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THE EFFECTIVENESS OF COMPUTER SIMULATION-BASED LEARNING FOR MASTERING FORCE AND MOTION CONCEPTS AMONG SECONDARY SCHOOL STUDENTS FORM FOUR PHYSICS

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Abstract

Force and Motion is among the difficult topics for students to learn in Physics because of the abstract concepts and the ability for the students to visualize the concepts. Computer simulations could be a solution for the students to learn this topic to help the students to visualize the concepts. Therefore, this study aims to evaluate the effectiveness of computer simulations in enhancing students' conceptual mastery of force and motion. The study was conducted in response to low student achievement in physics, particularly when traditional teaching methods are used. A quasi-experimental design with a one-group pretest-posttest model was implemented, involving 37 students from two secondary schools in Malaysia. The intervention involved simulation-based lessons using PhET tools. Data were collected using a test with 11 multiple choice items and analysed using descriptive statistics and a paired-sample t-test. The findings revealed a significant improvement in students' post-test scores (M = 76.66%) compared to their pre-test scores (M = 32.68%), with a statistical significance of $p < .001$. The result indicates that simulation-based instruction effectively enhances students' understanding of abstract physics concepts and supports the goals of Malaysia's Digital Education Policy in integrating technology into physics education.

Keywords: Force and Motion, Computer Simulation, Conceptual Mastery, PhET, Physics Education

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INTRODUCTION

The Malaysian Ministry of Education's Digital Education Policy aims to transform the educational landscape by integrating technology into learning processes across all levels [1]. In physics education, traditional methods have often failed to help students apply abstract concepts such as force and motion in real-world contexts [2]. Research [3,4] has shown that students frequently have misconceptions and low achievement in physics, particularly regarding Newtonian mechanics. To address this, computer simulations offer interactive environments where students can visualize dynamic processes, manipulate variables, and conduct virtual experiments safely and efficiently [5].

However, studies [6-8] report mixed findings: some indicate simulations significantly enhance conceptual understanding, while others [9-11] find little difference compared to traditional approaches unless combined with effective teaching strategies. This study focuses on assessing the effectiveness of simulation-based learning for improving mastery of force and motion concepts among Form Four students (16 years old) in Kulai, Johor, Malaysia. The objectives of this research are to identify students' conceptual mastery before and after using computer simulations, and to determine whether a significant difference exists between before and after the use of the computer simulations in their mastery of the concepts. This research is significant because it provides evidence to guide physics educators in adopting digital tools effectively, supporting Malaysia's educational transformation agenda.

LITERATURE REVIEW

2.1 Force and Motion Concepts

Many studies [2,3,4,12,13] have examined students' understanding of force and motion concepts, which are among the most fundamental yet challenging topics in physics. Misconceptions often begin in childhood and persist into secondary education, resulting in low mastery and fragmented knowledge structures [3,4]. In Malaysia, studies using instruments such as the Force Concept Inventory (FCI) and adapted assessments have shown that students struggle to apply Newtonian mechanics to explain everyday phenomena [12,13].

2.2 Computer Simulations in Learning Physics

Computer simulations have emerged as promising tools to address these issues by providing interactive and visual learning environments. Research shows that computer-based simulations, including PhET and Easy JavaScript Simulations (EJSS), significantly improve students' conceptual understanding, motivation, and engagement when integrated with effective pedagogy [5-6]. For example, Warneri et al. [7] demonstrated that PhET simulations combined with inquiry-based learning led to significant gains in physics achievement. Other studies have reported that simulations facilitate active exploration of variables, visual representation of dynamic processes, and the development of higher-order thinking skills [8-9].

Nevertheless, some researchers emphasize that simulations alone are not sufficient to achieve conceptual change. Their effectiveness depends on instructional design, scaffolding, and opportunities for reflection [10-11]. Simulation-supported lessons require clear guidance to help students construct scientifically accurate mental models [12].

This study applies interactive simulations (PhET) alongside appropriate teaching strategies to investigate whether they can enhance Malaysian secondary students' conceptual mastery of force and motion.

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RESEARCH METHOD

This study employed a quasi-experimental design, specifically a one-group pretest-posttest model, to measure students' conceptual mastery before and after the use of computer simulations in learning the topic of force and motion [1-5]. This approach involved administering a pretest to assess baseline knowledge, delivering an instructional intervention using PhET simulations, and then conducting a posttest to measure learning gains.

The population comprised Form Four secondary school students in Kulai District, Malaysia (N=640). The sample included 37 students purposively selected from one intact class due to logistical constraints [3-5]. This sampling method was appropriate because it focused on a relevant subgroup that had previously demonstrated low achievement in physics.

The intervention was implemented over a two-hour session consisting of:

1. Pretest administration (30 minutes),
2. Simulation-based instruction (60 minutes), and
3. Posttest administration (30 minutes).

The instruction utilized PhET simulations featuring dynamic visualization, adjustable variables, interactive controls, and embedded audio-visual explanations. A simulation-assisted class was conducted for 2 hours involving 30 Form 4 students. The contents of the Daily Lesson Plan can be referred to in Table 1. The lesson plan covers the entire 2-hour class session conducted at the respective school, including the pre-test, post-test, and simulation-based teaching. It outlines how the class will be conducted, starting from the induction set, followed by the teaching and assessment sessions.

Table 1: Content of Lesson Plan

Component	Content	Simulation Features Used	Key Terms
Introduction (10 min)	Demonstration of collision between two objects using PhET. Students observe changes after the collision.	Audio & Visual (Collision sounds and animations)	Momentum, collision, force, change in velocity
Concept Exploration (15 min)	Students vary the mass and velocity of objects to see the effects on momentum.	Adjustable Variables (Mass & velocity can be modified)	Momentum = Mass x Velocity
Types of Collisions (15 min)	Students test elastic and inelastic collisions and compare momentum before and after.	Interactive Buttons (Choose collision types)	Elastic collision, inelastic collision, conservation of momentum
Measurement & Analysis (10 min)	Students use digital meters & graphs in the simulation to analyze momentum before and after the collision.	Measurement Meters (Digital data, graphs, bar charts)	Conservation of momentum, data analysis, momentum graphs
Closure (10 min)	Students summarize concepts and relate them to real-life situations such as road accidents. Teacher conducts a quiz and assigns homework.	Full simulation control (Students can repeat the experiment at home)	Impulse, applications of momentum in real life

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The test was an adapted assessment developed by Liu et al. [6], consisting of 11 multiple-choice questions covering three key concepts: conservation of momentum, impulse-momentum theorem, and Newton's third law. It is shown in Table 2 below;

Table 2: Construction of Questions

Konsep Utama	Konteks	Soalan
Keabadian Momentum	Pelanggaran	Q4, Q9, Q10
	Daya bersih bukan sifar	Q2, Q8
Teorem Impuls-momentum	Geseran	Q5, Q6
	Letupan	Q7
Hukum Newton Ketiga	Pelanggaran	Q1, Q3, Q11

The instrument's content validity was established through expert review [7], and reliability was assessed using Kuder-Richardson Formula 20 (KR-20), achieving an acceptable internal consistency coefficient [8]. The value for Alpha Cronbach for KR-20 is 0.814.

The data analysis included:

1. Descriptive statistics to summarize pretest and posttest scores,
2. Paired-sample t-tests to determine significant differences in performance, and
3. A Confidence Response Index (CRI) matrix to detect misconceptions based on correctness and confidence levels [9].

RESULTS

This section presents the findings of the study, which aimed to evaluate the effectiveness of simulation-based learning in improving students' conceptual mastery of force and motion. A total of 37 Form Four physics students participated in the study. Data were analysed using descriptive and inferential statistics via Statistical Package for the Social Sciences (SPSS) version 29. Of the respondents, 73% were female (n=27) and 27% male (n=10), from two secondary schools in Kulai District.

4.1 Pretest Results

Referring to Table 3, prior to the intervention, students' mastery was generally low. The mean pretest score was 32.68% (SD = 22.91), categorised as "low." Detailed analysis per item indicated that most questions were answered correctly by fewer than 50% of students, suggesting difficulties in understanding fundamental physics concepts through traditional instruction.

4.2 Posttest Results

After the simulation-based intervention, students' performance improved significantly. The mean posttest score rose to 76.66% (SD = 13.98), categorised as "high." Seven out of eleven test items reached "very high" mastery levels (>80% correct responses), while the remaining items were classified as "high," except one item rated as "moderate."

Table 3: Pre-test and Post-test Mean score with Level of Mastery

Item	Pre-test		Post-test		Difference
	Mean score	Level	Mean score	Level	
1	51.0	Moderate	92.0	Very High	+41.0
2	24.0	Low	95.0	Very High	+71.0
3	19.0	Very Low	68.0	High	+49.0
4	51.0	Moderate	70.0	High	+19.0
5	11.0	Very Low	49.0	Moderate	+38.0
6	22.0	Low	68.0	High	+46.0
7	14.0	Very Low	65.0	Very High	+51.0
8	16.0	Very Low	86.0	Very High	+70.0
9	59.0	Moderate	92.0	Very High	+33.0
10	49.0	Moderate	78.0	High	+29.0
11	43.0	Moderate	81.0	Very High	+38.0
Average	**32.64**	**Low**	**76.73**	**Very High**	**+44.09**

4.3 Comparison of Pretest and Posttest

The paired-sample t-test revealed a statistically significant improvement in students' conceptual understanding ($t(36) = -15.919$, $p < .001$). The average score increased by approximately 44 percentage points, and the standard deviation decreased, indicating consistent improvements across respondents.

DISCUSSION AND IMPLICATIONS

This study investigated the effectiveness of computer simulations in improving students' conceptual mastery of force and motion among Form Four physics students. The findings demonstrated a significant improvement in students' understanding after the simulation-based intervention, as evidenced by the increase in post-test scores compared to pre-test scores. These results align with previous research indicating that interactive simulations enhance comprehension of abstract physics concepts [6-8].

The pre-intervention results revealed that many students struggled with fundamental principles such as conservation of momentum and Newton's laws, consistent with

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constructivist theories asserting that learning requires active engagement and meaningful experiences [3]. Traditional instruction alone was insufficient to support deep conceptual change, confirming findings by Nogueira et al. [4] and Josey [5].

Following the simulation intervention, students exhibited higher levels of mastery and confidence, with mean scores shifting from "low" to "high." This supports the Visual Learning Theory, which posits that dynamic visual representations can make abstract concepts more accessible and memorable [6]. Simulations allowed students to manipulate variables, test hypotheses, and observe the consequences of their actions in a controlled virtual environment, fostering critical thinking and inquiry skills [7].

5.1 Implications for Practice

Based on these results, it is recommended that physics instruction in Malaysian secondary schools integrate interactive simulations such as PhET into regular teaching practice. Simulations have been shown to not only improve academic performance but also increase motivation, engagement, and positive attitudes toward learning physics [8][9]. Teachers should receive targeted professional development to effectively incorporate simulation tools into lessons, while schools and the Ministry of Education should invest in technological infrastructure to support widespread implementation. Incorporating simulations aligns with 21st-century learning goals and helps students build lasting scientific understanding beyond rote memorization.

Overall, this study reinforces the role of computer simulations as a powerful instructional strategy to transform abstract science content into engaging, inquiry-driven learning experiences that promote higher-order thinking and conceptual mastery.

CONCLUSION

This study investigated the effectiveness of computer simulations in enhancing Form Four students' conceptual understanding of force and motion in physics. The results showed a statistically significant improvement in post-test scores after students engaged with simulation-based learning, compared to their pre-test performance. The mean score increased from 32.64% (Low) to 76.73% (Very High), with consistent gains across all test items. This supports the view that abstract physics concepts can be more effectively taught through interactive, visual simulations than through traditional methods alone.

The findings align with constructivist learning theory, which emphasizes the importance of active engagement and experiential learning. Tools such as PhET simulations enabled students to manipulate variables, observe real-time effects, and construct their own understanding of dynamic physics phenomena like momentum and collisions. The improved mastery levels suggest that simulations are not only effective in knowledge acquisition but also in fostering deeper conceptual change and problem-solving abilities.

In line with previous research [1–4], this study confirms that computer simulations can serve as a valuable pedagogical tool for improving learning outcomes in physics education. As Malaysia continues to implement its Digital Education Policy, integrating simulation-based instruction into science curricula offers a promising path to raising student achievement and engagement in STEM subjects.

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