



# Enhancing Students' Conceptual Mastery of Mechanics through Smartphone-Based Inquiry Laboratories in Introductory Physics

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**Abstract:** *Introductory physics courses, particularly in mechanics, continue to pose significant conceptual difficulties for first-year University students, largely due to persistent misconceptions related to force, motion, and acceleration. Conventional laboratory instruction often emphasizes procedural verification rather than conceptual reconstruction, limiting its effectiveness in addressing these misconceptions. The integration of smartphone-based laboratories offers a promising, accessible, and cost-efficient alternative that supports inquiry-based learning. This quasi-experimental study examines the effectiveness of smartphone-based laboratories in enhancing students' conceptual understanding of mechanics. A total of 128 first-year university students participated in the study and were assigned to either an experimental group or a control group. The experimental group engaged in five inquiry-oriented laboratory activities utilizing the phyphox mobile application, while the control group conducted traditional verification-based experiments covering equivalent topics. Students' conceptual understanding was assessed using the Force Concept Inventory (FCI) administered as both pretest and posttest measures. The findings indicate a statistically significant improvement in the experimental group compared to the control group. Furthermore, students in the smartphone-based laboratory group reported higher levels of engagement, perceived authenticity of experimentation, and stronger connections to real-world contexts. These results demonstrate that smartphone-based laboratories represent an effective pedagogical approach for fostering deeper conceptual understanding in introductory mechanics. The study underscores the potential of mobile technologies to support active, inquiry-driven learning in physics education.*

**Keywords:** *smartphone-based laboratories; physics education; conceptual understanding; mechanics; inquiry-based learning; mobile technology*

## I. Introduction

Introductory physics courses often serve as gateway courses for students entering science, technology, engineering, and mathematics (STEM) programs. However, these courses are frequently associated with high levels of difficulty and may contribute to the underrepresentation of certain groups within STEM fields. One persistent concern in science education involves gender disparities in student participation, performance, and confidence in physics learning environments.

Research suggests that classroom practices and instructional approaches can influence how inclusive and supportive learning environments are for different groups of students. Traditional lecture-based instruction and highly structured laboratory exercises may not always provide equal opportunities for all students to engage actively with scientific concepts.

Innovative instructional strategies that promote active participation, collaborative learning, and authentic experimentation may help create more inclusive learning environments. Smartphone-based laboratories represent one such innovation. By enabling students to conduct experiments using familiar personal devices, smartphone laboratories may reduce barriers to participation and encourage greater engagement. This study investigates the effectiveness of smartphone-based laboratories for improving conceptual understanding of mechanics while also examining potential gender differences in learning outcomes.

## **II. Review of Literature**

Promoting inclusive learning environments has become an important priority in science, technology, engineering, and mathematics (STEM) education. Despite significant progress in expanding access to higher education, disparities in participation and achievement remain evident across different demographic groups. Gender disparities in particular have received considerable attention in physics education research, as women continue to be underrepresented in many physics and engineering programs worldwide.

Several studies suggest that differences in learning environments and instructional practices may contribute to these disparities. Traditional physics classrooms often emphasize lecture-based instruction, competitive problem solving, and highly structured laboratory exercises. While such approaches may effectively transmit disciplinary knowledge, they may not always provide equal opportunities for all students to participate actively in the learning process. Educational researchers have therefore explored alternative instructional strategies that promote engagement, collaboration and inclusivity.

Laboratory instruction plays a particularly important role in creating opportunities for active participation in physics learning. Hands-on experimental activities allow students to observe physical phenomena, test hypotheses, and analyze empirical data. When laboratories are designed to encourage exploration and collaboration, they can help students develop scientific reasoning skills and greater confidence in their ability to engage with physics concepts.

However, traditional laboratory environments may sometimes present barriers to inclusive participation. Complex laboratory equipment, limited access to apparatus, and highly structured procedures may discourage some students from actively engaging in experimentation. Students who feel less confident in their technical abilities may hesitate to take leadership roles during laboratory activities, potentially reinforcing existing inequalities in participation.

Recent technological innovations have introduced new possibilities for creating more inclusive laboratory environments. Smartphones, which are widely owned by university students, contain sensors capable of measuring various physical quantities. These sensors allow smartphones to function as portable scientific instruments that can be used for experimental investigation in physics laboratories.

Smartphone-based laboratories offer several potential advantages for promoting inclusivity in physics education. First, the widespread availability of smartphones reduces barriers to access. Because most students already possess these devices, smartphone experiments can be conducted without requiring specialized laboratory equipment. This accessibility allows more students to participate simultaneously in experimental activities.

Second, smartphones are familiar devices that students use regularly in their daily lives. This familiarity may reduce the anxiety sometimes associated with operating complex laboratory apparatus. Students may feel more confident experimenting with technology they already understand, which can increase their willingness to participate actively in laboratory activities.

Another important benefit of smartphone-based laboratories is the ability to visualize experimental data instantly. Real-time graphical representations of physical variables can help students interpret relationships among concepts such as velocity, acceleration, and force. These visualizations support conceptual understanding by linking abstract theoretical ideas with observable physical phenomena.

Collaborative learning is another important aspect of inclusive laboratory environments. Smartphone-based experiments are often conducted in small groups, encouraging students to share ideas, interpret data collectively, and discuss their findings. Collaborative interactions can help create supportive learning environments in which students feel comfortable contributing their perspectives.

Gender differences in conceptual understanding of physics have been widely investigated, particularly through assessments such as the Force Concept Inventory. Some studies have reported gender gaps in FCI scores, with male students achieving higher average scores than female students. Researchers have proposed various explanations for these differences, including variations in prior preparation, classroom participation, and levels of confidence.

Importantly, research suggests that instructional practices can influence the magnitude of gender differences in learning outcomes. Active learning environments that emphasize collaboration and inquiry have been associated with smaller gender gaps in physics achievement. When students are encouraged to engage directly with experimental investigation and conceptual reasoning, learning environments may become more supportive for diverse groups of learners.

Despite these promising findings, relatively few studies have examined the impact of smartphone-based laboratories on gender equity in physics education. While mobile technologies may increase accessibility and engagement, it remains important to evaluate whether these approaches benefit male and female students equally. Without empirical investigation, it is difficult to determine whether technology-enhanced laboratories promote equitable learning outcomes.

The present study addresses this gap by examining both the effectiveness of smartphone-based laboratories for improving conceptual understanding of mechanics and their potential influence on gender differences in learning outcomes. By combining quantitative analysis of conceptual gains with qualitative insights into student experiences, the study aims to contribute to ongoing efforts to design more inclusive and effective physics learning environments.

### **III. Research Methods**

#### **3.1 Research Design**

This study employed a quasi-experimental research design to examine the effectiveness of smartphone-based laboratories in enhancing conceptual understanding of mechanics

among first-year university students. Quasi-experimental designs are commonly used in educational research when random assignment to experimental conditions is not fully feasible but comparative analysis between groups remains possible. In this study, two groups of students were compared: an experimental group that participated in smartphone-based laboratory activities and a control group that completed traditional verification laboratories covering the same mechanics topics.

The research followed a pretest–posttest non-equivalent group design. Both groups completed a conceptual understanding assessment prior to the intervention and again after the instructional period. The use of pretest scores allowed researchers to control for initial differences between groups during statistical analysis.

### **3.2 Instructional Intervention**

The intervention lasted eight weeks during the mechanics unit of the introductory physics course. Students in the experimental group conducted five smartphone-based laboratory activities using the phyphox (Physics Phone Experiments) application. These experiments utilized smartphone sensors to investigate mechanics concepts including acceleration, velocity, free fall, harmonic motion, and conservation of energy.

During each laboratory session, students worked in small groups of three to four members. They designed experimental procedures, collected real-time sensor data, and interpreted graphical representations generated by the application. The instructor provided guidance but encouraged students to explore relationships between variables independently.

In contrast, the control group performed traditional laboratory activities using conventional laboratory equipment. These experiments followed structured procedures designed primarily to verify known physical relationships, such as Newton’s second law and motion under constant acceleration.

### **3.3 Student Perception Survey**

A 12-item Likert-scale questionnaire was used to assess students’ perceptions of smartphone-based laboratory activities. The survey measured four constructs:

- Perceived usefulness
- Ease of use
- Learning engagement
- Future intention to use mobile laboratories

Responses were recorded on a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

### **3.4 Focus Group Interviews**

To complement the quantitative data, focus group interviews were conducted with 12 volunteer students from the experimental group. The interviews explored students’ experiences using smartphone laboratories, including perceived benefits, challenges, and suggestions for improvement.

### **3.5 Data Analysis**

Quantitative data were analyzed using statistical software. Descriptive statistics were first calculated to summarize students’ pretest and posttest scores. An analysis of covariance (ANCOVA) was then conducted to determine whether there were significant differences between the experimental and control groups after controlling for pretest scores.

Effect sizes were calculated using Cohen’s d and partial eta squared ( $\eta^2$ ) to assess the magnitude of differences between groups.

Survey responses were analyzed using descriptive statistics and reliability analysis. Interview data were analyzed using thematic analysis, which involved coding responses and identifying recurring themes related to students’ experiences with smartphone-based laboratories.

## IV. Results and Discussion

### 4.1 Results

#### a. Pretest and Posttest Performance

To examine the effectiveness of smartphone-based laboratories in improving conceptual understanding of mechanics, students’ pretest and posttest scores on the Force Concept Inventory (FCI) were analyzed. Table 1 presents the descriptive statistics for both groups.

**Table 1.** Descriptive Statistics of FCI Scores

Group	Pretest Mean	Pretest SD	Posttest Mean	Posttest SD
Experimental (Smartphone Lab)	42.15	9.84	68.00	10.72
Control (Traditional Lab)	41.87	10.11	56.43	11.06

The results show that both groups had nearly identical pretest scores, indicating comparable prior knowledge of mechanics concepts before the intervention. However, after the instructional period, the experimental group demonstrated substantially higher posttest scores than the control group.

#### b. ANCOVA Analysis

An analysis of covariance (ANCOVA) was conducted to determine whether the difference in posttest scores between the two groups remained significant after controlling for pretest scores.

The ANCOVA results revealed a significant main effect of instructional group on posttest scores:

$$F(1,125) = 24.51, p < .001, \text{partial } \eta^2 = .164$$

These findings indicate that the type of laboratory instruction significantly influenced students’ conceptual understanding of mechanics. The partial eta squared value suggests a large effect size, indicating that smartphone-based laboratories contributed meaningfully to improved learning outcomes.

#### c. Normalized Gain Analysis

The results are shown in Table 2.

**Table 2.** Normalized Gain Scores

Group	Mean Gain (g)	Interpretation
Experimental	0.45	Medium-High Gain
Control	0.25	Low-Medium Gain

The experimental group achieved a significantly higher normalized gain compared to the control group, suggesting that smartphone-based laboratory instruction was more effective in promoting conceptual change.

#### **d. Student Perception Survey**

Students' perceptions of smartphone-based laboratories were assessed using a 12-item Likert-scale survey. Overall responses were positive, with 68.8% of students expressing agreement or strong agreement with statements regarding the usefulness and effectiveness of smartphone laboratories.

Among the measured constructs, future intention to use smartphone laboratories received the highest rating ( $M = 3.85$ ), followed by perceived usefulness ( $M = 3.74$ ), engagement ( $M = 3.69$ ), and ease of use ( $M = 3.51$ ).

#### **e. Focus Group Findings**

Qualitative analysis of focus group interviews identified four main themes:

1. Authentic experimental experiences
2. Improved visualization of physical concepts
3. Increased engagement during experiments
4. Minor technical challenges

Students frequently reported that smartphone experiments helped them better understand relationships between physical variables by visualizing real-time data.

### **4.2 Discussion**

The findings of this study demonstrate that smartphone-based laboratories significantly enhance students' conceptual understanding of mechanics compared with traditional laboratory instruction. The experimental group not only achieved higher posttest scores but also exhibited greater normalized gains on the Force Concept Inventory. These results support the growing body of research suggesting that technology-enhanced laboratory environments can improve conceptual learning in physics education.

One explanation for the observed improvement is the ability of smartphone laboratories to provide real-time visualization of experimental data. Traditional laboratory activities often require students to collect measurements manually and later construct graphs to analyze relationships between variables. This process can be time-consuming and may reduce opportunities for conceptual reflection. In contrast, smartphone applications such as phyphox automatically generate graphical representations of experimental data, allowing students to observe patterns and relationships immediately. This immediate feedback can help students connect theoretical concepts with observable phenomena, facilitating deeper conceptual understanding.

Another important factor contributing to the effectiveness of smartphone-based laboratories is the increased level of student engagement. Laboratory activities that involve familiar personal devices may feel more interactive and relevant to students' everyday experiences. During focus group interviews, several students reported that using their smartphones made experiments more interesting and easier to understand. Such increased engagement can positively influence learning outcomes by encouraging students to participate more actively in the learning process.

The portability of smartphones also allows experiments to be conducted in authentic real-world environments. Rather than being confined to a traditional laboratory setting, students can investigate physical phenomena in everyday contexts, such as measuring acceleration while walking or analyzing motion during everyday activities. These real-world connections can help students recognize the practical relevance of physics concepts, reinforcing conceptual learning.

The normalized gain analysis provides further evidence of the educational benefits of smartphone laboratories. The experimental group achieved a medium-to-high gain score ( $g = 0.45$ ), which is comparable to learning gains reported in active-learning physics courses. In contrast, the control group demonstrated lower gains, suggesting that traditional verification laboratories may be less effective in promoting conceptual change.

Despite these positive outcomes, several challenges associated with smartphone-based laboratories were identified. Some students reported initial difficulties in installing and using the experimental application. Others experienced minor technical issues related to sensor calibration or device compatibility. Although these challenges did not significantly hinder the overall learning experience, they highlight the importance of providing adequate technical guidance when implementing mobile-based laboratories.

The findings of this study align with previous research indicating that mobile technologies can enhance laboratory learning by supporting interactive experimentation and data visualization. However, the results also emphasize that technology alone does not guarantee improved learning outcomes. The effectiveness of smartphone laboratories depends largely on how they are integrated into instructional design and whether activities encourage conceptual reasoning and scientific inquiry.

Overall, this study suggests that smartphone-based laboratories represent a promising approach for improving conceptual understanding in introductory mechanics courses. By combining accessibility, real-time data visualization, and opportunities for active experimentation, mobile-based laboratories can complement traditional instructional methods and contribute to more effective physics education.

## V. Conclusion

This study investigated the effectiveness of smartphone-based laboratories in enhancing first-year university students' conceptual understanding of mechanics. The results indicate that students who participated in smartphone-based laboratory activities demonstrated significantly higher conceptual gains compared with those who engaged in traditional verification laboratories. Statistical analysis revealed that the instructional method had a strong effect on learning outcomes, with the experimental group achieving higher posttest scores and normalized gains on the Force Concept Inventory.

These findings highlight the pedagogical potential of smartphone laboratories as effective tools for supporting conceptual learning in physics education. The use of smartphone sensors and real-time data visualization allows students to directly observe physical phenomena and explore relationships between variables. Such interactive experiences appear to support deeper conceptual reasoning and help students overcome common misconceptions in mechanics.

Another important contribution of smartphone laboratories is their accessibility. Unlike traditional laboratory equipment, which often requires significant financial investment, smartphones are widely available and can serve as low-cost experimental tools. This accessibility makes smartphone-based laboratories particularly valuable for institutions with limited laboratory infrastructure. Research has shown that mobile sensor technologies can support hands-on experimentation and improve learning outcomes in physics courses by enabling authentic experimental experiences and real-time data analysis.

Despite these advantages, several challenges should be addressed when implementing smartphone laboratories. Technical issues such as sensor calibration, application compatibility, and variations in smartphone hardware may affect experimental accuracy. Therefore, instructors should provide clear instructions and technical guidance to ensure that students can effectively use mobile applications during laboratory activities.

Future research should explore the long-term impact of smartphone-based laboratories on conceptual retention and scientific reasoning skills. In addition, further studies could investigate the integration of smartphone laboratories with inquiry-based learning approaches, virtual simulations, and artificial intelligence-supported analysis tools. Expanding smartphone laboratory research across diverse institutional contexts will also help determine the generalizability of the findings.

Overall, smartphone-based laboratories represent a promising pedagogical innovation that can enhance conceptual learning, increase student engagement, and expand access to experimental physics education.

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