Development of Virtual Lab on Collision Dynamics Learning Object with Collision Algorithm Integration

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ABSTRACT

The objective of this study is to evaluate the efficacy of a Virtual Lab employing a collision algorithm in enhancing students' conceptual comprehension of collision dynamics, in comparison to traditional pedagogical approaches, within the context of physics education.The methodology employed in this study is as follows: The study employed an experimental approach, comprising a comparison between two groups: an experimental class that used the Virtual Lab, and a control class that utilised traditional teaching methods. Both groups were subjected to pre-tests to ascertain their existing level of understanding, after which post-tests were conducted to evaluate their knowledge after the instruction period. An independent t-test was employed to analyse the differences in post-test outcomes between the two groups.The results are as follows: The findings indicated a significant improvement in the experimental class's understanding, with an average increase from the pre-test to the post-test of 33.89%, in comparison to a 30.74% improvement in the control class. The results of the t-test demonstrated a statistically significant difference ($t = 4.32$, $p < 0.05$), indicating that the Virtual Lab was more effective in enhancing conceptual comprehension. In conclusion, the Virtual Lab, based on the collision algorithm, has been demonstrated to be an effective tool for teaching collision dynamics, offering a more interactive and engaging experience than traditional methods. This study highlights the potential of technology-based learning tools to enhance physics education and recommends further development of Virtual Labs with interactive features to increase accessibility and understanding in diverse educational environments.

I. Introduction

The use of technology in education is growing, especially in an effort to improve understanding of complex science concepts. One concept in physics that demands in-depth understanding is collision dynamics. This concept is often difficult to understand due to limitations in traditional physical laboratory facilities that require safe and scalable practical demonstrations. In addition, physical laboratories often face constraints in terms of limited resources and safety risks (Galan et al., 2016; Morales-Menendez et al., 2019). These limitations cause gaps in learning that impact students' less than optimal understanding of physics concepts[1][2].

Virtual laboratory (Virtual Lab) emerges as an innovative solution to address these issues. Virtual Lab can provide an interactive and safe learning platform, allowing students to explore physics phenomena in a controlled environment. The technology also enables realistic and immersive simulations, allowing students to conduct experiments and understand physics concepts in depth without the limitations of a physical laboratory [3][4].

Previous research has shown that virtual laboratories can significantly improve students' understanding of science concepts. For example, a study by Arianti, Astra, and Budi successfully developed a Virtual Physics Laboratory (VPL) focusing on the topic of collisions, which improved students' understanding of the concept [5]. In addition, Chan et al. [6]found that virtual chemistry laboratories can be more effective than traditional learning methods, especially when combined with conventional methods. However, although there are many studies examining the benefits of Virtual Lab, research gaps remain related to the optimisation of algorithms used in virtual laboratory simulations, especially collision algorithms that aim to improve simulation accuracy[6].

To address this gap, this research integrates the collision algorithm in the development of a virtual laboratory with the hope of improving the accuracy and realism of physics simulations. The collision algorithm, implemented using JavaScript 3, is expected to simulate the interaction between objects in accordance with the applicable laws of physics, which is crucial in understanding the concept of collision dynamics. This research seeks to develop a virtual laboratory that not only supports in-depth exploration of physics concepts, but can also be accessed easily through various devices, so that students can learn anytime and anywhere[7][8].

The main objective of this research is to produce a reliable and interactive virtual laboratory software, which can improve students' understanding of physics concepts related to collision dynamics. In addition, this research also aims to measure the effectiveness of the virtual laboratory in improving students' conceptual understanding before and after using the virtual laboratory. Thus, it is expected that this research can make a significant contribution to physics education, especially in learning concepts that require in-depth and experimental understanding [9][10][11]

II. METHODS

This research uses the ADDIE model (Analysis, Design, Development, Implementation, Evaluation), which is a systematic approach to instructional development and software applications.[12], [13] The ADDIE model was chosen because it can ensure structured and phased development, This series of development flows is shown in *Figure 1. V-Lab Development Flow with ADDIE* so that each phase can be evaluated and improved as needed. The following is a detailed description of each phase in the ADDIE model used in this study.

A. Analysis

The analysis stage was conducted to understand the existing problems and determine the learning objectives. The needs analysis involved interviews with physics lecturers at FMIPA Sam Ratulangi University to identify gaps in learning the concept of collision dynamics.Literature study was conducted to understand relevant concepts and review the existing physics curriculum. The results of the analysis were used to determine specific learning objectives, namely improving students' understanding of the concept of collision by using a virtual laboratory. This analysis also includes the identification of variables to be measured, such as the improvement of students' conceptual understanding before and after using the virtual laboratory.

B. Design

At this stage, the researcher conducted a design based on the results of the analysis. The design started with the Script

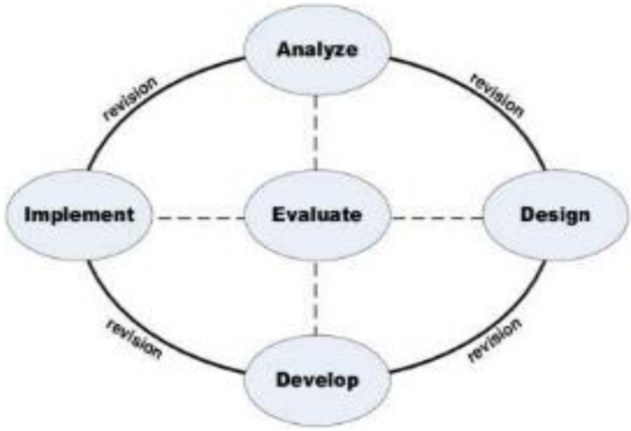

Figure 2.V-Lab development flow with ADDIE

of the virtual laboratory Figure 2. *Sample* V-Lab Script, including the user interface and the impact simulation script to be developed. An initial prototype of the user interface was created using the latest Adobe Animate to ensure functionality and ease of user engagement. The design of the collision script or scripts and the physics models used were also designed at this stage. This design includes the selection of the collision algorithm implemented in the simulation or

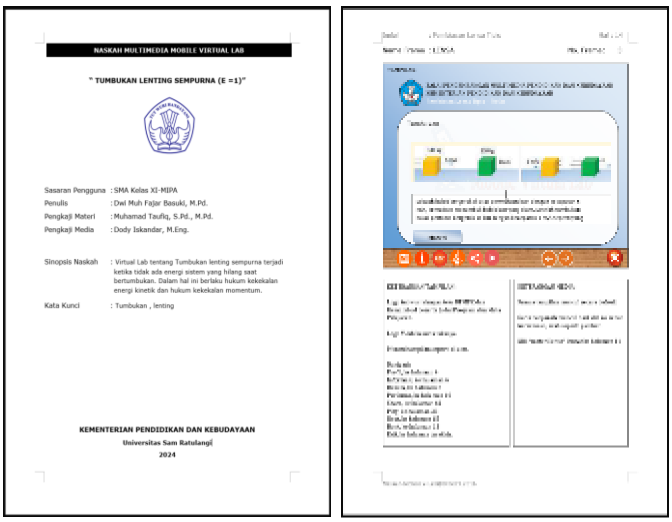

Figure 1. Sample V-Lab Script

virtual lab, which is designed to produce accurate calculations integrated with the collision algorithm and in accordance with the laws of physics according to the material. It is also designed *Usecase* diagram is designed to visualise the interaction between the user and the Virtual Lab system. This diagram illustrates the simulation usage script and feature interaction by the user, which can be seen in *Figure 3.*

C. Development

Development is carried out by researchers based on the design that has been formulated. This stage integrates collision algorithm programming using Adobe animate JavaScript convert to HTML5 simulate perfect collision. Virtual laboratory content development includes the preparation of learning materials and experiments that will be simulated. User interface development is done to ensure ease of use and effective interaction using Adobe Animate. After development, functionality testing is conducted to ensure all features function according to specifications. This testing includes material validation by physics lecturers, input validation, simulation reset, and animation control. Feasibility testing was also conducted to ensure that the virtual lab is ready to be used by end users without any errors or bugs. The process of virtual lab results of collision algorithm is validated by comparing tools such as matlab and manual measurement.

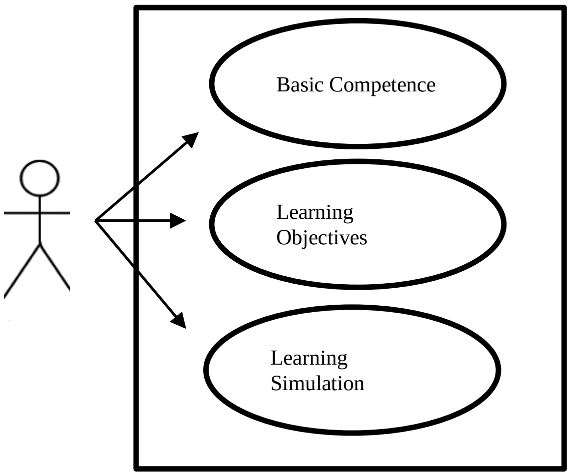

Figure 3 Usecase Diagram of Virtual Lab

D. Implementation

Implementation involves applying the virtual laboratory that has been developed into a real learning environment. This stage includes lecturers and students on how to use the virtual laboratory on FMIPA UNSRAT faculty students. Integration of the virtual laboratory with existing learning platforms is also done to ensure easy accessibility. Monitoring and technical support are provided during the use of the virtual laboratory to ensure the application is functioning properly and effective in enhancing learning. Data was collected during this stage for evaluation purposes, including user satisfaction survey and direct observation.

E. Evaluation

Evaluation was conducted to assess the effectiveness of the virtual laboratory and to make improvements if needed. Data collection was conducted through Questionnaires or questionnaires with users Lecturers and students to evaluate their experience with the virtual laboratory. The data collected was analysed to measure the improvement in participants' pre-test and post-test understanding, which is a key indicator of the success of this study. The results of the evaluation were used to refine the virtual laboratory and identify areas for improvement. The evaluation also aimed to validate the reliability of the collision algorithm and the consistency of the virtual laboratory as a learning and research tool.

It is expected that by providing an explanation of each step in the process of developing algorithms and interactive learning media in the form of Virtual Lab simulations, the application of the ADDIE model ensures that each stage, from analysis to evaluation, is carried out in a systematic and structured manner. Thus, this research not only produces an effective virtual laboratory in applying the collision algorithm to simulate perfect collision, but also provides methodological guidelines that can be applied in the development of simulation-based learning media integrated with the algorithm[14]

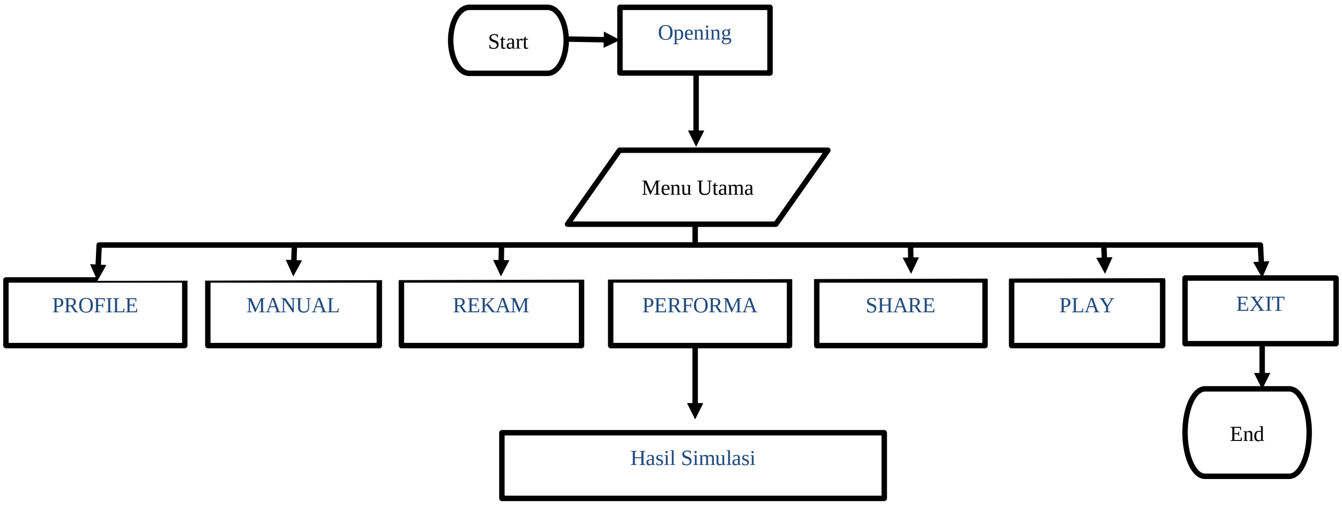

Figure 4. V-Lab FlowChart

III. Results and Discussions

A. Results

The findings of this study demonstrate that the utilisation of a virtual laboratory based on a collision algorithm markedly enhances students' comprehension of the concept of collision dynamics. In the final evaluation stage, the experimental method was employed with a comparison of two classes: the experimental class and the control class. A total of 40 students participated as respondents in this test, indicating that conventional physics laboratories on their campuses often face limitations in terms of equipment availability and safety. These constraints hinder the practical learning of physics concepts that require direct simulation, especially the concept of impact dynamics. The development of a virtual laboratory through the ADDIE (Analysis, Design, Development, Implementation, Evaluation) model approach was successfully implemented, allowing students to access perfect collision simulations more easily and safely.

This stage is a very important first step, where an in-depth analysis is conducted to understand the existing problems and determine specific learning objectives. In the context of this research, interviews were conducted with physics lecturers at FMIPA Sam Ratulangi University to identify limitations in learning the concept of collision dynamics. Based on the interviews, it was found that physical laboratories often face limitations in terms of tools, resources and safety, which impact on learning effectiveness. This analysis then led to the decision to develop a virtual laboratory that can help students understand the concept of perfect collision through interactive and safe simulations. In addition, the needs analysis also included the identification of research variables, such as students' level of understanding before and after using the virtual laboratory. Learning objectives were then set to improve the understanding of collision concepts, particularly through the use of collision algorithms.

Design Stage Based on the analysis results, this stage focuses on designing the learning script and intuitive user interface for the virtual lab. At this stage, the design of the perfect collision simulation script is formulated in detail, including the design of the visualisation of the collision algorithm to provide a realistic learning experience. The drafting of the script in the Virtual Lab aims to ensure that the simulation scenarios support interactive learning. An example of the script used for the experimental scenario can be seen in Figure 2. Sample V-Lab Script, which includes experimental instructions and explanatory content. The initial prototype was created using Adobe Animate with JavaScript, where the simulation was structured with interactivity and user engagement in mind. The design of the collision algorithm included the implementation of the law of conservation of momentum and kinetic energy, as well as the use of interpolation to improve the accuracy of collision detection at high speeds. The design process also includes simulation scripts or scripts with various collision conditions, so that students can explore variations in the input of different values of the collision concept. In addition, the interface navigation is made simple yet informative to facilitate users in using the simulation features.

Development Stage After the design was finalised, the user interface (UI) of the Virtual Lab was designed to ensure ease of interaction and navigation. This interface includes key visual elements that support a comfortable learning experience, as shown in Figure 5. V-Lab User Interface Development. The development stage was conducted to realise the design into a fully functional virtual laboratory. At this stage, programming of the collision algorithm was done using JavaScript, which is able to calculate the final velocity of two balls or objects after experiencing a perfect collision. The implementation of this algorithm is focused on accurate calculations that are consistent with the laws of physics. The development of the virtual laboratory also included the creation of learning content related to the simulation, including competency explanation materials, and simulated experiments. User interface development was also conducted to ensure ease of use and effective interaction. Once development was complete, internal functionality testing was conducted to ensure that all features, such as material validation, input validation, speed calculation, simulation reset, and animation control, functioned properly without any bugs or errors.

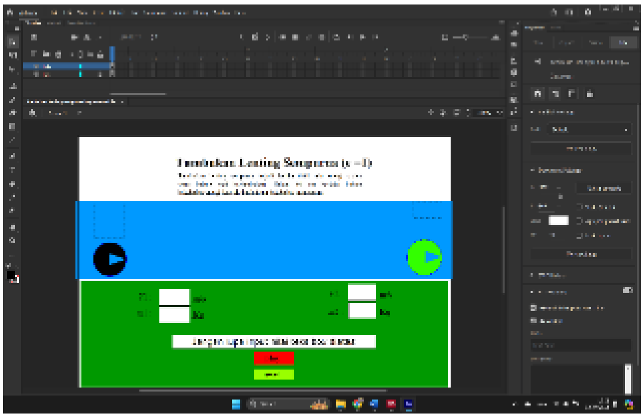

Figure 5. V-Lab User Interface Development

Implementation Stage The implementation stage is carried out by applying the virtual laboratory that has been developed into a real learning environment. This virtual laboratory was tested in the physics class of FMIPA students, where students and lecturers were involved in the implementation process to ensure that the virtual laboratory can be accessed easily and used effectively in the learning process. At this stage, students were given training on how to use the virtual laboratory, including how to run simulations, adjust parameters, and understand the simulation results generated. In addition, integration with online learning platforms is also done to facilitate student access. During implementation, monitoring and technical support are provided to ensure the simulation runs well and students can use the available features smoothly.

Evaluation Stage This final stage involves a thorough evaluation of the effectiveness of the virtual laboratory that has been developed. The evaluation was conducted through data collection from students and lecturer material reviewers, both through surveys and direct observation. Assessment of the simulation materials and functionality was conducted to validate the consistency and accuracy of the collision algorithm, as well as to ensure that all features were running according to specifications. The evaluation also included an analysis of the improvement of students' conceptual understanding.

The enhancement of students' conceptual comprehension of the concept of collision dynamics is gauged through a comparative analysis of pre-test and post-test outcomes in two cohorts: the experimental group, which utilises Virtual Lab as a pedagogical tool, and the control group, which employs conventional learning methodologies. The evaluation results indicated that the average pre-test score in the experimental class was 66.05, increasing to 88.45 in the post-test, representing an average increase of 33.89%. Meanwhile, the control class exhibited an average pre-test score of 60.30, which increased to 78.85 in the post-test, representing an average increase of 30.74%. The results of the statistical analysis, conducted using the t-test, indicated a statistically significant difference between the two groups, with a t-value of 4.32 and a p-value of less than 0.05. The results demonstrate that the utilisation of Virtual Lab is markedly more efficacious in enhancing student comprehension when compared to conventional learning methodologies. The evaluation further substantiates the efficacy of Virtual Lab as an effective learning instrument, although there are certain aspects that require enhancement, including the clarity of user guidance and the enrichment of interactive features.

Overall, the application of this model in this study shows that the development of a collision algorithm-based virtual laboratory can be done in a structured and scalable manner. Each stage in the model contributes significantly to the final outcome, which not only improves student understanding, but also provides a solid foundation for further development in physics research and learning.

To ensure the accuracy of an elastic collision simulation algorithm developed in JavaScript, the same algorithm was implemented in MATLAB and Python. The implementation was verified by calculating the final velocities of two colliding objects using identical parameters in all three programming environments. The consistency in results confirmed that the JavaScript-based algorithm adheres to the principles of momentum and kinetic energy conservation, establishing its validity as a learning tool.

MATLAB Implementation, the algorithm is executed by defining a function, calculateElasticCollision, which accepts the masses and initial velocities of the two objects and returns their final velocities post-collision:

```
function [newV1, newV2] =
calculateElasticCollision(m1, v1, m2, v2)
      % Calculate the final velocities after an
elastic collision
      newV1 = ((m1 - m2) * v1 + 2 * m2 * v2) / (m1
+ m2);
      newV2 = ((m2 - m1) * v2 + 2 * m1 * v1) / (m1
+ m2);
  end
  % Example usage:
  m1 = 1; v1 = 2; m2 = 1; v2 = -3;
  [newV1, newV2] = calculateElasticCollision(m1,
v1, m2, v2);
```

Running this code in MATLAB provides values for newV1 and newV2, representing the final velocities of the respective objects after the collision. These results can then be compared to those obtained from the JavaScript simulation.

Python Implementation, the algorithm is implemented by defining the calculate_elastic_collision function, which similarly accepts the masses and initial velocities of the objects and returns their final velocities after the collision:

```
def calculate_elastic_collision(m1, v1, m2, v2):
      # Calculate the final velocities after an
elastic collision
      new_v1 = ((m1 - m2) * v1 + 2 * m2 * v2) /
(m1 + m2)
      new_v2 = ((m2 - m1) * v2 + 2 * m1 * v1) /
(m1 + m2)
      return new_v1, new_v2
  # Example usage:
  m1, v1, m2, v2 = 1, 2, 1, -3
  new_v1, new_v2 = calculate_elastic_collision(m1,
v1, m2, v2)
```

When this code is executed, Python yields the values for new_v1 and new_v2, which can be directly compared to the MATLAB and JavaScript results.Using identical input data (mass and initial velocity), the results obtained from MATLAB and Python consistently align with the JavaScript simulation outputs. This accuracy confirms that the JavaScript-based algorithm functions according to the principles of conservation of momentum and kinetic energy, making it a valid educational tool for studying elastic collisions, Algorithm validation test results can be seen in Table I.

In terms of functionality, all virtual laboratory features were subjected to rigorous testing by respondents from the experimental class through the utilisation of a range of simulation scripts. The results of the tests demonstrate that the simulation features function effectively, including the initiation, pause, and resumption of the simulation process. The utilisation of this virtual laboratory is beneficial for students enrolled in the experimental class, as it facilitates comprehension of abstract concepts that are challenging to convey directly in conventional physics laboratories. This includes the principle of perfect collision. To illustrate, students enrolled in the experimental class, including Vijel S.

C. S., Audrey E. S., and Miracle T. R., exhibited a notable enhancement in their comprehension, as reflected in the elevated scores they attained on the post-test following their utilisation of the virtual laboratory (as evidenced in the Pre-Test and Post-Test Results Table).

TABLE I.
ALGORITHM VALIDATION TEST RESULTS

No	Kasus Uji	Hasil Simulasi (v1', v2')	MATLAB (v1', v2')	Mathematica (v1', v2')	Python (v1', v2')
1	m1: 1, v1: 2, m2: 1, v2: -3	-3, 2	-3, 2	-3, 2	-3, 2
2	m1: 2, v1: 4, m2: 3, v2: -1	-0.2, 2.6	-0.2, 2.6	-0.2, 2.6	-0.2, 2.6
3	m1: 1.5, v1: 3, m2: 2.5, v2: -2	-1.3, 2.2	-1.3, 2.2	-1.3, 2.2	-1.3, 2.2
4	m1: 3, v1: 5, m2: 2, v2: -4	-3.67, 2.67	-3.67, 2.67	-3.67, 2.67	-3.67, 2.67
5	m1: 4, v1: 1, m2: 3, v2: -3	-2, 1.5	-2, 1.5	-2, 1.5	-2, 1.5

In terms of functionality, all virtual laboratory features were subjected to rigorous testing by respondents from the experimental class through the utilisation of a range of simulation scripts. The results of the tests demonstrate that the simulation features function effectively, including the initiation, pause, and resumption of the simulation process. The utilisation of this virtual laboratory is beneficial for students enrolled in the experimental class, as it facilitates comprehension of abstract concepts that are challenging to convey directly in conventional physics laboratories. This includes the principle of perfect collision. To illustrate, students enrolled in the experimental class, including Vijel S. C. S., Audrey E. S., and Miracle T. R., exhibited a notable enhancement in their comprehension, as reflected in the elevated scores they attained on the post-test following their utilisation of the virtual laboratory (as evidenced in the Pre-Test and Post-Test Results Table).

The average increase in student understanding in the experimental class was observed to be in the range of 30.00% to 37.70%. The largest increase was achieved by Audrey E. S. (36.51%) and Miracle T. R. (37.70%). In contrast, students in the control class, who were taught using conventional methods, demonstrated an average increase in understanding of between 27.87% and 33.33% (see the Pre-Test and Post-Test Results Table). This indicates that virtual laboratories provide a more efficacious methodology for enhancing comprehension of physics principles than conventional instructional techniques.

This finding serves to reinforce the conclusion that the collision algorithm-based virtual laboratory not only serves to enhance students' conceptual understanding, but also serves to increase their interest and engagement in the process of learning physics. The students in the experimental class reported that the visualisation of the simulation was more lucid and afforded a more profound insight into the concept of collision dynamics than the traditional learning method employed in the control class. Therefore, this virtual laboratory represents a solution to the limitations of conventional physics laboratory facilities, while also functioning as an effective learning tool for enhancing students' comprehension and analytical abilities with regard to complex physics concepts.

This research demonstrates the significant potential of simulation technology in the field of physics education, particularly in the creation of engaging, realistic, and enjoyable learning experiences. It is anticipated that this virtual laboratory will undergo further development, incorporating additional interactive and user-friendly features, and will be integrated with online learning platforms to facilitate access for students in diverse educational settings.

B. Discussion

1) Algorithm Implementation in JavaScript Virtual Lab

The implementation of this algorithm was revised to JavaScript using the calculateElasticCollision function. This function accepts four parameters: the masses and initial velocities of the two colliding objects, and it returns an object containing the new velocities after the collision. By using JavaScript, the collision algorithm aims to simulate an ideal elastic collision accurately. The main structure of the code used to calculate the final velocities of the objects can be seen in Figure 5, illustrating the implementation of the collision algorithm in JavaScript. Here is the JavaScript implementation of the function:

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

Implementation Explanation Calculating the New Velocity of the First Object (newV1): The first part of this formula, (m1 - m2) * v1, calculates the contribution of the first object's initial velocity to its final velocity. The second part, 2 * m2 * v2, accounts for the influence of the second object’s initial velocity on the first object's final velocity. The result of these two parts is then divided by the sum of the masses (m1 + m2) to obtain the new velocity of the first object after the collision.

Calculating the New Velocity of the Second Object (newV2): Similarly, the calculation for the second object's new velocity uses the formula (m2 - m1) * v2 to compute the contribution of the second object's initial velocity and 2 * m1 * v1 to consider the effect of the first object's velocity. The result is divided by (m1 + m2) to yield the new velocity of the second object after impact. This function returns an object with the new velocities for both objects, labeled as v1 for the first object and v2 for the second.

JavaScript Virtual Lab Flow The flowchart for the Perfect Collision simulation in the JavaScript Virtual Lab starts with user input, where users specify variables such as the mass and initial velocity of both objects. The simulation process is depicted in Figure 5, detailing each step from data input to output calculation. First, the system performs input validation to check data completeness and correctness. If the inputs are valid, the perfect collision simulation is executed using the calculateElasticCollision function. This algorithm uses interpolation to achieve high-accuracy collision detection, especially at high speeds. Next, the new velocities are calculated based on the laws of conservation of momentum and kinetic energy.

The results are displayed on an interactive interface, allowing the user to view the speed and direction of each object after impact. The simulation concludes by outputting the results, giving the user the option to either repeat the simulation or end it. This flow provides a structured and efficient approach to interactively understanding the concept of an ideal elastic collision.

The Virtual Lab simulation flowchart for Perfect Collision begins with system initiation, where the user enters variables such as the mass and initial velocity of the two balls. The Virtual Lab simulation flow is depicted in the form of a flowchart that covers the entire process, starting from user data input to the calculation of the output results. This flowchart clarifies each step in the simulation, as shown in Figure 5. After that, the system performs input validation to ensure the completeness and correctness of the data. If valid, the perfect collision simulation runs by applying the collision algorithm. This algorithm uses interpolation to detect collisions with high accuracy, especially at high speeds. Next, a new velocity calculation is performed using the law of conservation of momentum and kinetic energy formula, and the results are displayed through an interactive interface. The user can see a visualisation of the speed and direction of the ball post-impact. The simulation ends with the output of the results, and the user can choose to repeat the simulation or finish it. This flow illustrates a structured and efficient process in understanding the concept of perfect collision interactively.

2) Functionality Validation Test

Functionality validation tests were conducted to ensure that all features and functions in the virtual laboratory simulation work according to the expected specifications. This test includes input validation, calculation of velocity after impact, simulation reset, and animation control (start, pause, continue). The results of the material validation test by the reviewer show the level of suitability and effectiveness of the material in supporting learning. Table II shows the results of the Virtual Lab functionality test, which includes input validation, speed calculation, and animation control. The results of this test are summarised in the following table

TABLE II.
VIRTUAL LAB FUNCTIONALITY VALIDATION TEST RESULTS

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

The results of the testing of the Virtual Lab, which incorporates the Collision algorithm for the Collision Dynamics learning object, were found to be highly satisfactory. The blank input and negative velocity validation functions were effective in providing appropriate warnings, thereby ensuring that users complete all input fields and adhere to the prescribed physics rules. In the negative velocity validation test, for instance, the system indicated that the velocity of the second ball must be negative, in accordance with the laws of physics that govern elastic collision simulations. Furthermore, the velocity calculation following a collision was validated for a range of scenarios, demonstrating that the algorithm adheres to the fundamental laws of conservation of momentum and kinetic energy, which are essential to the dynamics of a perfect collision.

Furthermore, the reset button and animation controls were found to function as anticipated. The reset functionality effectively reinstates all simulation elements, including ball position, velocity, input, text output, and arrow rotation, to their initial state, thus enabling users to readily restart the simulation. The simulation functions were found to operate without issue, from the start button, to pause, to resuming the animation. Additionally, when the ball touches the boundary of the stage, the reflection of the ball follows its initial velocity, in accordance with the physics theory of reflection. The success of all these tests demonstrates that this Virtual Lab is ready to be used as an effective and interactive learning tool, facilitating a deeper understanding of the concept of collision dynamics.

TABLE III.
MATERIAL REVIEWER VALIDATION TEST RESULTS

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

Based on the test results, Table III summarises the results of the material reviewer's assessment of the suitability and quality of material presentation in the Virtual Lab, this learning media obtained an average score of **93.67%**. This assessment shows that Virtual Lab is considered **Very Appropriate** for use in learning, especially on the topic of Collision Dynamics. The material reviewer also stated that this media is effective in helping students visualise abstract concepts such as collisions through interactive simulations. Suggestions for further development include adding simulation variations for a wider range of materials. Thus, this learning media can be implemented as a very useful tool in improving the quality of physics learning on campus or in schools.

This evaluation employs an experimental methodology, comprising a comparison between two distinct classes: the experimental class, which utilises Virtual Lab, and the control class, which adheres to conventional learning methods. The objective of this approach is to assess the impact of utilising Virtual Lab on enhancing students' conceptual comprehension in comparison to conventional learning techniques.

$$Percentage\ increase = \frac{Post\ Test\ Score - Pre\ Test\ Score}{Pre\ Test\ Score} \text{ x } 100\%$$

At the outset of the study, both groups were administered a pre-test to ascertain their baseline comprehension of the concepts to be taught. Following the administration of the treatment, namely the utilisation of Virtual Lab in the experimental class and conventional methods in the control class, a post-test was conducted to ascertain the extent of the increase in understanding. The results of the pre-test and post-test were subjected to analysis in order to calculate the percentage increase in understanding exhibited by both groups. Moreover, an independent t-test was performed to ascertain whether there was a notable discrepancy between the post-test outcomes of the two groups, thereby substantiating the efficacy of Virtual Lab as an educational tool.

$$t = \frac{X1 - X2}{\sqrt{\frac{s_1^2}{n1} + \frac{s_1^2}{n1}}}$$

The aforementioned formula was then applied to the pre-test and post-test results of each individual participant in order to ascertain the extent of change in understanding that occurred as a result of the treatment. Furthermore, to ascertain the significance of the discrepancy in the improvement of understanding between the experimental group (which utilised Virtual Lab) and the control group (which employed a conventional methodology), a two-independent samples t-test was employed. In this test, the average post-test score of each group was represented by the variable , while the variance of each group was represented by the variable . Additionally, the number of participants in each group was represented by the variable . The results of the t-test demonstrated a p-value of less than 0.05, indicating a statistically significant difference between the two groups. The findings support the hypothesis that the use of Virtual Lab is more effective than conventional methods in enhancing conceptual understanding.

Table 4 presents a comparison of scores between the experimental group, who used Virtual Lab, and the control group, who used conventional learning methods. The initial stage of the study involved a pre-test, which was conducted on both groups to assess students' prior understanding of the concept of collision dynamics. The mean pre-test scores for the experimental class ranged from 61 to 70, while those for the control class ranged from 58 to 63. The pre-test scores suggest that the initial understanding of the students in both groups was relatively comparable, with the experimental class exhibiting slightly higher scores than the control class. This result is significant in that it demonstrates that both groups exhibited comparable initial levels of understanding, thereby establishing a valid foundation for comparative analysis of the results following the intervention.

TABLE IV.
PRE-TEST AND POST-TEST RESULTS

Experiment Class (Using Virtual Lab)					Control Class (Using Conventional Methods)				
No	**Participant Name**	**Pre-Test (X1)**	**Post-Test (X2)**	**Improvement (%)**	**No**	**Participant Name**	**Pre-Test (X1)**	**Post-Test (X2)**	**Improvement (%)**
1	VIJEL S. C. S	65	88	35.38.00	1	INGGRIT L	60	80	33.33.00
2	TERIOVINA G T	68	90	32.35.00	2	DENIKO DAHRUN	59	78	32.20.00
3	KENJI TUMUJU	64	86	34.38.00	3	DEA GLORIA PANTOW	61	79	29.51.00
4	MOHAMMAD RFA	63	85	34.92	4	HEOLIFA RR	62	80	29.03.00
5	ANGGRAYNI KT	62	84	35.48.00	5	ARJUN EOS	58	77	32.76
6	GRATIA LS	66	89	34.85	6	FREGITA RU	60	79	31.67
7	ANGELITA AGT	70	91	30.00.00	7	VIJEL S. C. S	61	78	27.87
8	GAREND OHL	65	87	33.85	8	GABRIEL FT	60	79	31.67
9	JELITA ST	67	88	31.34.00	9	SYANTA D	62	80	29.03.00
10	JELOVENDRA MS	69	90	30.43.00	10	AYONG ABMI AD	63	81	28.57.00
11	JORJI AS	66	88	33.33.00	11	MAGDALENA M	61	79	29.51.00
12	JUWINDA DP	68	90	32.35.00	12	MEYSHIE MTL	60	78	30.00.00
13	MONICHA PL	65	87	33.85	13	JESSICHA A	62	80	29.03.00
14	PRAISETICIA AR	67	89	32.84	14	TERIOVINA GT	63	81	28.57.00
15	GERALDY JP	68	89	30.88	15	KENJI T	61	78	27.87
16	AUDREY ES	63	86	36.51.00	16	MOHAMMAD RFA	60	77	28.33.00
17	JOSUA IP	64	87	35.94	17	MARY KR	59	78	32.20.00
18	MORIENTES CP	66	88	33.33.00	18	RAFLY AA	62	80	29.03.00
19	INJILINO AL	69	90	30.43.00	19	ANGGRAYNI KT	58	77	32.76
20	MIRACLE TR	61	84	37.70	20	ALFONSO WU	60	78	30.00.00

Following the implementation of the treatment, a post-test was administered to both groups in order to assess the extent of any changes in their understanding of the concept. In the experimental class, the post-test scores exhibited a notable increase, ranging from 84 to 91, whereas in the control class, the post-test scores ranged from 77 to 81. The percentage increase was calculated in order to measure the change in understanding exhibited by each participant. The experimental class exhibited a higher average percentage increase, ranging from 30.43% to 37.70%, while the control class demonstrated an average percentage increase of 27.87% to 33.33%. The higher average percentage increase observed in the experimental class suggests that the utilisation of Virtual Lab may facilitate more efficacious enhancement of students' conceptual understanding than conventional learning methodologies.

A statistical test was conducted to ascertain whether a significant difference existed between the two groups. This was achieved by undertaking an independent t-test on the post-test results of the experimental and control classes. The independent t-test was selected as the most appropriate method for comparing the means of two non-interdependent groups. The null hypothesis (H_o) in this study is that there is no significant difference in comprehension improvement between the experimental and control classes. The alternative hypothesis (H_a) states that there is a significant difference.

TABLE V.
AVERAGE PRE-TEST AND POST-TEST SCORES AND PERCENTAGE INCREASE

Group	Pre-Test Average (X1)	Average Post-Test (X2)	Average Improvement (%)
Experiment Class (Virtual Lab)	66.05.00	88.45.00	33.89
Control Class (Conventional Method)	60.30.00	78.85	30.74

TABLE VI.
T-TEST FOR SIGNIFICANT DIFFERENCE BETWEEN EXPERIMENTAL AND CONTROL CLASSES

Group	N	Mean	SD	t	p-value
Experiment	20	88.45.00	02.50	04.32	< 0.05
Control	20	78.85	02.10		

The present study compares two groups: the experimental class, which uses Virtual Lab, and the control class, which uses conventional learning methods. The aim is to ascertain the effect of the former on students' understanding of the concept of collision dynamics. The results of the pre-test and post-test, averaged for each group, indicate that the experimental class demonstrated a more pronounced improvement. The mean pre-test score for the experimental class was 66.05, while the mean post-test score was 88.45, indicating an average increase of 33.89%. Meanwhile, the control group, which was taught using conventional methods, had an average pre-test score of 60.30 and a post-test score of 78.85, representing an average increase of 30.74%. To ascertain the significance of the difference between the two groups, a t-test was conducted. The results of the t-test demonstrated a statistically significant difference between the experimental and control groups, with a t-value of 4.32 and a p-value of less than 0.05. This suggests that the utilisation of Virtual Lab has a more favourable impact on enhancing students' comprehension of the concept of collision dynamics in comparison to conventional learning methodologies. It can therefore be concluded that Virtual Lab represents an effective learning tool for facilitating comprehension of complex physics concepts.

IV. CONCLUSIONS

The findings of this study indicate that the utilisation of a Virtual Lab based on the collision algorithm is an efficacious approach for enhancing comprehension of the concept of collision dynamics, when compared to conventional learning methodologies. The data from the pre-test and post-test demonstrated that the experimental class, which utilized Virtual Lab, exhibited a notable enhancement in comprehension, with an average increase of 33.89%, surpassing the control class, which attained an average of 30.74%. The results of the independent t-test demonstrated a statistically significant difference between the two groups, with a t-test value of 4.32 and a ppp-value of less than 0.05. This indicates that the use of Virtual Lab had a significant positive effect on student understanding.

These findings reinforce the position that Virtual Lab is an effective interactive learning tool that can overcome the limitations of conventional physics laboratories, providing a more realistic and in-depth learning experience. It is therefore anticipated that this Virtual Lab will be further developed with additional interactive features and integration with online learning platforms, with the aim of expanding access for students to understand complex physics concepts more effectively.

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