Impact of PhET Simulations on student understanding

Shafiq Rasulan
Sarawak Matriculation College
E-mail: `shafiq@kmsw.matrik.edu.my`

Abstract. This study examines the effect of PhET Interactive Simulations on pre-university students' understanding of force concepts at Sarawak Matriculation College. Thirty students were divided into control and experimental groups based on prior physics achievement. Both groups received identical instructional content over four sessions, with the experimental group using PhET simulations and the control group taught through traditional methods. Conceptual understanding was assessed using the Force Concept Inventory (FCI) administered as a pre- and post-test. Results showed that the experimental group achieved significantly higher normalized gains (M = 0.27) compared to the control group (M = 0.09), suggesting that PhET simulations support more effective conceptual learning. These findings highlight the potential of interactive simulations to enhance physics education at the pre-university level.

1. Introduction

Understanding fundamental force concepts remains a persistent challenge for many pre-university physics students. Despite formal instruction, misconceptions about Newtonian mechanics are widespread and resistant to traditional lecture-based approaches. This conceptual gap is well-documented through diagnostic tools such as the Force Concept Inventory (FCI), which reveals that students often retain intuitive but incorrect notions about motion and force even after completing coursework.

In response, physics educators have increasingly turned to interactive technologies to facilitate conceptual change. One such tool, the PhET Interactive Simulations project developed at the University of Colorado Boulder, offers dynamic, research-based simulations designed to visually and interactively represent core physics principles. These simulations aim to bridge the gap between abstract concepts and students' intuitive understanding by enabling exploratory, visual, and kinesthetic engagement with physical phenomena.

While PhET simulations have been widely adopted in various educational contexts, evidence of their impact on learning outcomes, particularly within pre-university physics programs in Southeast Asia, remains limited. Moreover, few empirical studies have specifically measured their effect using validated instruments such as the FCI. This study addresses that gap by examining the impact of PhET-based instruction on students' conceptual understanding of force at Sarawak Matriculation College in Malaysia.

The objective of this research is to determine whether students who participate in lessons incorporating PhET simulations exhibit significantly better performance on the FCI compared to those receiving traditional instruction. By comparing pre- and post-test results between experimental and control groups, this study offers insights into the effectiveness of simulation-enhanced learning environments in addressing persistent misconceptions in mechanics.

2. Methodology

This study involved 30 pre-university students aged 18 to 19 at Sarawak Matriculation College. Participants were divided into two groups of equal size (15 students each) to form the experimental and control groups. Group assignment was based on students' Sijil Pelajaran Malaysia (SPM) Physics results to ensure comparable mean academic performance between groups.

The intervention spanned four teaching sessions focusing on the topic of force. Both groups received identical content; however, the experimental group's instruction incorporated PhET Interactive Simulations, while the control group experienced traditional teaching methods without simulation support.

Conceptual understanding was assessed using the Force Concept Inventory (FCI) administered as both a pre-test and post-test to all participants. The FCI was employed in its original form without translation or modification. Student performance was analyzed by calculating normalized gain scores, and data analysis was conducted using Python.

3. Results

Initial FCI pre-test scores were similar between the control (M = 12.02) and experimental groups (M = 11.46), confirming comparable baseline understanding of force concepts. After the four-session intervention, the experimental group showed a notable increase in post-test scores (M = 16.49) compared to the control group (M = 13.63).

Table 1. Summary of FCI Scores and Normalized Gains

Group	Pre-test Mean	Post-test Mean	Normalized Gain
Control	12.02	13.63	0.09
Experimental	11.46	16.49	0.27

Normalized gain analysis demonstrated that the experimental group achieved a mean gain of 0.27 (SD = 0.07), significantly higher than the control group's mean gain of 0.09 (SD = 0.06). This suggests that the use of PhET simulations facilitated greater conceptual learning gains in force understanding.

Figure 1 illustrates these differences in pre- and post-test scores whilst Figure 2 illustrates the normalized gains for both groups.

4. Discussions

The results of this study suggest that integrating PhET simulations into physics instruction significantly enhances students' conceptual understanding of force. Although both the control and experimental groups began with comparable pre-test scores, students in the experimental group demonstrated substantially higher post-test scores and normalized gains on the Force Concept Inventory.

These findings align with prior research indicating that interactive simulations can support the development of mental models and correct misconceptions, particularly in abstract domains like Newtonian mechanics. The visual and exploratory features of PhET may have enabled students to better connect physical representations with underlying principles, leading to deeper conceptual change.

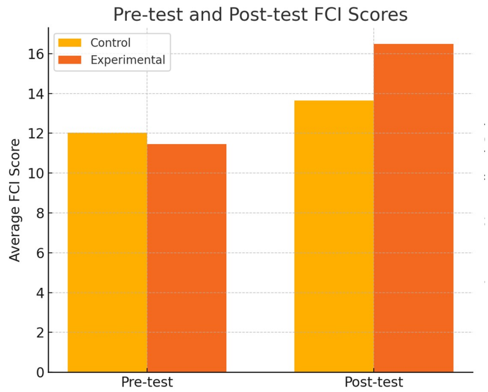

Figure 1. Average pre-test and post-test FCI scores for control and experimental groups. The experimental group, which received PhET-based instruction, showed a greater improvement in conceptual understanding of force.

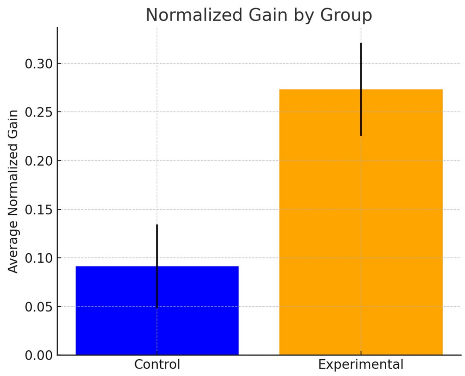

Figure 2. Normalized gain comparison between control and experimental groups. Students taught with PhET simulations achieved significantly higher gains in force concept understanding. Error bars represent standard deviation.

The comparatively modest gains in the control group imply that traditional lecture-based instruction alone may be insufficient to address entrenched misconceptions. In contrast, the active engagement afforded by PhET likely provided opportunities for students to test, revise, and refine their understanding through feedback-rich interactions.

One limitation of this study is the small sample size, which may restrict the generalizability of the findings. Additionally, while the FCI is a widely validated instrument, it does not capture all dimensions of conceptual growth, such as students' qualitative reasoning or transfer skills. Future research could extend this work by incorporating qualitative data (e.g., interviews or reflective journals) to better understand how students interact with and benefit from simulations.

Nevertheless, the results support the value of integrating simulation-based tools like PhET into pre-university physics curricula to promote meaningful learning, particularly in areas known to be conceptually challenging.

5. Conclusions

This study investigated the impact of PhET simulations on pre-university students' understanding of force concepts using the Force Concept Inventory as an assessment tool. Results showed that students who experienced PhET-based instruction achieved significantly higher normalized gains compared to those taught through traditional methods.

The findings highlight the potential of interactive simulations to address persistent misconceptions in physics by promoting active engagement and visual conceptualization. Given the promising results, incorporating tools like PhET into physics education at the matriculation level is recommended to support deeper and more effective learning.

Future studies with larger sample sizes and mixed-method approaches could further validate and extend these findings across different topics and educational contexts.