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Creation of a Virtual Laboratory for Collision Dynamics Educational Tool with Integrated Collision Algorithm

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Abstract

Conventional physics laboratories often suffer from limitations in terms of equipment availability and safety, which hinders optimal learning of collision dynamics concepts. This research aims to develop a virtual laboratory based on collision algorithm to simulate perfect collision as an alternative solution in physics learning. The development uses the ADDIE model, which includes the stages of analysis, design, development, implementation, and evaluation. The collision algorithm was implemented using ActionScript 3, with interpolation allowing for more accurate collision detection at high speeds. The validation results show that the simulation is in line with the law of conservation of momentum and kinetic energy and is consistent with analytical solutions from MATLAB and Python. Functionality testing was conducted by 20 students, and the results showed that the use of this virtual laboratory significantly improved their concept understanding, with the average improvement ranging from 24% to 56%. Students also reported that this virtual laboratory is more interactive and interesting, thus increasing their learning motivation. The conclusion of this study is that the collision algorithm-based virtual laboratory is effective as a physics learning media and can be adopted more widely in technology-based education, especially to understand complex physics concepts more deeply.

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INTRODUCTION

Technology integration in education is increasing, particularly in enhancing comprehension of intricate scientific subjects. A fundamental concept in physics that requires comprehensive comprehension is collision dynamics. This idea is frequently challenging to comprehend due to the constraints of conventional physical laboratory facilities that necessitate secure and scalable practical demonstrations. Moreover, physical laboratories frequently have limitations with scarce resources and safety hazards (Galan et al., 2016; Morales-Menendez et al., 2019). These constraints create deficiencies in learning that adversely affect students' comprehension of physics ideas (Galan et al., 2016; (Morales-Menendez et al., 2019).

The Virtual Laboratory (Virtual Lab) presents an innovative solution to these challenges. The Virtual Lab offers an interactive and secure educational platform, enabling students to investigate physical phenomena in regulated settings. The technology facilitates realistic and immersive simulations, permitting students to perform experiments and comprehend physics ideas thoroughly without the constraints of a physical laboratory (Riwayati et al., 2014; (Yusupa, 2023).

Prior studies have demonstrated that virtual laboratories can markedly enhance students' comprehension of scientific ideas. Arianti, Astra, and Budi conducted a study that effectively constructed a Virtual Physics Laboratory (VPL) centered on collisions, enhancing students' comprehension of the idea (Arianti et al., 2021). In addition, Chan et al. (2021) discovered that virtual chemistry laboratories can surpass traditional learning methods in effectiveness, particularly when integrated with conventional approaches. Despite numerous studies investigating the advantages of Virtual Lab, research deficiencies persist concerning the optimization of algorithms employed in virtual laboratory simulations, particularly collision algorithms designed to enhance simulation accuracy (Chan et al., 2021).

This research incorporates the collision algorithm in creating a virtual laboratory to enhance the precision and realism of physics simulations. The collision algorithm, developed in ActionScript 3, aims to replicate object interactions in alignment with relevant physical principles, essential for comprehending collision dynamics. This research aims to create a virtual laboratory that facilitates comprehensive exploration of physics ideas and is readily accessible across multiple devices, enabling students to learn anytime and from any location (Liu et al., 2015; Zhuoluo et al., 2019).

This research aims to develop dependable and interactive virtual laboratory software that enhances students' comprehension of physics principles about collision dynamics. This research intends to assess the efficacy of the virtual laboratory in enhancing students' conceptual knowledge before and after its utilization. Consequently, this research is anticipated to significantly enhance physics education, particularly in the comprehension of topics necessitating profound and experimental insight (van der Graaf et al., 2020; Ray et al., 2012; Saeedabadi et al., 2022).

RESEARCH METHODS

This research employs the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), a systematic framework for instructional development and software applications (Aeni & Yusupa, 2018; Cahyadi, 2019). The ADDIE model was selected for its capacity to guarantee structured and phased development, as illustrated in Figure 1. The V-Lab Development Process utilizes ADDIE to facilitate the evaluation and enhancement of each phase as required. This document provides a comprehensive overview of each phase in the ADDIE paradigm utilized in this research.

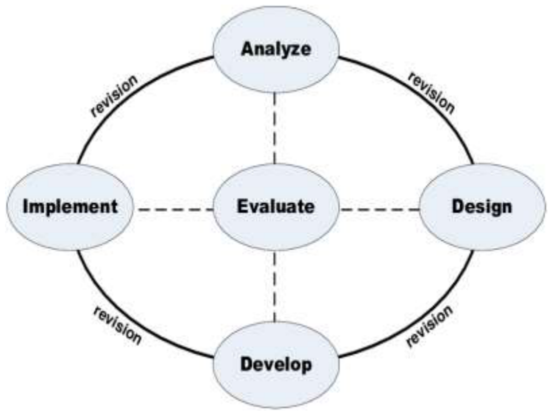

Figure 1. V-Lab development process utilizing ADDIE

A. Analysis

The analysis phase was executed to identify the current issues and establish the learning objectives. The requirements analysis comprised interviews with physics teachers at FMIPA Sam Ratulangi University to assess deficiencies in understanding the concept of collision dynamics. A literature review was performed to comprehend pertinent ideas and evaluate the current physics curriculum. The analytical results were utilized to establish particular learning objectives, specifically enhancing students' comprehension of collision using a virtual laboratory. This analysis encompasses identifying variables for measurement, including enhancing students' conceptual comprehension prior to and following the utilization of the virtual laboratory.

B. Design

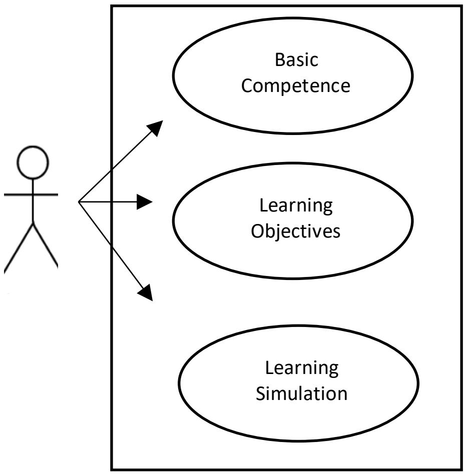

Figure 2. *Usecase diagram of* virtual laboratory

At this juncture, the researcher executed a design informed by the analytical data. The design commenced with the scripting of the virtual laboratory, encompassing the user interface and the development of the effect simulation script. A preliminary user interface prototype was developed with the newest Adobe Animate to guarantee functionality and user engagement. The design of the collision scripts and the employed physics models were formulated at this point. This design includes the choice of the collision algorithm utilized in the simulation or virtual laboratory, engineered to yield precise calculations harmonized with the collision method and aligned with the physical laws pertinent to the material. The Use Case diagram illustrates the interaction between the user and the Virtual Lab system. This figure depicts the user's utilization of the simulation script and feature interaction, as illustrated in Figure 2.

C. Development

Researchers execute development according to the established design. This phase incorporates the creation of collision algorithms utilizing Adobe Animate ActionScript 3.0 to mimic flawless collisions. The construction of virtual laboratory content entails the creation of educational materials and simulated experiments. User interface development is conducted to guarantee usability and efficient interaction utilizing Adobe Animate. Subsequent to development, functionality testing is performed to verify that all features operate in accordance with specifications. This assessment encompasses material validation by physics instructors, input validation, simulation reset, and animation regulation. Feasibility testing confirmed that the virtual lab was prepared for end users and free from faults or problems. The validation of virtual lab data for the collision algorithm is conducted through a comparison with tools like MATLAB and manual measurements.

D. Implementation

Implementation entails integrating the designed virtual laboratory into an actual learning setting. This phase involves instructing lecturers and students on utilizing the virtual laboratory for FMIPA UNSRAT faculty students. The virtual laboratory is integrated with current learning platforms to facilitate accessibility. Oversight and technical assistance are offered while utilizing the virtual laboratory to guarantee the program operates correctly and effectively enhances learning. Data was gathered at this phase for assessment reasons, encompassing user satisfaction surveys and direct observation.

E. Evaluation

Evaluation An evaluation was performed to determine the efficacy of the virtual laboratory and to implement enhancements if necessary. Data was collected via questionnaires administered to lecturers and students to assess their experiences with the virtual laboratory. The obtained data were analyzed to assess the enhancement in participants' comprehension from pre-test to post-test, serving as a crucial sign of the study's success. The evaluation results were utilized to enhance the virtual laboratory and pinpoint areas for enhancement. The assessment also sought to confirm the dependability of the collision algorithm and the uniformity of the virtual laboratory as an educational and research instrument.

By elucidating each phase in the development of algorithms and interactive learning media through Virtual Lab simulations, the implementation of the ADDIE model guarantees a systematic and structured execution of all stages, from analysis to evaluation. This research generates an efficient virtual laboratory for implementing the collision algorithm to simulate perfect collisions. It offers methodological guidelines for developing simulation-based learning media integrated with the algorithm (Rozi & Romadhoni, 2023).

RESULTS AND DISCUSSION

A. Results

This study's results indicate that employing a collision algorithm-based virtual laboratory markedly enhances students' comprehension of collision dynamics. Twenty students participated as respondents in this exam, revealing that traditional physics laboratories on their campuses frequently encounter constraints regarding equipment availability and safety. These limitations impede the effective comprehension of physics principles that necessitate direct simulation, particularly the concept of collision dynamics. The effective implementation of a virtual laboratory utilizing the ADDIE (Analysis, Design, Development, Implementation, Evaluation) strategy has facilitated easier and safer access for students to optimal collision simulations.

This phase is a crucial initial step, involving a comprehensive study to identify existing issues and establish precise learning objectives. This research involved interviews with physics teachers at FMIPA Sam Ratulangi University to evaluate limits in understanding collision dynamics. The interviewees revealed that physical laboratories frequently encounter constraints regarding instruments, resources, and safety, adversely affecting learning efficacy. This investigation subsequently resulted in the decision to create a virtual laboratory designed to assist students in comprehending the notion of perfect collision through interactive and secure simulations. The needs analysis encompassed identifying research variables, including students' comprehension levels before and after using the virtual laboratory. Learning objectives were established to enhance comprehension of collision ideas, namely via collision algorithms.

The Design Stage, informed by the analysis results, concentrates on creating the learning script and an intuitive user interface for the virtual lab. At this step, the design of an optimal collision simulation script is meticulously developed, encompassing the visualization of the collision algorithm to deliver a genuine educational experience. The

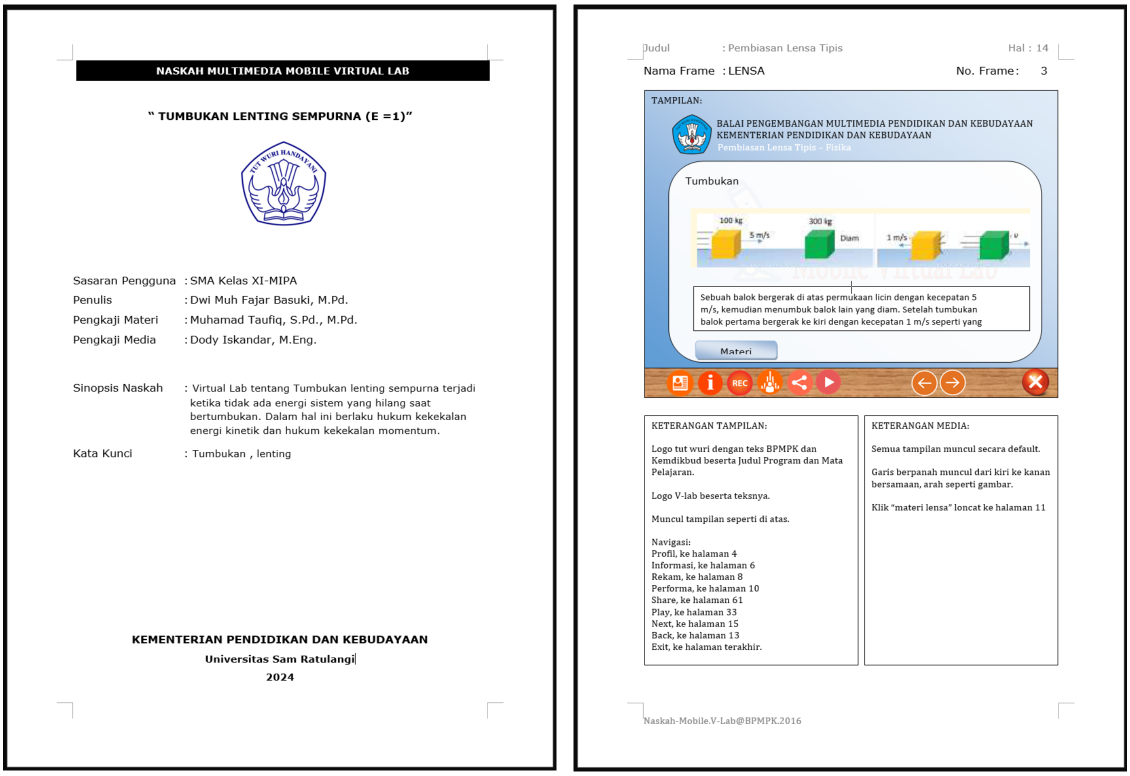

Figure 1. Exemplar V-Lab manuscript

script development in the Virtual Lab seeks to guarantee that the simulation scenarios facilitate participatory learning. Figure 3 illustrates an example of the script employed for the experimental setting. Sample V-Lab Script containing experimental protocols and explanatory material. The preliminary prototype was developed on Adobe Animate with ActionScript 3.0, designed to incorporate interactivity and user engagement. The collision algorithm's design incorporated the principles of momentum and kinetic energy conservation, alongside interpolation techniques to enhance collision detection accuracy at elevated velocities. The design method incorporates simulation scripts or scripts featuring diverse collision conditions, enabling students to investigate variations in the input of alternative collision idea values. Moreover, the interface navigation is designed to be both straightforward and instructive, aiding users in utilizing the simulation features.

Development Phase Following the finalization of the design, the user interface (UI) of the Virtual Lab was crafted to facilitate seamless interaction and navigation. This interface comprises essential visual components that facilitate a conducive learning environment, as illustrated in Figure 4.

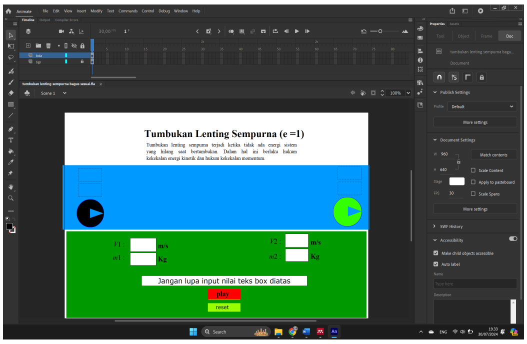

Figure 2. V-Lab user interface development

The development phase was executed to transform the design into a fully operational virtual laboratory. At this juncture, the collision algorithm was programmed utilizing ActionScript 3.0, which can compute the final velocity of two spheres or objects following a flawless collision. This algorithm's implementation prioritizes precise calculations that adhere to physics principles. The establishment of the virtual laboratory encompassed the formulation of educational content pertinent to the simulation, including resources for competency elucidation and simulated experiments. User interface development was undertaken to guarantee usability and efficient interaction. Upon completion of development, internal functionality testing was performed to verify that all functions, including material validation, input validation, speed calculation, simulation reset, and animation control, operated correctly without any defects or problems.

The implementation stage involves applying the designed virtual laboratory within an actual learning setting. The virtual laboratory was evaluated in the physics class of FMIPA students, with participation from both students and lecturers in the implementation process to ensure ease of access and effective utilization in the learning experience. At this juncture, students received instruction on utilizing the virtual laboratory, encompassing the execution of simulations, modification of parameters, and interpretation of the resultant simulation data. Moreover, connectivity with online learning platforms is implemented to enhance student accessibility. During deployment, oversight and technical assistance are offered to guarantee the simulation operates effectively and students can utilize the various functionalities seamlessly.

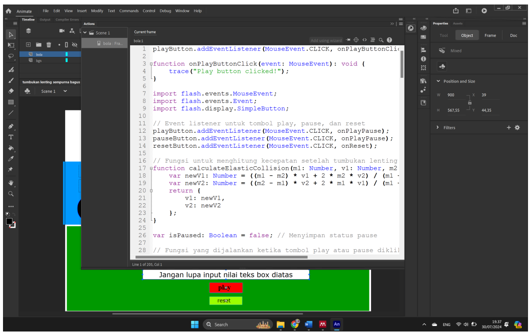

Figure 3. Collision algorithm implementation in action script 3.0

Evaluation Phase This concluding phase entails a comprehensive assessment of the efficacy of the developed virtual laboratory. The assessment was done by gathering data from students and lecturer material reviewers via surveys and direct observation. An evaluation of the simulation materials and functionality was performed to verify the consistency and precision of the collision algorithm, and to confirm that all features operated in accordance with specifications. The assessment also investigated the enhancement of students' conceptual comprehension, measured by comparing pre-test and post-test outcomes. The evaluation results indicated that the virtual laboratory effectively enhanced students' comprehension of collision dynamics principles, with an average improvement ranging from 24% to 56%. The assessment also pinpointed areas for enhancement, including the clarity of the user guide and the need for more comprehensive interactive features, which may serve as focal points for subsequent development (Aeni & Yusupa, 2018).

This work demonstrates that the implementation of a collision algorithm-based virtual laboratory may be executed in a systematic and scalable fashion. Every phase in the model substantially influences the ultimate result, enhancing student comprehension and establishing a robust basis for advanced physics research and education exploration.

The collision technique in this simulation is implemented using ActionScript 3.0, enabling the estimation of new velocities during collisions while adhering to the principles of conservation of momentum and kinetic energy. Validation studies demonstrated that the simulation results were congruent with established physical laws and aligned with analytical answers produced by tools such as MATLAB and Python. Students who virtual laboratory significantly aids in comprehending abstract concepts that are challenging to grasp in a physical laboratory, such as the principle of perfect collision. Students like Dea Gloria Pantow, Syanta Dalengkade, and Jessicha Asumbak demonstrated a substantial enhancement in comprehension, as indicated by the rise in their post-test scores following the utilization of the virtual laboratory.

The average enhancement in student comprehension ranged from 24% to 56%, with the most significant improvements observed in responders like Teriovina Gita Tatiwung and Fregita Rahayu Ubatta, who attained increases of up to 56% and 54%, respectively. The mean improvement in scores from pre-test to post-test indicates that this virtual laboratory effectively closes the learning gap that existed in traditional physics laboratories. These results substantiate the conclusion that the collision algorithm-based virtual laboratory enhances conceptual comprehension while simultaneously augmenting students' interest and involvement in physics education. Students

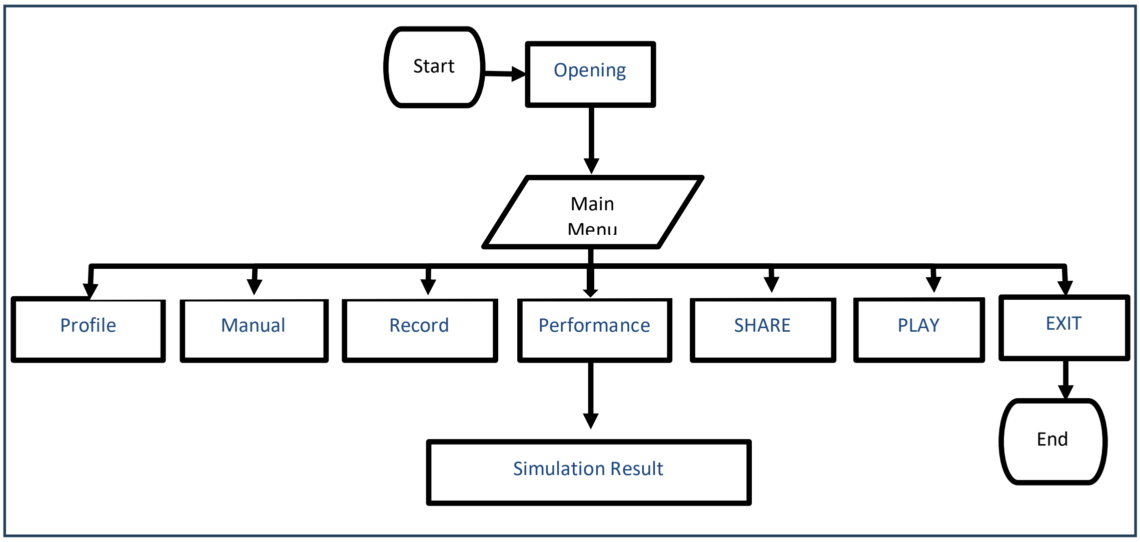

Figure 6. System workflow diagram

evaluated the virtual laboratory indicated that employing interpolation in collision detection enhanced accuracy, particularly at elevated speeds, rendering the simulation more realistic and akin to actual situations.

All functionalities of the virtual laboratory were thoroughly evaluated by respondents using diverse simulation scripts. The test results indicate that the simulation functionalities operate seamlessly during commencement, pausing, and resumption of the simulation. Furthermore, utilized by students as an alternative learning tool, this indicated that the visualization generated by this simulation is more lucid and offers a more comprehensive understanding of collision dynamics than conventional learning approaches.

Consequently, our virtual laboratory addresses the constraints of traditional physics laboratory facilities and serves as an excellent educational instrument for enhancing students' comprehension and analytical abilities regarding intricate physics subjects. This study's results demonstrate the significant potential of simulation technology in physics education, particularly in facilitating interactive, realistic, and engaging learning experiences. This virtual laboratory is anticipated to undergo further development with new attributes that are increasingly dynamic and user-centric, capable of integration with online learning systems to enhance accessibility for students across diverse educational settings.

B. Discussion

1. Algorithm Implementation in ActionScript 3.0 Virtual Lab

The implementation of this algorithm is done through the calculateElasticCollision function in ActionScript 3. This function accepts four parameters: the masses and initial velocities of the two balls, and returns an object containing the new velocities of the two balls after the collision. Implementing the collision algorithm in the simulation using ActionScript 3.0 aims to simulate a perfect collision accurately. The main code structure used in calculating the final velocity of the ball can be seen in *Figure 5. Implementation of the Collision Algorithm in ActionScript 3.0* (López-Adeva Fernández-Layos & Merchante, 2024; Milak et al., 2020; R & Dermawan, 2021). Here is the implementation of the function.

```
function
calculateElasticCollision(m1: Number,
v1: Number, m2: Number, v2: Number):
Object {

    var newV1: Number = ((m1 - m2) *
v1 + 2 * m2 * v2) / (m1 + m2);
    var newV2: Number = ((m2 - m1) *
v2 + 2 * m1 * v1) / (m1 + m2);
    return {
        v1: newV1,
        v2: newV2
    };
}
```

Implementation Explanation Calculating the New Velocity of the First Ball (**newV1**)**:** The first part of this formula (m1-m2)∗v1(m1-m2) * v1(m1-m2)∗v1 calculates the contribution of the first ball's initial velocity to the final velocity. The second part 2∗m2∗v22*m2*v22∗m2∗v2 calculates the contribution of the initial velocity of the second ball to the final velocity of the first ball. The sum of the two parts is then divided by the sum of the masses of the two balls (m1+m2)(m1 + m2)(m1+m2) to get the new velocity of the first ball after impact.

Calculating the New Velocity of the Second Ball (**newV2**)**:** Similar to the calculation of the new velocity of the first ball, the first part of this formula (m2-m1)∗v2(m2 - m1) * v2(m2-m1)∗v2 calculates the contribution of the initial velocity of the second ball to the final velocity. The second part 2∗m1∗v12*m1*v12∗m1∗v1 calculates the contribution of the initial velocity of the first ball to the final velocity of the second ball. The sum of the two parts is then divided by the sum of the masses of the two balls (m1+m2)(m1 + m2)(m1+m2) to get the new velocity of the second ball after impact. Returns a Result with a caption this function returns an object containing the new velocities of both balls (v1 for the first ball and v2 for the second ball).

The Virtual Lab simulation System Workflow Diagram for Perfect Collision commences with system start, during which the user inputs variables including the mass and initial velocity of the two spheres. The Virtual Lab simulation method is illustrated as a flowchart encompassing the complete procedure, beginning with user data input and concluding with the computation of output results. This flowchart elucidates each simulation phase, as depicted in Figure 6. Subsequently, the system executes input validation to ascertain the completeness and accuracy of the data. Upon validation, the optimal collision simulation operates by implementing the collision algorithm. This algorithm uses interpolation to precisely identify collisions, particularly at elevated velocities. A further velocity calculation is executed utilizing the momentum conservation principle and the kinetic energy equation. The results are presented via an interactive interface. The user can observe a visualization of the ball's speed and direction upon impact. The simulation concludes with the presentation of findings, allowing the user to rerun or terminate the simulation. This flow demonstrates a systematic and effective method for interactively comprehending the notion of perfect collision.

2. Functionality Validation Test

Functionality validation tests were performed to confirm that all features and functionalities in the virtual laboratory simulation operate in accordance with the specified requirements. This assessment encompasses input validation, computation of impact velocity, simulation reset, and animation management (initiate, pause, resume). The outcomes of the material validation assessment conducted by the reviewer indicate the degree of appropriateness and efficacy of the material in facilitating learning. Table 1 presents the Virtual Lab functionality assessment outcomes, encompassing input validation, speed computation, and animation regulation. The outcomes of this exam are encapsulated in the subsequent table.

Table 1. Results of The Validation Test for Virtual Lab Functionality

No.	Test Case	Input	Expected Output	Output Obtained	Status
1	Blank Input Validation	m1: "", v1: "", m2: "", v2: ""	Warning: "Fill in all input boxes!"	Warning: "Fill in all input boxes!"	Pass
2	Negative Speed Validation	m1: "1", v1: "2", m2: "1", v2: "3"	Warning: "Ball Speed 2 must be negative!"	Warning: "Ball Speed 2 must be negative!"	Pass
3	Calculate Velocity After Collision (Case 1)	m1: "1", v1: "2", m2: "1", v2: "-3"	v1': "-3", v2': "2"	v1': "-3", v2': "2"	Pass
4	Calculate Velocity After Collision (Case 2)	m1: "2", v1: "4", m2: "3", v2: "-1"	v1': "-0.2", v2': "2.6"	v1': "-0.2", v2': "2.6"	Pass
5	Simulation Reset	Click the reset button	Ball position reset, ball speed set to 0, text input reset, text output reset, arrow rotation reset	Ball position reset, ball speed set to 0, text input reset, text output reset, arrow rotation reset	Pass
6	Start Simulation	m1: "1", v1: "2", m2: "1", v2: "-3" and click the play button	Animation of the ball starting to move at the initial speed	Animation of the ball starting to move at the initial speed	Pass
7	Simulation Pause	Click the pause button	Ball animation pauses	Ball animation pauses	Pass
8	Continue Simulation	Click the play button after the pause	Animation of the ball resuming movement from the pause point	Animation of the ball resuming movement from the pause point	Pass
9	Collision Validation (Interpolation)	m1: "1", v1: "3", m2: "1", v2: "-2", the balls move and collide at certain positions with interpolation	The balls collide with each other, the new velocity is calculated according to the formula for perfect collision	The balls collide with each other, the new velocity is calculated according to the formula for perfect collision	Pass
10	Stage Boundary Validation (Reflection from wall)	m1: "1", v1: "5", the ball moves towards the stage wall	The ball bounces off the wall in the opposite direction according to the previous speed	The ball bounces off the wall in the opposite direction according to the previous speed	Pass

Incorporating the Collision algorithm in Virtual Lab testing for the Collision Dynamics Learning Object yielded favorable outcomes. The validation of null input and negative velocity effectively issued the appropriate warning. The calculation of velocity post-collision adheres accurately to the principles of physics. The reset function operates effectively, reinstating the simulation's position, velocity, and input/output parameters. The simulation operates seamlessly, encompassing the pause and resume functionalities. The ball's impact is accurately computed utilizing the theory of an ideal collision. Furthermore, the ball that contacted the stage boundary rebounded with its initial velocity. All assessments were successful, signifying that this Virtual Lab is prepared for utilization as an educational resource.

Table 2. Results of Material Reviewer Validation Test

Assessment Aspect	Description	Score	Description
Appropriateness of Material	Suitability of material content with Basic Competencies (KD) and physics learning curriculum.	95%	Very much in line with the KD and curriculum
Relevance to Learner Needs	The suitability of the media to the needs of students in understanding Collision Dynamics material.	92%	Helps visualise abstract concepts
Quality of Material Presentation	Presentation of material is systematic, clear, and supported by an informative interface.	94%	Presentation of material is easy to understand

According to the test findings, Table 2 encapsulates the material reviewer's evaluation of the appropriateness and quality of material presentation in the Virtual Lab, which received an average score of 93.67%. This evaluation indicates that Virtual Lab is deemed highly suitable for educational purposes, particularly on the subject of Collision Dynamics. The material reviewer indicated that this media effectively aids pupils in visualizing abstract ideas, such as collisions, through interactive simulations. Recommendations for further enhancement involve including simulation variants to accommodate a broader spectrum of materials. Consequently, this educational media can serve as an invaluable instrument for enhancing the quality of physics instruction at academic institutions or schools. Several pupils exhibited remarkable improvement, such as Teriovina Gita Tatiwung, who achieved a 56% enhancement, and Mohammad Risky Firmansyah Adam, who had a 54% gain in comprehension.

Table 3. Comparison of Pre-Test and Post-Test Scores

Respondent	Pre-Test Score (%)	Post-Test Score (%)	Difference (%)
Inggrit Londoran	55	89	34
Deniko Dahrun	44	95	51
Dea Gloria Pantow	59	83	24
Heolifa Risye Runtuwene	48	76	28
Arjun Efraim Owen Sembel	36	91	55
Fregita Rahayu Ubatta	32	86	54
Vijel S. C. Sondakh	42	79	37
Gabriel Fransiskus Tumbelaka	56	92	36
Syanta Dalengkade	49	88	39
Ayong Abmi Alfi Damaledo	47	85	38
Magdalena Manus	53	90	37
Meyshie Milanie Thesalonica Liem	41	94	53
Jessicha Asumbak	38	80	42
Teriovina Gita Tatiwung	37	93	56
Kenji Tumuju	33	75	42
Mohammad Risky Firmansyah Adam	50	87	37
Mary Kathryn Rasubala	52	78	26
Rafly Aditya Abudu	45	82	37
Anggrayni Kezia Tamangendar	46	84	38
Alfonso Willy Umboh	43	81	38

Table 3 presents a comparison of students' pre-test and post-test scores, indicating a substantial enhancement following the utilization of the Virtual Lab. The analysis of pre-test and post-test results from 20 students demonstrated a marked improvement in comprehension of collision dynamics after engaging with the Virtual Lab. Before utilizing the Virtual Lab, the average pre-test score of students ranged from 30% to 60%, reflecting a rather inadequate comprehension of the physics principles assessed, particularly in collision dynamics. Subsequently, following the utilization of the Virtual Lab, students' post-test scores significantly rose to between 70% and 100%, reflecting a considerable enhancement in comprehension. The mean enhancement in student comprehension varied between 24% and 56%, with the most significant progress shown in the capacity to elucidate the idea of perfect collision and forecast velocity post-impact. The enhancements demonstrate that the interactive simulations in the Virtual Lab effectively aid students in visualizing and comprehending abstract ideas that are frequently challenging to understand through traditional physics laboratory instruction. This suggests that the Virtual Lab exerts varying effects on individual students; yet, the overall average enhancement in comprehension above 40% has yielded quite favorable outcomes.

The utilization of Virtual Lab enhances conceptual comprehension and simultaneously encourages more student engagement in the learning process. Interactive simulations offer a more engaging and immersive experience compared to traditional approaches. Students can directly observe simulation results that adhere to the principles of physics, including the law of conservation of momentum and kinetic energy, within the framework of collisions.

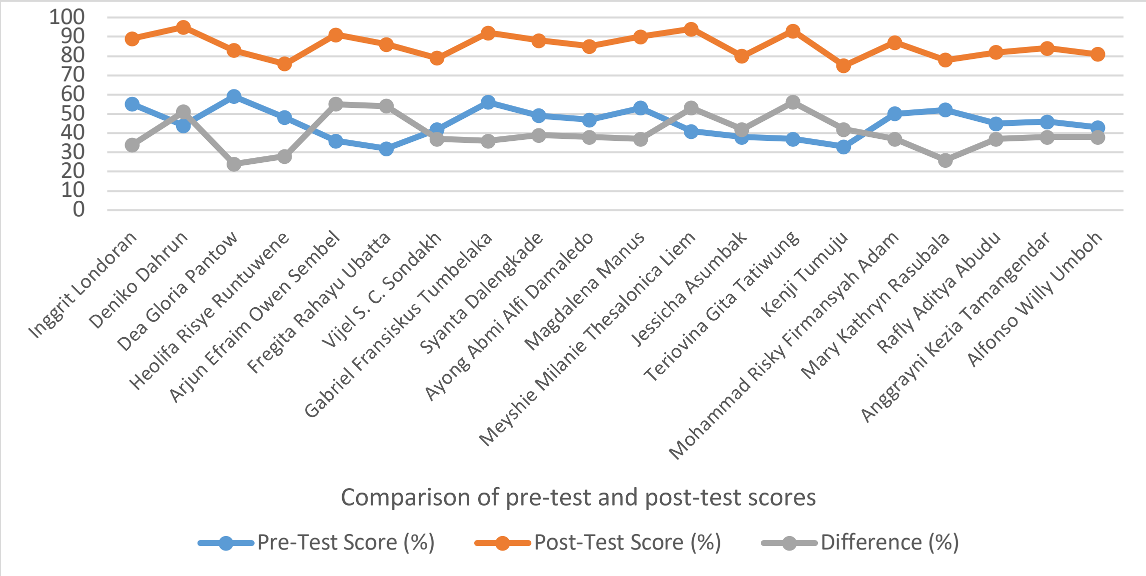

Figure 7. Analysis of pre-test and post-test scores

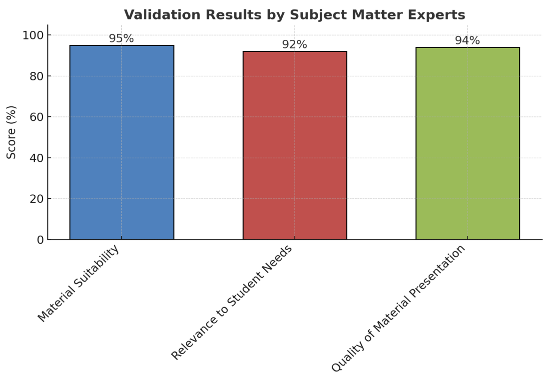

Figure 8: Validation Test Results for Material Reviewer

This substantial enhancement validates that implementing Virtual Lab is an exceptionally efficient method for augmenting students' comprehension of intricate physics subjects. The outcomes of the material validation assessment indicate that Virtual Lab is highly appropriate for the physics educational curriculum. The results are illustrated in Figure 8. Results of the Material Reviewer Validation Test. The Virtual Lab transcends the constraints of traditional physical laboratories, offering students an opportunity to investigate physics phenomena comprehensively and interactively, with reduced risk and precise outcomes. The comparison of students' pre-test and post-test scores indicates a substantial enhancement in comprehension, as illustrated in Figure 7. This graph illustrates the variation in average scores prior to and subsequent to the utilization of Virtual Lab. It presents a comparison of pre-test and post-test outcomes from 20 pupils. The blue line illustrates the pre-test scores, which varied from 30% to 60%, with a mean below 50%. After utilizing Virtual Lab, the post-test results (orange line) rose markedly to between 70% and 100%.

The disparity between the pre-test and post-test scores (green line) indicates an enhancement in comprehension, averaging between 24% and 56%. Teriovina Gita Tatiwung is the student with the most significant improvement, exhibiting a 56% increase. This result demonstrates the efficacy of Virtual Lab in enhancing students' comprehension of collision dynamics.

CONCLUSION

This study effectively created a virtual laboratory with a collision algorithm for simulating ideal collisions, employing the ADDIE model as the development framework. The validation results indicate that the implemented algorithm accurately and consistently computes the final velocity of colliding objects in accordance with the laws of physics, as demonstrated by results that align with analytical calculations from various mathematical software, including MATLAB, Mathematica, and Python. Functionality testing confirmed that all simulation features operated according to specifications, including the capacity to manage diverse inputs, reset the simulation, and execute animations seamlessly. The virtual lab has demonstrated commendable performance across various workload situations, delivering a satisfying user experience. At the same time, many aspects necessitate enhancement, including the clarity of advice and the interactivity of features. This research offers a valuable educational instrument for comprehending fundamental physics ideas, including collision dynamics, and holds potential for further development as a research tool in advanced collision investigations. The results underscore the significance of incorporating technology in science education and establish a foundation for the enhancement of new features and integration with online learning platforms to augment accessibility and efficacy of learning. This simulation is pertinent not just for secondary and tertiary students but also as a benchmark for future advancements in educational technology.

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