 kPa	Horizontal range (m) 3.4 kPa	Maximum height (m) 3.4 kPa
15	0.554	0.037	0.688	0.046
20	0.682	0.062	0.806	0.073
25	0.766	0.090	1.036	0.121
30	0.850	0.122	1.138	0.165

Elevation angle (°)	Horizontal range (m) 2.0 kPa	Maximum height (m) 2.0 kPa	Horizontal range (m) 3.4 kPa	Maximum height (m) 3.4 kPa
35	0.920	0.161	1.196	0.210
40	0.940	0.197	1.236	0.275
45	0.970	0.242	1.304	0.325
50	0.906	0.287	1.234	0.369
55	0.858	0.329	1.172	0.423
60	0.810	0.351	1.086	0.472
65	0.706	0.402	0.982	0.512
70	0.604	0.405	0.804	0.551
75	0.482	0.457	0.644	0.583
80	0.318	0.475	0.432	0.606
85	0.160	0.486	0.220	0.621
90	0.000	0.490	0.000	0.625

At both applied pressures, horizontal range increased as the elevation angle approached 45° and decreased at angles above 45°. The maximum measured horizontal ranges were 0.970 m at 2.0 kPa and 1.304 m at 3.4 kPa, both at 45°. At 90°, the horizontal range was 0 m under both pressure conditions. Maximum height generally increased with elevation angle, reaching 0.490 m at 2.0 kPa and 0.625 m at 3.4 kPa at 90°. The range-angle relationship is illustrated in Figure 4, whereas the maximum-height relationship across elevation angles is shown in Figure 5.

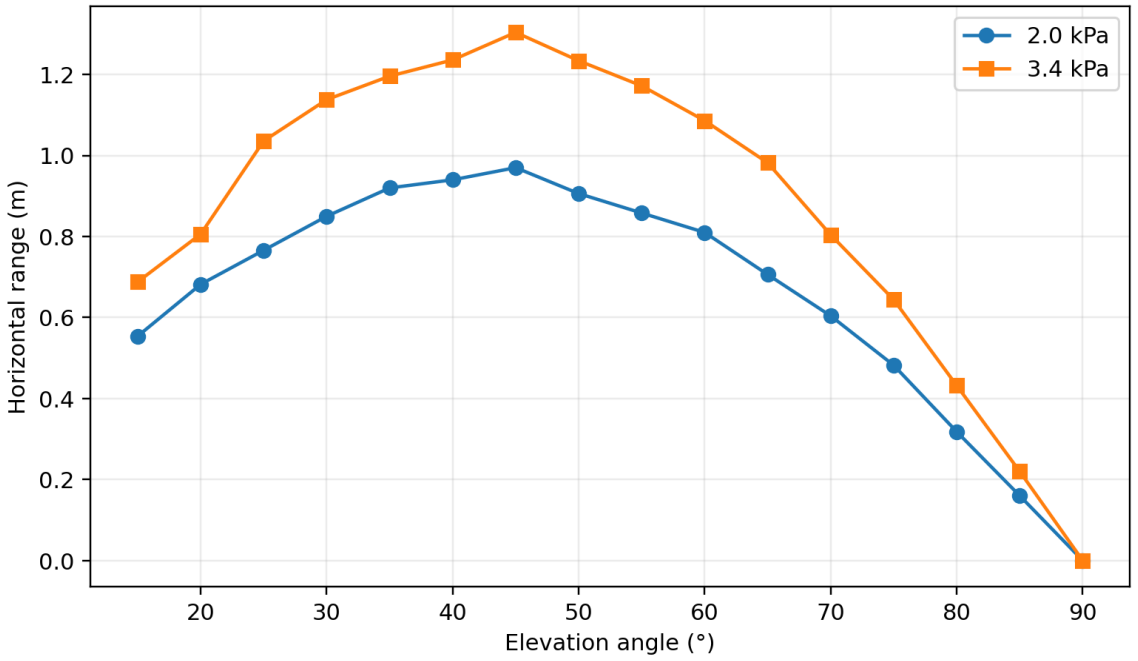


Figure 4. Maximum Horizontal Range versus Elevation Angle

For every nonvertical launch angle, the 3.4-kPa condition produced a greater horizontal range than the 2.0-kPa condition, and maximum height was also greater at 3.4 kPa across all investigated angles. At 45°, increasing the applied pressure from 2.0 to 3.4 kPa increased horizontal range from 0.970 to 1.304 m (approximately 34.4%) and maximum height from 0.242 to 0.325 m (approximately 34.3%). Because projectile exit velocity was not directly measured, pressure is reported as a controlled experimental input rather than as a direct measure of initial velocity.

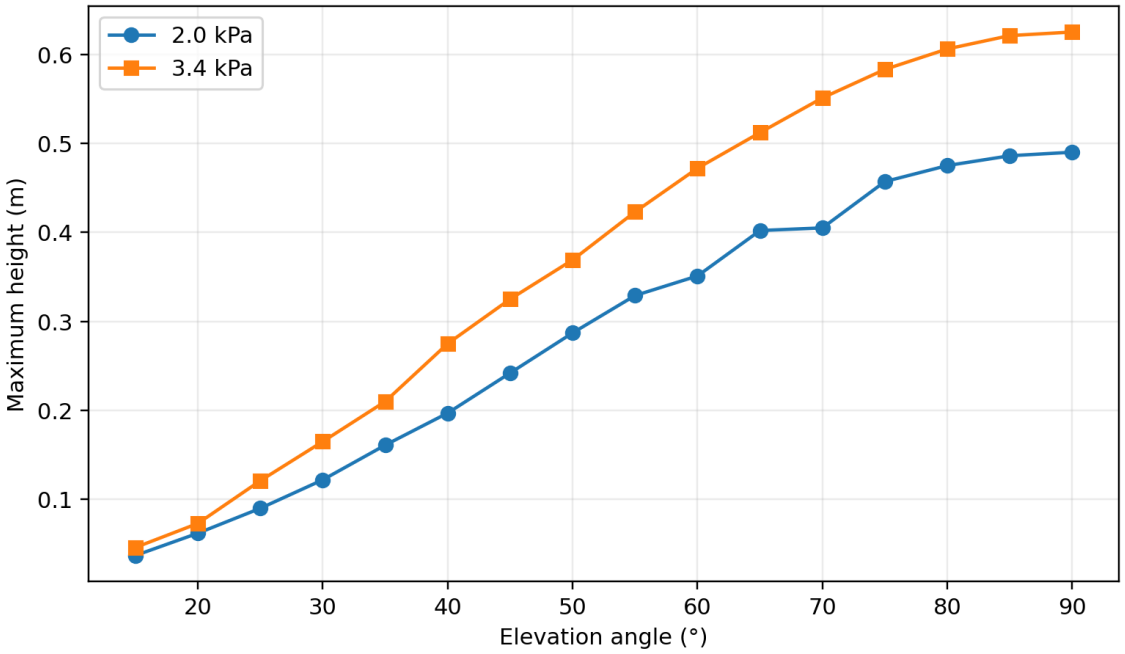


Figure 5. Maximum Height versus Elevation Angle

Repeatability Under Fixed Launch Conditions

Repeatability was examined using five launches at 45° and 2.0 kPa. The measured horizontal ranges were 0.970, 0.970, 1.000, 0.980, and 0.960 m. These measurements produced a mean horizontal range of 0.976 m and a sample standard deviation of 0.015 m, giving a repeated-launch result of 0.976 ± 0.015 m (mean ± SD, n = 5). The standard deviation describes the dispersion of repeated measurements under the fixed launch condition.

Expert Validation and Product Revision

Before the limited classroom trial, five validators evaluated the teaching aid. To present the validation evidence more compactly, the content/material and media results are consolidated in Table 11. The overall expert-validation result was 81.2%, corresponding to a mean item score of 4.06 on the five-point scale and meeting the predetermined "very valid" criterion.

Table 11. Expert Validation Results

Validation domain	Items	Item mean scores	Domain mean	(%)
Content/material	1–7	4.4, 4.2, 3.4, 4.2, 4.4, 3.6, 3.8	4.00	80.0
Media	8–20	4.0, 3.8, 4.2, 4.2, 4.4, 3.2, 4.0, 4.2, 4.6, 4.4, 3.8, 3.8, 4.6	4.09	81.8
Overall	1–20		4.06	81.2

Within the content/material domain, item means ranged from 3.4 to 4.4, with Items 1 and 5 receiving the highest mean ratings. Within the media domain, item means ranged from 3.2 to 4.6; Item 13 received the lowest mean rating, whereas Items 16 and 20 received the highest ratings. Quantitative ratings and qualitative recommendations were used to refine the apparatus before the limited classroom implementation. The principal product modifications made in response to validator feedback are illustrated in Figure 6.



Before revision 1



After revision 1



Before revision 2



After revision 2

Figure 6. Product Modifications Before and After Expert Validation

Limited Classroom Evaluation

The limited classroom trial involved one physics teacher and 18 Grade XI students. Figure 7 shows the use of the developed apparatus during the classroom implementation. Teacher response, student response, and post-instruction learning outcomes are consolidated in Table 12 to provide a concise summary of the classroom evaluation.



Figure 7. Use of the Projectile-Motion Teaching Aid During Classroom Learning

The teacher-response score was 43/50 (86.0%), with a mean item score of 4.30, and was categorized as "very effective" according to the predetermined response criteria. The student-response score was 56.72/75 (75.6%), corresponding to a mean

item score of approximately 3.78, and was categorized as "effective." These response results indicate positive user acceptance during the limited implementation.

Table 12. Limited Classroom Evaluation Outcomes

Evaluation outcome	Participants	Instrument	Descriptive result	Percentage / mastery	Classification
Teacher response	1 physics teacher	10-item questionnaire	43/50; mean item score = 4.30	86.0%	Very effective*
Student response	18 students	15-item questionnaire	56.72/75; mean item score ≈ 3.78	75.6%	Effective*
Post-instruction learning outcome	18 students	15-item test	Mean = 83.33; median = 82.5; SD = 9.55; range = 65–100	94.4% mastery (17/18)	MMC = 70

**Category terminology follows the predetermined questionnaire criteria. Teacher and student response percentages are interpreted as indicators of user acceptance/usability rather than as causal evidence of instructional effectiveness.*

The post-instruction learning-outcome scores ranged from 65 to 100, with a mean of 83.33, a median of 82.5, and a sample standard deviation of 9.55. Seventeen of the 18 students achieved scores of at least 70, corresponding to a mastery proportion of 94.4%, while one student scored 65 and did not meet the minimum mastery criterion. The distribution of individual scores relative to the minimum mastery criterion is illustrated in Figure 8. Because the assessment was administered only after instruction, the findings are reported as post-instruction achievement and mastery rather than as measured learning gains.

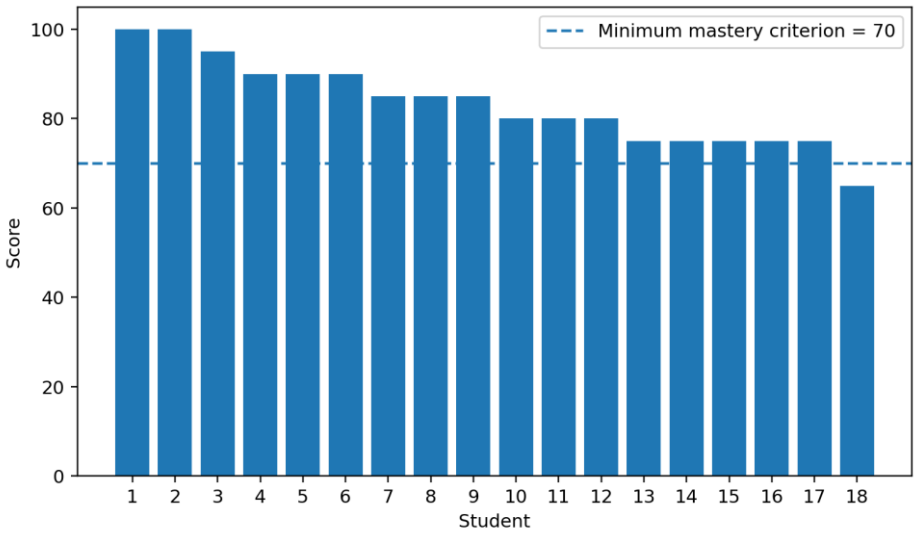


Figure 8. Student Learning Outcomes

Overall, the streamlined Results show that the apparatus reproduced the expected qualitative projectile-motion patterns, achieved a very valid expert-assessment result, received positive teacher and student responses during limited implementation, and was accompanied by high post-instruction mastery. These

findings provide evidence of preliminary technical and classroom feasibility without implying causal improvement in learning outcomes.

Discussion

Technical Performance in Relation to Projectile-Motion Theory

The technical measurements showed a systematic relationship between elevation angle, horizontal range, and maximum height. At both 2.0 and 3.4 kPa, horizontal range increased as the launch angle approached 45° and decreased at higher angles. This pattern is consistent with the ideal projectile-motion model, in which the range for a projectile launched and landing at the same height is maximized at 45° when air resistance is neglected. Contemporary classroom datasets likewise use range–angle and trajectory measurements to compare experimental observations with ideal projectile-motion predictions (Wadsworth et al., 2025).

The correspondence between the measured maximum range and the ideal 45° prediction indicates that the apparatus reproduced a fundamental qualitative characteristic of projectile motion. This is relevant for instruction because projectile motion requires students to coordinate horizontal and vertical motion simultaneously. Concrete or visual representations can help students connect these components with an observable trajectory (Rosita et al., 2020; Pineda, 2020; Widyastuti, 2021).

Maximum height generally increased with elevation angle and reached its highest measured value at 90°. This pattern is also consistent with the ideal model because a larger launch angle increases the vertical component of the initial velocity for a fixed speed. The agreement should nevertheless be interpreted qualitatively rather than as proof of exact physical accuracy because the present system includes real experimental factors such as air resistance, launcher geometry, friction, pressure variation, projectile properties, and measurement uncertainty.

Air Pressure as a Controlled Launch Parameter

The 3.4-kPa condition produced greater horizontal range and maximum height than the 2.0-kPa condition across all investigated nonvertical angles. At 45°, increasing pressure from 2.0 to 3.4 kPa increased horizontal range by approximately 34.4% and maximum height by approximately 34.3%. These observations demonstrate that applied air pressure functioned as an experimentally controllable parameter that changed the projectile response.

Air pressure should not, however, be interpreted as a direct measurement of initial velocity. Pneumatic-launcher research shows that exit velocity is affected by supply pressure together with launcher geometry and gas-flow characteristics (Sobczyk et al., 2021; Jastrzębski & Ułanowicz, 2022). Thus, the pressure gauge in the present apparatus provided a controlled input, whereas v_0 was not measured directly. Future calibration using a photogate, chronograph, or validated video analysis would allow a quantitative pressure–velocity relationship to be established.

Repeatability of the Experimental Measurements

The five repeated launches at 45° and 2 kPa produced a mean horizontal range of 0.976 ± 0.015 m. Standard deviation is appropriate here because the analysis concerns dispersion among repeated measurements performed under nominally identical conditions. In projectile-motion laboratory work, repeated measurements and uncertainty analysis are used to distinguish measurement scatter from

disagreement with theoretical values (Ametepe et al., 2023; Wadsworth et al., 2025). The relatively small spread provides preliminary evidence of repeatability at the tested condition, although additional repeated trials across multiple angles and pressures are needed for comprehensive characterization.

Expert Validation and Product Suitability

The expert-validation score of 81.2% placed the teaching aid in the "very valid" category according to the predetermined criteria. This result indicates that the content and media characteristics of the apparatus were judged suitable for limited classroom implementation after revision. Validation is particularly important for a physical physics teaching aid because the apparatus must represent the intended concepts without introducing misleading relationships. Projectile motion involves interrelated concepts including trajectory, initial velocity, launch angle, and gravity (Tuárez-Zambrano et al., 2024). Developmental studies likewise emphasize expert evaluation as a basis for refining instructional media before implementation (Febrianti & Prabowo, 2021).

The validation result should be interpreted as evidence of expert-assessed suitability rather than as proof of instructional effectiveness. The lower-rated validation items identified aspects requiring refinement, while the qualitative feedback informed the product revisions shown in Figure 6.

Usability, Teacher Response, and Student Acceptance

The teacher response of 86% and student response of 75.6% indicate generally positive evaluations of the apparatus during the limited classroom trial. According to the original questionnaire categories, these scores were classified as "very effective" and "effective," respectively. In educational-media development, response data are commonly used alongside validation and classroom trials to describe practical acceptance and usability (Wulanningtyas et al., 2023). The teacher and student results are therefore best interpreted as positive user responses rather than direct estimates of causal instructional effectiveness.

This distinction is consistent with the developmental purpose of the study. An apparatus may accurately represent physics concepts but still be difficult to integrate into classroom practice. Conversely, positive user responses cannot establish conceptual accuracy or learning gains by themselves. The combination of expert validation and positive user responses thus provides complementary evidence of suitability and classroom acceptance. Evaluation of instructional devices remains important for determining whether a product functions as intended in instructional practice (Jan & San, 2025).

Physical Experimentation and Complementarity with Virtual Simulation

The air-pressure apparatus provides a physical learning experience that differs from, but does not need to compete with, virtual projectile-motion environments. Simulation-based approaches allow rapid and controlled manipulation of variables and have supported projectile-motion learning in previous studies (Meka Jane C, 2025; Mohamad, 2025; Uwayezu & Yadav, 2023). Physical investigations, in contrast, expose students to actual instruments, measurement variability, and manipulation of tangible components.

Evidence comparing physical and virtual investigations suggests that both can support conceptual learning, with their relative advantages depending on learning goals and task design (Muilwijk & Lazonder, 2023). Comparative work has also shown

that simulations and physical experiments can emphasize different aspects of learning and may be complementary when carefully integrated (Krüger et al., 2022). The developed apparatus can therefore serve as a physical component in a blended projectile-motion learning sequence rather than as a replacement for simulation tools.

Potential Educational Role of Hands-On Projectile-Motion Activities

The physical manipulation of launch angle and air pressure provides an opportunity for students to connect abstract projectile-motion variables with observable events. Previous studies using projectile-motion props have shown that concrete representations can facilitate visualization of trajectories and support conceptual learning (Putri & Suwarna, 2020). Earlier work also reported differences in academic performance between students taught with instructional aids and those without such materials (Adebayo, 2018). These findings provide a rationale for hands-on media, although they do not substitute for causal evidence in the present study.

Active participation in experiments may also support deeper engagement with physics concepts when students predict, observe, measure, and interpret results. Research on physics learning emphasizes the importance of active participation and suitable instructional media (Irsalina, 2025; Tanti, 2025). Broader educational innovation likewise depends on systematic integration of teaching methods and professional practice (Durasa, 2024). However, motivation, engagement, and scientific-process skills were not directly measured in the present study and therefore remain potential rather than demonstrated outcomes.

Student Learning Outcomes and the Meaning of Mastery

The post-instruction assessment showed that 17 of 18 students (94.4%) achieved the minimum mastery criterion, with a class mean of 83.33. End-of-instruction assessment provides information about whether students demonstrate targeted competencies (Sirait et al., 2017), and successful physics problem solving requires conceptual mastery in addition to procedural use of equations (Sulman et al., 2023). Learning outcomes therefore provide evidence of achieved competence within the investigated instructional setting (Megasafitri, 2023; Hatiku et al., 2022).

The high mastery proportion is compatible with previous findings from projectile-motion instructional media. Putri and Suwarna (2020) reported a normalized gain of 0.64 for students using projectile-motion props compared with 0.50 in a control group. Uwayezu and Yadav (2023) likewise reported stronger gains in understanding projectile-motion graphs when computer-simulated teaching tools were used. These studies support the educational plausibility of visual and interactive approaches.

Nevertheless, the present study did not include a pretest or comparison group. The 94.4% mastery proportion therefore represents high post-instruction achievement rather than measured learning gain, and the effect of the apparatus cannot be separated from teacher explanation, prior knowledge, classroom interaction, or other instructional factors. Causal interpretation requires a design that supports comparison or counterfactual reasoning (Shepherd et al., 2024). The one student who did not meet the mastery criterion also indicates the continuing need for diagnostic follow-up and remedial support (Umar & Abdjul, 2022).

Safety and Responsible Classroom Implementation

Because the apparatus uses compressed air and launches a physical projectile, safe operation is part of its instructional feasibility. The 4-kPa value should be

interpreted as the operating ceiling adopted in this study rather than as a certified structural pressure limit. Pressure monitoring, leak inspection, control of projectile direction, teacher supervision, and routine maintenance are therefore necessary during classroom use. If a pressure-relief valve is not physically integrated into the current apparatus, it should be described as a recommended improvement rather than as an existing component.

Study Limitations and Directions for Further Research

Several limitations constrain interpretation of the findings. First, the classroom trial involved only 18 students from one school and one physics teacher. The results should therefore be treated as preliminary evidence of feasibility rather than generalized estimates of effectiveness.

Second, the study used a posttest-only limited-trial design. Without baseline data or a comparison group, causal learning improvement cannot be attributed to the teaching aid. Future studies should employ validated pre- and post-assessments together with comparison or control groups.

Third, projectile initial velocity was not directly measured. Future work should calibrate the apparatus across several pressure levels using direct exit-velocity measurements. Fourth, repeatability was evaluated only with five launches at 45° and 2 kPa; further technical validation should include repeated trials across multiple angles and pressures and a more complete uncertainty analysis. Fifth, conceptual change, misconceptions, motivation, engagement, and scientific reasoning were not measured directly and should be evaluated with dedicated instruments in subsequent studies.

Taken together, the findings support three complementary conclusions. First, the apparatus demonstrated technical functionality by producing the expected qualitative relationships among elevation angle, horizontal range, and maximum height, including maximum measured range at 45°. Second, expert validation and user-response results indicate that the apparatus was considered suitable and acceptable for limited classroom use. Third, 94.4% of the participating students achieved the predetermined mastery criterion after instruction. The principal contribution of the study therefore lies in integrating a controllable physical projectile-motion apparatus with preliminary technical and classroom evaluation. The evidence establishes technical feasibility, expert-assessed suitability, positive user responses, and high post-instruction mastery, while leaving causal effectiveness for future controlled investigation.

CONCLUSIONS

This study developed an air-pressure-based projectile-motion teaching aid and evaluated its technical performance, expert-assessed validity, user responses, and student mastery during a limited classroom trial. Technical testing showed that the apparatus reproduced the expected qualitative characteristics of projectile motion: horizontal range increased toward a maximum at approximately 45° and then decreased, whereas maximum height generally increased with elevation angle. Higher applied air pressure also produced greater measured horizontal range and maximum height. Under repeated conditions of 45° and 2 kPa, the apparatus produced a mean horizontal range of 0.976 ± 0.015 m, providing preliminary evidence of repeatability.

Expert validation yielded 81.2%, placing the teaching aid in the "very valid" category according to the predetermined criteria. The teacher response reached 86% and was categorized as "very effective," while the student response reached 75.6% and was categorized as "effective." The post-instruction learning-outcome assessment produced a mean score of 83.33, with 17 of 18 students (94.4%) meeting the minimum mastery criterion of 70. Thus, the apparatus demonstrated technical functionality, expert-assessed suitability, positive classroom acceptance, and high post-instruction mastery. Because the study did not include a pretest or comparison group, these findings should not be interpreted as causal evidence that the teaching aid improved student learning outcomes.

RECOMMENDATIONS

The developed air-pressure projectile-motion teaching aid can be used as a complementary hands-on resource for senior high school physics instruction, particularly to support direct observation of the relationships among launch angle, horizontal range, maximum height, and applied air pressure. Classroom use should follow the established safety procedures, including pressure monitoring, inspection of connections and components, teacher supervision, and maintenance of a clear projectile path.

Further research should extend the present limited evaluation before routine or large-scale implementation. Future studies should involve larger samples, multiple schools, and pretest–posttest designs with appropriate comparison or control groups. Technical development should include direct calibration of projectile initial velocity across pressure settings, repeated measurements over a wider range of angles and pressures, and more comprehensive uncertainty analysis. Further work could also compare the physical apparatus with virtual simulations or combined physical–virtual approaches and examine conceptual understanding, misconceptions, scientific reasoning, engagement, and experimental skills.

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Conflict of Interest Statement

The authors declare no conflict of interest.

Informed Consent

Participant privacy was protected throughout the study. Written informed consent was obtained from all individuals prior to their inclusion in the research.

Ethical Approval

This research was conducted in accordance with principles of research ethics and academic integrity. All research procedures complied with applicable institutional policies. Participants' privacy and data confidentiality were protected, and research data were used solely for scientific purposes.

Data Availability

The data supporting the findings of this study are available from the corresponding author upon reasonable request. The data reported in this study are derived from original research conducted by the authors' research team.

Author Contributions Statement

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Mitra Rahayu	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	✓
Jeffri Parrangan	✓	✓	✓			✓		✓	✓	✓	✓	✓		✓
Ihang Ramadhan A.	✓	✓		✓			✓	✓	✓	✓	✓		✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

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