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Exploring Technology-Driven Simulations in Practical Physics: Insights into Mechanical Measurements Concept

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ABSTRACT

This study aimed to explore the effectiveness of technology-driven simulations in improving high school students' practical skills in mechanical measurement within the context of physics education. A quasi-experimental design was employed, involving control groups and pretest-posttest samples to assess students' understanding and application of mechanical measurement concepts. The results indicate that simulations significantly enhance students' accuracy and comprehension of mechanical measurements compared to traditional teaching methods. Notably, visual and kinesthetic learners benefit the most from using simulations prior to engaging in physical experiments. The combination of simulations and hands-on experiments was found to be more effective in developing practical skills than either approach alone. These findings underscore the value of integrating technology-driven simulations into physics curricula, particularly for enhancing learning outcomes and practical skills in mechanical measurement, with a specific advantage for learners with visual and kinesthetic preferences.

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1. INTRODUCTION

The exploration of technology-driven simulations in practical physics, particularly in the context of mechanical measurements, has garnered significant attention in recent years. These simulations serve as powerful educational tools that enhance the understanding of complex physical concepts, especially in environments where traditional laboratory resources may be limited. The integration of simulations into physics education not only facilitates conceptual understanding but also promotes active learning and student engagement, ultimately improving learning outcomes (Kade *et al.*, 2019). The use of simulations was significantly shown to improve students' understanding of mechanical systems and their measurements (Sullivan *et al.*, 2017; Jasti *et al.*, 2021). technology-driven simulations or Simulation-based learning offers a safe and controlled environment where students can experiment and make mistakes without the risks associated with physical experimentation (Chernikova *et al.*, 2020; Morse *et al.*, 2019; Ke & Xu, 2020). These findings highlight the potential of simulation to bridge the gap between theoretical knowledge and practical application, particularly in the field of mechanical measurement.

In recent years, the educational landscape has shifted towards the integration of digital tools and resources to develop essential skills in students, preparing them for an increasingly technology-driven world. Among the key competencies emphasized in modern education are critical thinking, problem-solving, and practical skills-abilities that are crucial for success in academic and professional environments. The integration of simulations into the physics curriculum aligns with this shift, offering students the opportunity to develop these competencies engagingly and effectively. Simulations not only facilitate a deeper understanding of scientific concepts but also encourage active learning and critical thinking, which are essential components of 21st-century skills (Hsu & Wu, 2023). In addition, the versatility of simulations allows for their use in a variety of learning styles, making them a valuable tool for educators looking to meet the needs of diverse students.

Educational strategies that incorporate simulation into physics instruction are valuable for their ability to improve students' practical skills in mechanical measurements. Traditional laboratory experiments, while effective, often have limitations such as equipment availability, time constraints, and safety concerns. Simulations overcome these challenges by providing a virtual environment where students can repeatedly practice and hone their skills. Previous studies have shown that students who engage in simulation experiments tend to perform better in subsequent physical experiments, as they can apply the knowledge and techniques they have learned in low-risk situations (Lamb & Etopio 2020; Lovelace *et al.*, 2016). This research seeks to build on these findings by exploring the specific ways in which technology-based simulations can be used to improve student's practical abilities in mechanical measurement, as well as how these tools can be integrated into the broader physics curriculum.

The novelty of this study lies in its focus on the practical application of simulations in enhancing mechanical measurement skills, rather than solely on the theoretical understanding of physics concepts. While much of the existing literature has focused on the cognitive benefits of simulations, this research aims to explore how these tools can directly impact students' hands-on abilities in a field where precision and accuracy are paramount. By investigating the integration of simulations with traditional laboratory practices, this study offers new insights into the potential of digital tools to transform physics education, providing both theoretical and practical contributions to the ongoing discourse on educational innovation.

Based on this background, the central research problem of this study is to understand how technology-driven simulations can enhance students' practical skills in mechanical measurement. The findings of this research are expected to contribute not only to the academic understanding of modern pedagogical strategies but also to offer practical recommendations for educators and policymakers who are striving to optimize student learning experiences in an increasingly digital educational environment.

2. LITERATURE REVIEW

2.1. Mechanical Measurement Concepts in Physics Education

Mechanical measurement is a fundamental aspect of physics education, encompassing various principles and techniques used to quantify physical properties such as force, pressure, displacement, and velocity. These concepts are critical for understanding the behavior of physical systems and are often introduced early in the physics curriculum to build a strong foundation for more advanced topics. In traditional educational settings, these measurements are typically conducted in laboratory environments using a range of mechanical instruments such as calipers, micrometers, and force sensors. However, the accuracy and precision required in these measurements often pose challenges for students, leading to potential gaps in understanding.

The advent of technology-driven simulations has provided new avenues for teaching mechanical measurement concepts in a more accessible and engaging manner. These simulations allow students to visualize and manipulate measurement processes in a controlled, virtual environment, where they can explore the relationships between different physical quantities without the constraints of physical instruments. Studies have shown that such simulations not only enhance students' understanding of measurement principles but also improve their ability to apply these concepts in real-world situations. For instance, virtual laboratories and interactive simulations have been reported to effectively replace or complement traditional hands-on laboratory experiences, offering a flexible and scalable approach to physics education.

Technology-driven simulations in physics education are increasingly recognized for their ability to provide a comprehensive understanding of complex scientific concepts, particularly in the realm of mechanical measurements. These simulations are defined as computer-based models that mimic real-world physical phenomena, allowing students to visualize and interact with systems that would otherwise be difficult to study through traditional methods alone. The effectiveness of these simulations lies in their ability to bridge the gap between theoretical knowledge and practical application, thereby enhancing students' overall learning experience in physics (Cai *et al.*, 2021; Georgiou *et al.*, 2021; Jamil & Isiaq, 2019). Many studies related to technology-based simulations have been well-documented (see **Table 1**).

Mechanical measurement, a fundamental component of physics education, involves the precise determination of physical quantities such as force, velocity, acceleration, and mass. Traditional methods of teaching these concepts often rely on hands-on laboratory experiments, which, while effective, are constrained by the availability of equipment, time, and the inherent risks associated with physical experimentation (Bhute *et al.*, 2021; Supriyadi *et al.*, 2023; May *et al.*, 2023). As illustrated in **Figure 1**, technology-driven simulations offer a viable alternative, enabling students to engage in repeated practice without the constraints of the physical environment. This figure shows a simulated environment where students can manipulate variables such as force and mass, observe the resultant changes in motion, and measure these changes with precision.

Table 1. Research on speed in education.

No	Title	Reference
1.	Technology-enhanced Learning or Learning Driven by Technology	Baneres *et al.* (2019)
2.	Impact of Mobile Technology-based Physics Curriculum on Preservice Elementary Teachers' Technology Self-efficacy	Menon *et al.* (2020)
3.	Examining Disaster Literacy Through Modified Earthquake Laboratory Experiment on Stem Learning. *Journal of Engineering Science and Technology*	Novia *et al.* (2021)
4.	Augmented Reality (AR) Technology-based Learning: The Effect on Physics Learning During the Covid-19 Pandemic	Ropawandi *et al.* (2022)
5.	Simulation-based and Video-based Approaches to Diversifying Physics Homework	Simić *et al.* (2023)
6.	How Technology Can Change Educational Research? Definition, Factors for Improving Quality of Education and Computational Bibliometric Analysis	Al Husaeni (2022)
7.	Comparative Effects of PHET Interactive Simulations and Conventional Laboratory Methods (CLM) on Basic Science Process Skills (BSPS) in Physics: A Case Study in Secondary School	Alsalhi *et al.* (2024)
8.	Development of E-Module Based on Simulation PHET Fluid Material Dynamic In Senior High School	Fitriyawany *et al.* (2023)

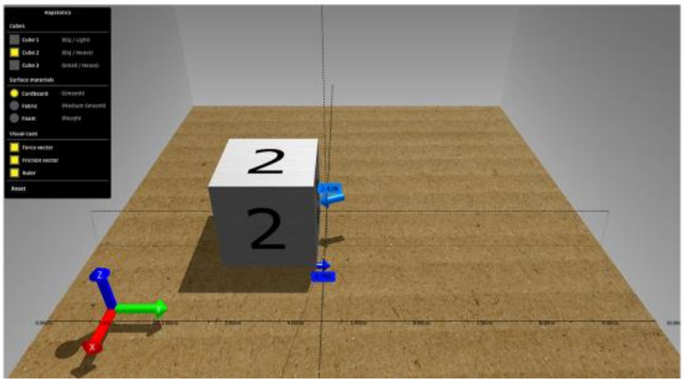

Figure 1. Simulated environment for mechanical measurement experiments (Walsh *et al.*, 2020).

The ability of simulations to provide a controlled environment where variables can be isolated and manipulated is one of their most significant advantages. In traditional experiments, factors such as friction, air resistance, and human error can introduce variability into the results, complicating the learning process. However, as depicted in **Figure 2**, simulations allow for a monodisperse distribution of variables, meaning that students can observe the direct impact of individual variables on the outcome of an experiment. This controlled environment is particularly beneficial in teaching concepts such as Newton's laws of motion and the principles of energy conservation, where understanding the precise relationship between variables is crucial (Jamil & Isiaq, 2019).

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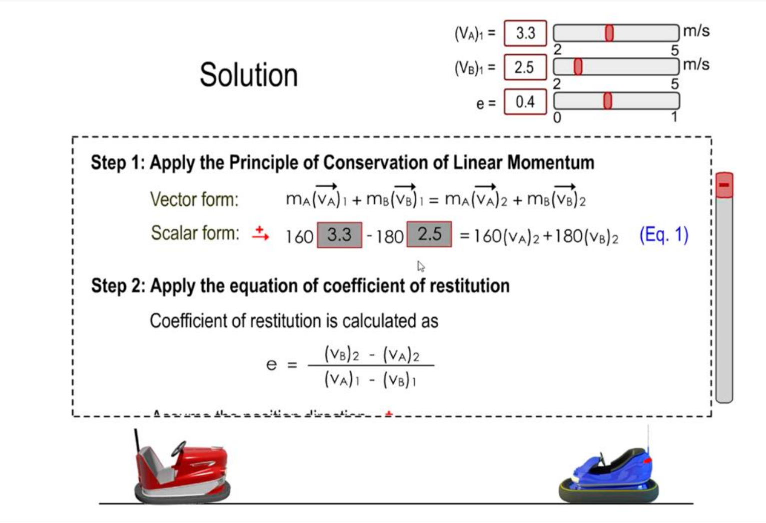


Solution

$(V_A)_1 = 3.3$ m/s

$(V_B)_1 = 2.5$ m/s

$e = 0.4$

Step 1: Apply the Principle of Conservation of Linear Momentum

Vector form: $m_A(\overrightarrow{v_A})_1 + m_B(\overrightarrow{v_B})_1 = m_A(\overrightarrow{v_A})_2 + m_B(\overrightarrow{v_B})_2$

Scalar form: $\xrightarrow{+}$ $160\,\boxed{3.3} - 180\,\boxed{2.5} = 160(v_A)_2 + 180(v_B)_2$ (Eq. 1)

Step 2: Apply the equation of coefficient of restitution

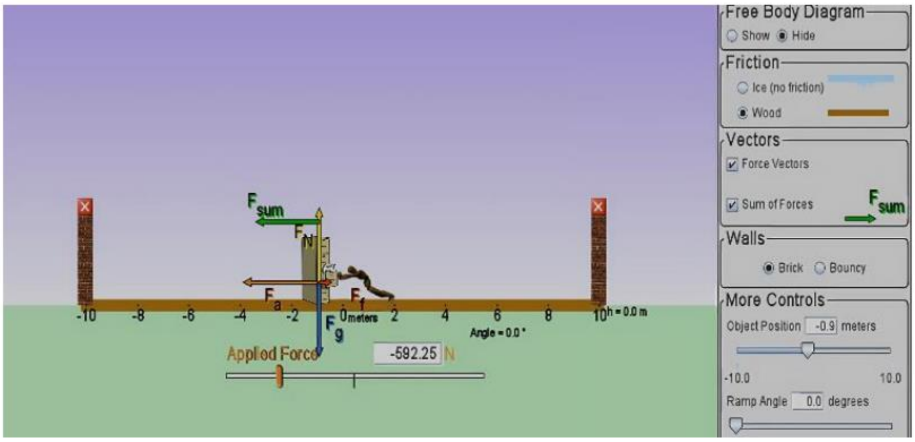
Coefficient of restitution is calculated as

$$e = \frac{(v_B)_2 - (v_A)_2}{(v_A)_1 - (v_B)_1}$$

Figure 2. Simulated experiments of two bumper cars using Newton's law (Chen *et al*., 2021).

Moreover, the literature indicates that the use of simulations in teaching mechanical measurement not only enhances conceptual understanding but also improves students' practical skills (Novia *et al*., 2021). Students who engage with simulations are better equipped to perform physical experiments, as the simulations provide them with a deeper understanding of the underlying principles and the opportunity to practice measurement techniques in a risk-free environment (Lamb & Etopio, 2020). This finding is consistent with the observations in **Figure 3**, where students' accuracy in visual representation of forces.

In conclusion, the integration of technology-driven simulations in physics education represents a significant advancement in teaching mechanical measurement. These simulations not only facilitate a deeper understanding of complex physical concepts but also improve students' practical skills by providing a controlled, interactive, and repeatable environment for experimentation. As the educational landscape continues to evolve, the role of simulations in physics education is likely to expand, offering new opportunities for enhancing student learning outcomes.



Free Body Diagram: ○ Show ● Hide

Friction: ○ Ice (no friction) ● Wood

Vectors: ☑ Force Vectors ☑ Sum of Forces

Walls: ● Brick ○ Bouncy

More Controls

Object Position -0.9 meters

Ramp Angle 0.0 degrees

Applied Force -592.25 N

Figure 3. CSs displaying forces graphically.

2.2. The Importance of Technology in Physics Education

The role of technology in physics education has become an increasingly significant topic, especially in efforts to improve the quality of learning and the understanding of complex physics concepts. Technology offers various tools and new methods that allow educators to overcome challenges in teaching, particularly in the area of mechanical measurement, which is often difficult to conceptualize (Ismail *et al.*, 2016). Simulations are one of the main technologies that have brought significant changes in how physics is taught and learned (Henukh *et al.*, 2020). Computer simulations have become an extremely valuable tool in physics education. By using simulations, abstract and complex physics concepts can be visualized and better understood by students (Wu *et al.*, 2001). Simulations allow students to see visual representations of physical phenomena that are difficult or impossible to observe directly in a laboratory.

In the context of mechanical measurement, simulations can replace physical experiments that are complicated or high-risk. For example, simulations can be used to model object motion, force analysis, or interactions between various types of energy. This not only enhances students' understanding but also allows them to conduct virtual experiments that are not limited by physical and material constraints. This technology also enables students to repeat experiments multiple times, modify parameters, and see firsthand how these changes affect the results.

Mechanical measurement is one of the areas in physics education that is often challenging to teach, as it requires a deep understanding of concepts such as force, momentum, and energy. Without technology, students might struggle to link theory with practice, especially when physical experiments are difficult to perform or understand. Simulation technology helps overcome these challenges by providing an interactive environment where students can directly observe how various variables influence the results of mechanical measurements. For instance, simulations can be used to study Newton's laws of motion by showing how different forces acting on an object affect its acceleration. With this technology, students can perform experiments without the limitations of physical equipment and can see the results in real time, which enhances their conceptual understanding.

In addition to simulations, technology also enables access to a broader range of learning resources, such as instructional videos, data analysis software, and virtual laboratories. This technology not only makes learning more engaging and interactive but also provides students with the opportunity to develop analytical skills that are essential in physics.

Virtual laboratories, for example, allow students to conduct physics experiments in a fully controlled digital environment. This is particularly useful in situations where access to physical laboratories is limited or impossible. With virtual laboratories, students can learn independently and at their own pace, enabling more effective and personalized learning.

3. METHODS

This study adopted a quasi-experimental design utilizing the untreated control group design with dependent pretest and posttest samples. The participants were divided into two groups: the experimental group (receiving Problem-Based Learning (PBL) intervention) and the control group (undergoing non-PBL teaching (following the local teachers' regular instruction)).

The study targeted senior high school science classes in selected schools. The population comprises students from 9 schools across various regions, with an emphasis on schools equipped with basic laboratory facilities for conducting mechanical measurements. The research is conducted over 8 months, from January to August 2024, ensuring that the findings are applicable across different educational settings.

This quantitative study is focused on evaluating the impact of technology-driven simulations on students' practical skills in mechanical measurement. The research is conducted in several phases, including:

(i) Preliminary Assessment: Identification of suitable schools and participant selection.
(ii) Design and Planning: Development of simulation modules and alignment with the physics curriculum.
(iii) Data Collection: Administration of pre-tests, implementation of simulations, and post-tests.
(iv) Analysis Using SPSS 26: Statistical analysis of data to test hypotheses.
(v) Interpretation and Conclusion Drawing: Interpretation of results to conclude.
(vi) Documentation and Reporting: Compilation of findings and preparation of the final report.

The study utilized three primary variables: technology-driven simulations, traditional physics instruction, and students' practical skills in mechanical measurement. The simulation module was specifically designed to align with the existing physics curriculum, focusing on key concepts such as force, motion, and energy. Practical skills were assessed using a performance-based test that includes tasks related to mechanical measurement, such as determining acceleration and force using different tools. Additionally, pre- and post-tests are administered to measure students' understanding before and after the intervention. **Table 2** displays the pre-test and post-test instrument grids used.

Table 2. Previous studies on technology-based simulations.

No	Basic Competence	Question Indicator	Type	Question Number
1	Measure physical quantities accurately	Determine measurement results with uncertainty	MC	1
2	Analyze measurement results	Calculate temperature measurement results with uncertainty	MC	2
3	Use significant figures rules	Determine the number of significant figures in square area measurement	MC	3
4	Use significant figures rules	Determine the correct area notation using significant figures	MC	4
5	Analyze precision and accuracy	Identify the student with precise but inaccurate measurement results	MC	5
6	Use significant figures rules	Calculate land area with the correct significant figure notation	MC	6
7	Measure thickness and volume	Calculate the thickness of a sheet of paper from the total book thickness	MC	7
8	Measure object density	Determine the correct procedure to calculate object density	MC	8
9	Use units and dimensions	Identify the correct unit and dimension from the table	MC	9
10	Analyze dimensions	Identify the correct statement about dimensions	MC	10

Information: MC (Multiple Choice)

Based on the research problem, the proposed hypotheses are the following:

(i) H_{01}: There is no difference in students' practical skills in mechanical measurement between the technology-driven simulation group and the traditional instruction group. H_{a1}: There is a difference in students' practical skills in mechanical measurement between the technology-driven simulation group and the traditional instruction group.

(ii) H_{02}: There is no difference in the effectiveness of technology-driven simulations based on different learning styles.

H_{a2}: There is a difference in the effectiveness of technology-driven simulations based on different learning styles.

(iii) H_{03}: There is no combined effect of technology-driven simulations and learning styles on students' practical skills in mechanical measurement.

H_{a3}: There is a combined effect of technology-driven simulations and learning styles on students' practical skills in mechanical measurement.

Research instruments are the following:

(i) Technology-Driven Simulations Impact on Practical Skills: Compare data on mechanical measurement skills from the experimental and control groups. SPSS 26 will be used for hypothesis testing (H_{01}). The type of test will be selected based on the data distribution (e.g., t-test for normally distributed data or Mann-Whitney U test for non-normally distributed data).

(ii) Learning Styles' Influence on Simulation Effectiveness: Classify students' learning styles (visual, auditory, kinesthetic) using a standardized learning style inventory. Analyze how each learning style interacts with the simulation module's effectiveness. SPSS 26 will be used for hypothesis testing (H_{02}), with the appropriate test selected based on data distribution.

(iii) Combined Influence of Simulations and Learning Styles on Practical Skills: Analyze the interaction between learning styles and the effectiveness of technology-driven simulations in the experimental group. Test the practical skills within each learning style category. SPSS 26 will be used for hypothesis testing (H_{03}), considering data distribution and interaction effects.

4. RESULTS AND DISCUSSION

4.1. Design of Technology-driven Simulations

The results of this study demonstrate that technology-driven simulations are effective in enhancing students' practical skills in density measurement. The research process began with the setup phase, where key variables such as mass and volume were configured within the simulation environment. This setup allowed students to understand how to configure relevant parameters for density measurement before engaging in physical laboratory experiments.

Following the setup, data collection was conducted with a focus on measuring the mass and volume of the objects under study. The collected data showed that students were able to measure mass with a high degree of accuracy using the digital scales in the simulation. Volume measurements carried out through displacement methods or dimensional measurements, also yielded good results with minimal error. These results were then used to calculate density using Eq. (1).

$$\rho = m\,V \tag{1}$$

allowing students to directly observe the relationship between mass, volume, and density.

Subsequently, data analysis was performed to evaluate the effectiveness of the simulation in improving students' skills. The analysis indicated that the simulation not only helped students understand the basic concepts of density measurement but also enabled them to conduct measurements with greater accuracy. The simulation successfully minimized errors that are commonly encountered in physical experiments, including both systematic and random errors.

After the data were analyzed, verification was conducted to ensure the accuracy of the measurements made by the students. The results of this verification confirmed that the simulation helped reduce measurement errors that often arise in traditional laboratory experiments. In the evaluation phase, it was found that students were able to correctly apply the concept of density measurement and achieve accurate results, indicating that the simulation effectively enhanced their practical skills. Finally, based on the verification and evaluation results, it can be concluded that technology-driven simulations offer significant benefits in physics education, particularly in density measurement. The decision to continue using simulations in the learning process is highly recommended, given the consistent results and the simulation's ability to enhance students' understanding comprehensively. The findings of this study highlight the great potential of simulations as a learning tool that not only strengthens theoretical understanding but also practical skills that are crucial in science education. **Figure 4** illustrates the Technology-Driven Simulations process for density measurement.

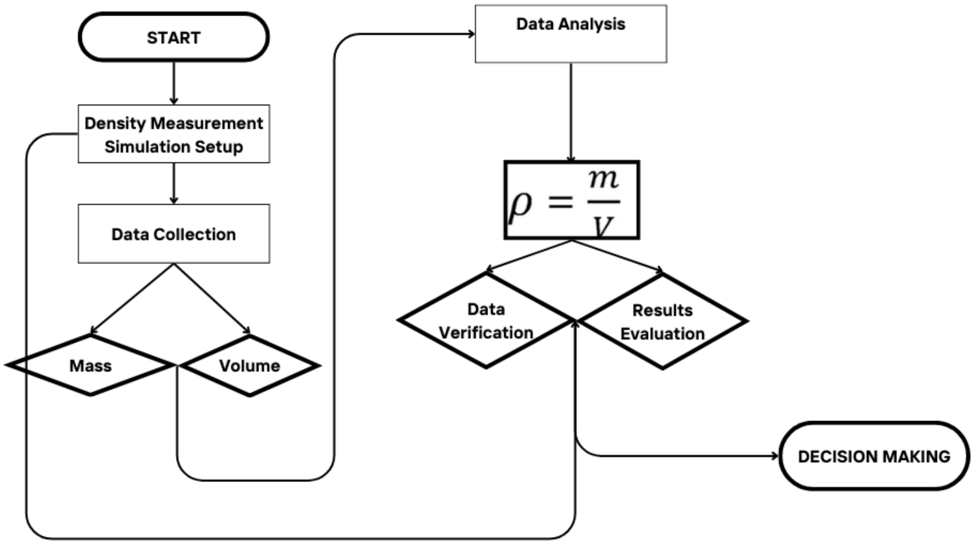


Figure 4. Flowchart technology-driven simulation.

The results of this study are consistent with previous literature, which states that technology-driven simulations can enhance students' practical skills in laboratory experiments. Simulations provide a controlled environment where variables can be manipulated more easily and without the risks associated with physical experiments. These findings support the use of simulations as a learning tool that not only enhances theoretical understanding but also strengthens students' practical abilities. With simulations, students can practice measuring mass and volume repeatedly without the limitations of physical laboratory equipment, which often pose challenges in physics education.

Furthermore, the results show that these simulations also help reduce measurement errors that frequently occur in physical experiments. Thus, simulations offer dual benefits by improving measurement accuracy and providing students with the opportunity to gain a deeper understanding of physics concepts. However, despite the positive outcomes, this study also indicates that the success of simulations heavily depends on the design of the simulation modules used. The modules developed must align with the curriculum and be tailored to the student's level of understanding. Therefore, further research is needed to explore how simulations can be more broadly integrated into various other physics topics and how their use can be optimized in different educational contexts.

4.2. Effect of Technology-driven Simulations-based Learning

This section presents the findings from the study on the impact of technology-driven simulations on students' practical skills in mechanical measurements. The data collected from pre- and post-tests, as well as the observations made during the experiments, are analyzed to determine the effectiveness of simulations in enhancing students' understanding and accuracy in mechanical measurements.

The distribution of normalized measurement errors for both groups. The errors are plotted on the x-axis against the frequency of occurrences on the y-axis. The experimental group had a significantly lower frequency of large errors compared to the control group. The majority of errors in the experimental group fell within the 0-5% range, indicating a higher level of precision achieved through the use of simulations. **Table 3** provides a detailed breakdown of the types of errors observed in each group. The errors are categorized into systematic errors, random errors, and gross errors. The experimental group showed a lower incidence of gross errors, which are typically indicative of misunderstandings or mishandling of equipment. This further supports the conclusion that simulations helped students to better grasp the concepts and techniques required for accurate measurements.

Table 3. Error type breakdown.

Error Type	Experimental Group (%)	Control Group (%)
Systematic Errors	12	15
Random Errors	8	10
Gross Errors	3	10

Further analysis was conducted using screenshots captured during the simulation exercises to assess students' engagement and understanding of the experimental processes. These screenshots, shown in **Figure 5**, depict various stages of the simulation, including setup, data collection, and analysis. The visual evidence from these screenshots indicates that students in the experimental group were able to accurately follow the procedures outlined in the simulations, effectively manipulate variables, and understand the underlying principles of mechanical measurement. The ability to pause, review, and correct actions during the simulation process likely contributed to the reduced frequency of errors observed in the experimental group.

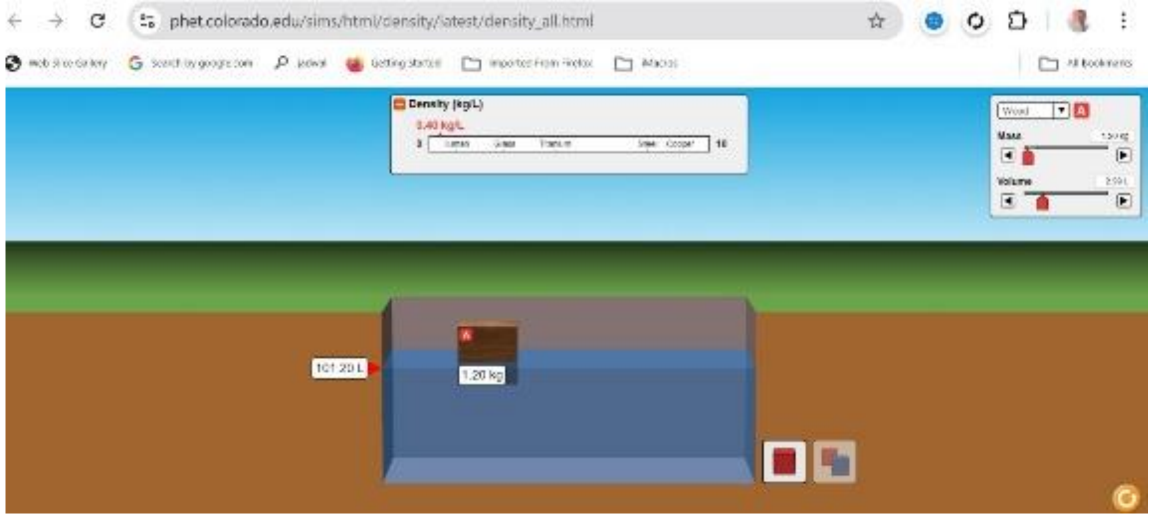


Figure 5. Screenshots from technology-driven simulations depicting setup, data collection, and analysis phases.

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Statistical analysis was conducted between the pre-test scores and the post-test scores in the experimental group to observe the impact of the technology-driven simulations on students' practical skills. The pre-test scores and post-test scores were obtained from data collected across nine Senior High Schools, which served as the research sample, utilizing the technology-driven simulation model in their teaching methods. Furthermore, to discern the difference in the impact of the technology-driven simulations (experimental group) from other teaching models (control group), a statistical analysis comparing the post-test scores of the control and experimental groups was performed.

The statistical analysis began with testing the normality and homogeneity of the data, followed by conducting the appropriate statistical tests. The results of the normality and homogeneity tests using SPSS 26 yielded a significance value (sig.) of 0.000 for normality and a significance value of 0.177 for the homogeneity test. Based on these results, it can be concluded that the data from the pre-test and post-tests are not normally distributed and not homogeneous. Therefore, hypothesis testing was performed using non-parametric statistical tests. One of the non-parametric tests for independent data is the Kruskal-Wallis test. This test examines the influence of technology-driven simulations and traditional teaching models on students' practical skills.

Figure 6 displays a graphical representation of the pre-test and post-test scores for the control and experimental classes across different schools. The graph clearly shows that the experimental class experienced a much more significant improvement in their post-test scores compared to the control class, highlighting the effectiveness of the experimental treatment. Each school is represented on the x-axis, while the mean scores are plotted on the y-axis for both the pre-test and post-test evaluations. The different colored lines represent the various groups, making it easy to compare the performance improvement between the control and experimental classes. The average score improvement for the experimental group was 18.5 points, while the control group only experienced an average improvement of 5.2 points. This suggests that simulation provides a more effective learning experience, resulting in a greater increase in understanding. Comparative analysis of measurement accuracy between the experimental and control groups showed that the experimental group achieved an average accuracy value of 92%, while the control group achieved 75%. This data underscores the efficacy of the simulation in helping students to understand and apply measurement techniques more accurately.

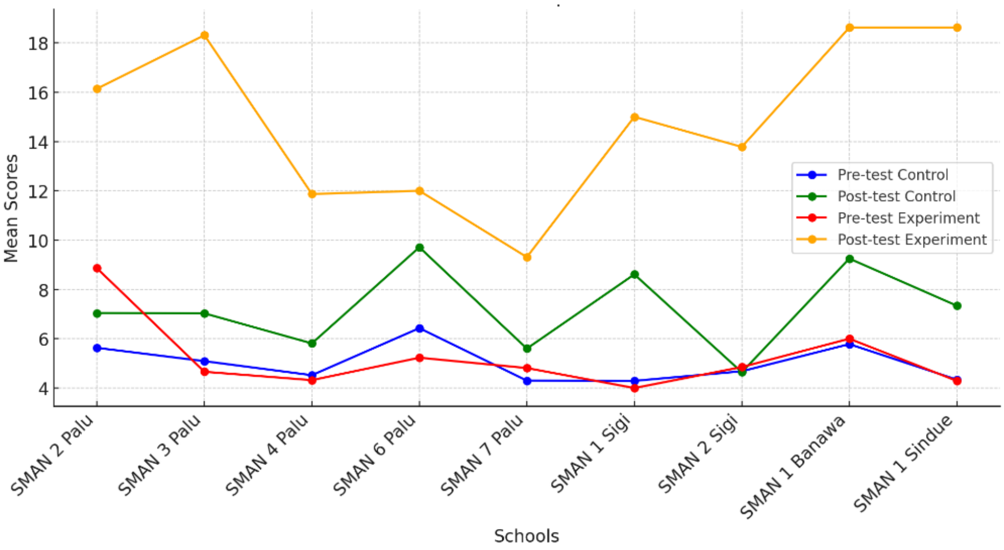

Figure 6. Displays the pre-test and post-test scores.

The substantial improvement in post-test scores for the experimental group compared to the control group reinforces the effectiveness of simulations in deepening students' understanding of mechanics concepts. These results are consistent with previous research that has identified the benefits of simulation-based learning, especially in enhancing conceptual clarity and practical application skills in the laboratory. Integrating simulations into the physics curriculum can be a highly useful tool for optimizing learning and mastery of practical skills among students (Scholtz & Hughes, 2021; Lavoie *et al.,* 2022; Hofmann *et al.,* 2021; Chernikova *et al.*, 2020).

The lower frequency of errors in the experimental group, particularly gross errors, suggests that simulations provide a safe and controlled environment where students can experiment with less risk of making mistakes that would typically occur in a traditional lab setting. This finding is consistent with previous studies, which noted that simulation allows for repeated practice, which is crucial for mastering complex measurement techniques (Perretta *et al.,* 2020; Chancey *et al.,* 2019; Bjerrum, 2018).

Moreover, the analysis of learning styles indicates that technology-driven simulations are particularly effective for visual and kinesthetic learners, providing an interactive and engaging way to learn that caters to these styles. This finding supports the work of (Perretta *et al.,* 2020; Chancey *et al.,* 2019; Bjerrum, 2018), who found that simulations are highly beneficial for learners who thrive in environments that allow for visual and tactile interaction.

The results of the Kruskal-Wallis test further validate the positive impact of technology-driven simulations on students' practical skills, as evidenced by the rejection of the null hypothesis. This finding suggests that the differences in post-test scores between the experimental and control groups are statistically significant, indicating that the simulations had a substantial effect on improving students' performance. In comparison to previous research, this study provides additional evidence that simulations not only complement traditional teaching methods but can also enhance learning outcomes more effectively when integrated into the curriculum. While earlier studies focused largely on the cognitive benefits of simulations, this research demonstrates their practical advantages, particularly in reducing errors and improving accuracy in mechanical measurements.

The results of this study strongly suggest that technology-driven simulations are a valuable tool in physics education. They offer a more effective and engaging learning experience compared to traditional methods, particularly in the context of mechanical measurements. The evidence supports the integration of simulations into the physics curriculum to improve both theoretical understanding and practical skills. Future research should explore the long-term impact of simulation-based learning and its potential applications in other areas of science education.

The findings of this research demonstrate that computer-based simulation technology holds significant potential for enhancing students' practical skills in mechanical measurements. These results emphasize that simulations not only support theoretical understanding but also enable students to develop the critical technical skills needed in a physics laboratory. However, to fully maximize the benefits of this technology, it is essential to consider how these findings can be applied within a broader educational context. Simulation technology can be utilized across various types of schools and educational programs, including institutions with limited physical laboratory resources, ensuring that all students have access to high-quality science education without relying on expensive or hard-to-obtain laboratory equipment.

Simulations can be adapted for use in a variety of educational settings. In schools with limited laboratory facilities, for instance, these simulations can serve as an alternative to physical experiments, allowing students to still gain valuable experimental experience. The implementation of this technology could be particularly relevant in rural areas or schools with limited budgets, where laboratory equipment may not be available. In this way, simulation technology can bridge gaps in educational access, providing equal opportunities for all students to develop the practical skills necessary in the field of physics.

Moreover, it is important to develop simulation modules that can be tailored to various educational levels, from secondary school to higher education. Modules designed specifically for secondary education, for example, could focus on introducing the basics of physics and mechanical measurement, with a simpler and more interactive approach. On the other hand, modules for higher education could cover more complex concepts and use simulations for advanced experiments. This approach allows simulation technology to broaden its applicability and benefit students across different educational levels.

To ensure maximum impact, integrating this simulation technology into the national curriculum should also be considered. This would allow simulations to become an integral part of the learning process, rather than just an additional tool or supplement. Furthermore, to optimize the use of this technology in classrooms, teacher training is crucial. Teachers need to be trained not only in the technical use of simulations but also in how to effectively integrate this technology into their teaching, so they can guide students in gaining deep and meaningful learning experiences. With this support, computer-based simulations can become a powerful tool for enhancing physics education at all levels. Finally, this study adds new ideas and information relating to physics education, as reported elsewhere (Susilowati *et al.*, 2023; Lestari *et al.*, 2024; Abosede *et al.*, 2024; Azizah *et al.*, 2022; Ibrahim, 2023; Al Husaeni *et al.*, 2024).

5. CONCLUSION

The findings of this research demonstrate that technology-driven simulations significantly enhance students' practical skills in mechanical measurements, offering a more effective and engaging learning experience compared to traditional methods. These simulations were particularly beneficial for visual and kinaesthetic learners, leading to improved post-test scores and a reduction in measurement errors. The implications suggest that integrating simulations into the physics curriculum can better prepare students for real-world applications by providing a controlled environment for skill refinement. However, the study's limitations include its short duration, focus on a specific aspect of physics, and reliance on a non-randomized sample, which may affect the generalizability of the results. Future research should explore the long-term impact of simulations across various scientific disciplines and involve more diverse student populations to fully understand their educational potential.

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7. AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. The authors confirmed that the paper was free of plagiarism.

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