



Exploring the impact of teaching based on PhET interactive simulations on student learning motivation: A case study of K12 physics experiment teaching

Yang Qian

Department of Education, China West Normal University, Nanchong, China

Abstract

The digital transformation of education presents numerous challenges for middle school physics education, including the difficulty students face in grasping abstract concepts, traditional teaching methods failing to engage students, and the lack of financial resources for adopting technological aids like VR in teaching. The utilization of PhET simulations emerges as a potent solution, offering several benefits. These simulations transform abstract physics concepts into tangible experiences, enhancing students' comprehension and mastery of the subject matter, thereby increasing teaching effectiveness. Furthermore, the free and low-requirement nature of PhET simulations addresses the financial constraints faced by underprivileged regions. Additionally, PhET simulations facilitate personalized teaching approaches, catering to the diverse learning needs of students. Through quasi-experimental research, this study demonstrates that physics education utilizing PhET interactive simulations significantly boosts students' motivation to learn, as evidenced by improvements in self-efficacy, perceived value of physics learning, achievement goals, and attitudes towards the use of PhET simulations in both teaching and learning processes.

Keywords: PhET, interactive simulations, teaching, physics, experiments

Introduction

In the digital era, every sector is in pursuit of transformation, with education at the forefront of embracing digital reforms globally ^[1]. The rapid innovation and development of technology have necessitated the digitalization of education. Educational programs, especially highlighted during the COVID-19 pandemic, have become a quintessential application of digital education as many schools were forced to shut down, disrupting the traditional educational flow. This disruption has led to a significant increase in the demand for digital resources and educational programs, propelling a shift towards online education centered around student engagement and learning enjoyment. These developments have significantly impacted teachers and students by facilitating teaching and learning through digital resources and tools.

Physics, a subject inherently reliant on experimental learning, faces challenges due to constraints like the shortage of laboratory equipment, limited experiment time, and safety concerns ^[2]. Despite the advancement of information technology, traditional teaching methods, predominantly lectures, prevail, with limited integration of technology in educational practices ^[3]. Distance learning technologies, although reducing costs, have not enhanced teaching effectiveness, merely replicating traditional classroom settings through digital platforms ^[4]. PhET interactive simulations introduce a revolutionary learning approach for the 21st century, enabling students to conduct experiments in physics, mathematics, chemistry, and more, thus verifying scientific laws ^[5]. This method not only transforms the teaching model but also significantly enhances teaching efficiency.

Research by Herbert James Banda and colleagues highlights that most PhET studies focus on virtual laboratories and visual learning in Western contexts, with less attention on the effectiveness in Asian educational settings ^[6]. This study investigates whether PhET interactive simulations can enhance learning motivation among students in China's less

developed regions. Addressing these research questions, the study was conducted in rural middle schools in Chengdu, Sichuan, aiming to investigate the effect of PhET interactive simulations on enhancing the learning motivation among students from less developed regions outside China's major metropolitan areas. This choice of location underscores the focus on assessing educational interventions in settings often overlooked in educational technology research.

Current Insights on PhET Simulations

Initiated in 2002 by Nobel Prize laureate Carl Wieman at the University of Colorado, the PhET project represents a pivotal non-profit initiative aimed at enriching science education. Through interactive, game-like simulations, PhET engages students in a multi-dimensional learning experience, enhancing comprehension of complex subjects such as physics, chemistry, mathematics, and biology. These simulations herald a modern approach to education, enabling hands-on experimentation and a deeper understanding of scientific principles ^[5].

Evidence from various studies underscores the effectiveness of PhET simulations in improving educational outcomes. Research by Banda and Nzabahimana on Malawian middle school students demonstrated that PhET-based instruction in "Oscillations and Waves" significantly boosted students' motivation and academic achievement ^[6]. Similarly, an investigation by Haryadi and Pujiastuti revealed that students learning "Temperature and Heat" through PhET simulations achieved a 37% higher learning gain compared to those in traditional settings ^[7]. This enhancement of physics skills through PhET is further corroborated by Hoi-Ting Wu's findings, which advocate for the flipped classroom model integrated with PhET simulations to improve both immediate and long-term student performance in larger class settings ^[8]. Collectively, these findings affirm the substantial impact of PhET simulations in fostering an interactive and effective learning environment.

Implementing PhET Interactive Simulations in Physics Education Process

1. Content Selection

Within the PhET platform, the physics curriculum encompasses over 50 diverse simulations, covering key topics such as geometric optics, density, and collision lab, among others. For this study, "Geometric Optics" was chosen to illustrate how lenses converge rays to form images and how alterations to the lens (like radius, index, and diameter) impact the image's display location and appearance (including magnification, brightness, and orientation).

2. Teaching Design

A PhET-based teaching sequence was developed for the experimental group, with precise learning objectives aimed at mastering geometric optics principles and applying them in real-world contexts. The geometric optics simulation on PhET was selected, and the computer lab was utilized to ensure all students had access to the interactive simulations. The teaching approach was hands-on, with students actively engaging in the simulations while the teacher provided guidance and answered questions, fostering a learning environment that was both teacher-guided and student-centered. Post-instruction, a survey was conducted to assess the teaching effectiveness, focusing on students' self-efficacy, value of physics learning, achievement goals, and attitudes toward PhET simulations in the learning process.

Implementation of PhET Interactive Simulations in Physics Education: A Quasi-Experimental Approach

1. Hypothesis

Integrating PhET interactive simulations into physics education is hypothesized to significantly boost students' learning motivation.

2. Participant Selection and Setup

In middle school from Chengdu, two freshman classes were chosen for this study, one as the experimental group (55 students) and the other as the control group (54 students), making up a total of 109 participants. The experimental group engaged in PhET-based interactive simulations in a computer lab setting, contrasting with the control group's conventional classroom learning, which involved traditional lectures. Prior exposure to geometric optics was absent in both groups.

3. Procedure

The study commenced with two classes unfamiliar with geometric optics. In the computer lab, the experimental group interacted with PhET simulations on geometric optics, conducting experiments independently after initial instruction, with the teacher providing support as needed. Conversely, the control group adhered to traditional teaching methods, relying on lectures supplemented with video and image resources. Following the instructional period, a comprehensive questionnaire was distributed to all participants.

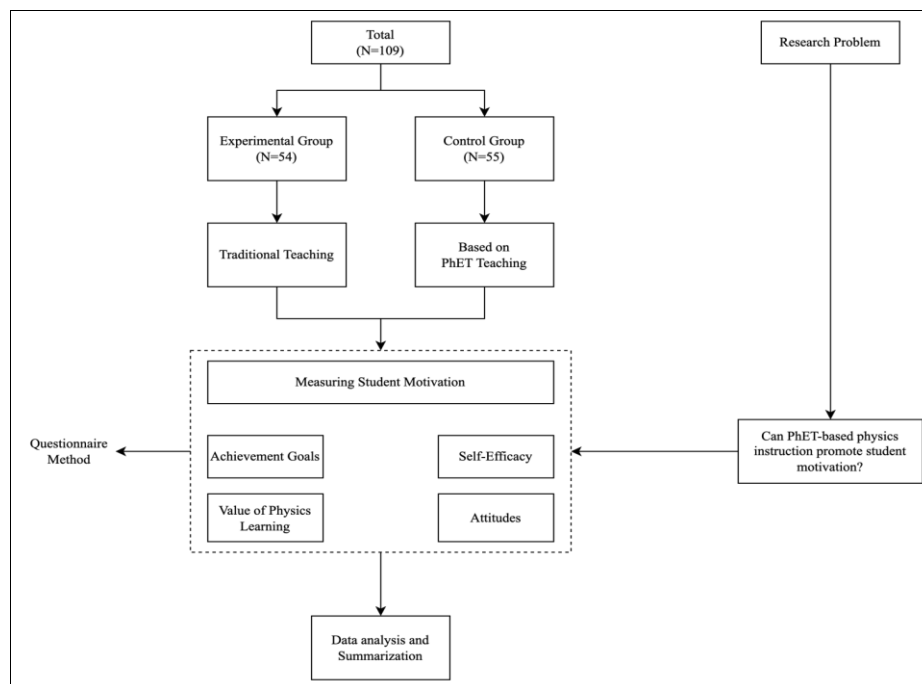


Fig 1: Experimental Procedure

4. Metrics

The motivational assessment was based on modified scales from Tuan *et al.* [9] and Knezek and Christensen [10], consisting of 20 items rated on a 5-point Likert scale from strong disagreement to strong agreement. Adjustments were made to focus on self-efficacy, perceived value of learning physics, achievement goals, and attitudes toward the PhET simulations in education, omitting dimensions like active learning strategies due to sample size constraints.

5. Measurement Analysis

Out of the 109 questionnaires issued, all responses were valid with an effective return rate of 100%, none being excluded for having response times of zero.

5.1 Reliability Analysis

The reliability of the questionnaire was assessed across multiple dimensions, yielding the following Alpha coefficients

Table 1: Reliability Statistics

Dimensions	Cronbach's Alpha	Cronbach's Alpha (Standardized)	Number of Items
Self-Efficacy	.887	.887	6
Value of Physics Learning	.886	.886	5
Achievement Goals	.795	.795	3
Attitudes	.929	.929	6

Reliability was assessed across various measures, revealing that the standardized Cronbach's Alpha values fall within the range of 0 to 1, closely approaching 1. This suggests a high level of reliability for the assessments.

5.2 Comprehensive Validity Assessment.

An exploratory factor analysis using SPSS 25 was performed to evaluate the validity of the study. The results highlighted a KMO Sampling Adequacy Measure and Bartlett's Test of Sphericity score of 0.970, nearing 1. This score indicates a high level of data adequacy for factor analysis, thus confirming the validity of the measurements.

Table 2: KMO and Bartlett's Test KMO

KMO Sampling Adequacy Measure Bartlett's Test of Sphericity		.970
Approximate Chi-Square	Approximate Chi-Square	1765.066
	Degrees of Freedom	190
	Significance	.000

5.3 Independent Samples t-Test of Survey Questionnaire

Table 3: Independent Samples Test of Self-Efficacy

	Levene's Test for Equality Of Variances		Mean Equality t-Test				
	F	Significance	t	Degrees of Freedom	Sig. (two-tailed)	Mean Difference	Standard Error Difference
Equal Variances Assumed	.117	.732	7.293	107	.000	7.96094	1.09161
Equal Variances Not Assumed			7.293	106.976	.000	7.96094	1.09158

Table 4: Independent Samples Test of Value of Physics Learning

	Levene's Test for Equality of Variances		Mean Equality t-Test				
	F	Significance	t	Degrees of Freedom	Sig. (two-tailed)	Mean Difference	Standard Error Difference
Equal Variances Assumed	1.166	.283	8.270	107	.000	7.44747	.90053
Equal Variances Not Assumed			8.264	105.954	.000	7.44747	.90121

Table 5: Independent Samples Test of Achievement Goals

	Levene's Test for Equality of Variances		Mean Equality t-Test				
	F	Significance	t	Degrees of Freedom	Sig. (two-tailed)	Mean Difference	Standard Error Difference
Equal Variances Assumed	2.977	.087	6.483	107	.000	3.69495	.56994
Equal Variances Not Assumed			6.473	103.209	.000	3.69495	.57085

Table 6: Independent Samples Test of Attitudes Toward PhET Simulations

	Levene's Test for Equality of Variances		Mean Equality t-Test				
	F	Significance	t	Degrees of Freedom	Sig. (two-tailed)	Mean Difference	Standard Error Difference
Equal Variances Assumed	.769	.382	7.935	107	.000	9.08350	1.14477
Equal Variances Not Assumed			7.930	106.201	.000	9.08350	1.14550

The independent samples t-test conducted on the experimental and control groups across four dimensions reveals significant differences, as evidenced by sig (two-tailed) values all being less than 0.05. This indicates that the experimental group experienced a notably enhanced motivation compared to the control group. Such findings underscore PhET's effectiveness in fostering an increased motivation among students for learning physics.

Conclusion and Limitations

In the era of educational digitalization, integrating information technology with teaching methodologies is becoming increasingly important. The necessity for classroom teaching model innovation is clear. This study introduces a new model for classroom instruction utilizing PhET interactive simulations, aimed at fostering students

equipped with innovative thinking, collaborative skills, and the ability to learn independently.

Leveraging PhET's virtual lab capabilities, this approach allows for cost-effective teaching methods where students can engage in interactive activities like clicking and dragging, mitigating the risks associated with physical experiments. Given its free access, PhET simulations are particularly beneficial for schools in underdeveloped regions facing financial constraints. The interactive and game-like nature of PhET also facilitates a deeper understanding of concepts, thereby enhancing teaching and learning efficiency.

Nonetheless, the study acknowledges several limitations. It's constrained to subjects provided by PhET, such as math, physics, chemistry, and earth science, and may not cover all academic disciplines. Additionally, the study lacked a comparative analysis of students' knowledge before and after the experiment, limiting the conclusiveness of the findings. Furthermore, the implementation of this model requires significant hardware resources, specifically a computer lab, to ensure every student can participate fully.

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