ASSESSING LEARNING OUTCOMES FROM SMARTPHONE-BASED EXPERIMENTS: A STATISTICAL APROACH

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Annotation. *Smartphone-based mobile laboratories having built-in sensors and computational capabilities is supporting technology enhanced physics education for distant learners. These laboratories enable the learners to perform limited experiments with most comfort in topics related to mechanics, optics waves and electromagnetism. The present research focus on investigation of smartphone-based physics laboratories implemented in Undergraduate physics course at the department of Physics, Navoi State University, Uzbekistan. A quasi-experimental methodology was adopted to examine the science process skills, conceptual understanding and learning engagement using descriptive statistics and paired t-test. Qualitative feedback from student reflections was thematically analyzed through a software HEMIS that is commonly used in almost all Higher Educational Instituitions of Uzbekistan. The findings suggest that smartphone-based laboratories represent a scalable, cost-effective and an supportive alternative for distance learners.*

Key words: *physics education, smartphone-based laboratories, technology-enhanced learning, mobile learning, experimental pedagogy, distance education.*

INTRODUCTION

Laboratory instruction is fundamental for conceptual understanding and reasoning of science subjects. The traditional laboratories often require costly apparatus, physical space and limited access time (Grivokosto-poulou et al., 2020; Milner-Bolotin et al., 2021; Rodrigues & Carvalho, 2022) that can resist student's experimental opportunities as well as senior/older adult learners (Guat Im Bok 2021). In most of the underdeveloped and developing countries, young as well as senior/older adult learners are showing much interest towards their career and joining in distance education mode at various reputed universities. The major problem for these distant learners is the limited access time (Guat Im Bok 2021). In the case of teaching physics, the distribution of teaching theory as well as practical should be uniform. Both the theory and practical should be taught simultaneously which requires more access of time. The search for alternatives to overcome this difficulty has been in progress and succeeded through IT based laboratories such as

Virtual, Simulation, Augmented Reality and Virtual Reality, Video based etc., Recent studies reported the pros and cons of IT based laboratories over traditional hands-on laboratories (Faulconer, E. K., & Gruss, A. B. et al., 2018). Many case studies and statistical surveys reported the major advantages and excellent learning outcomes through blended learning approach that combines face-to-face teaching with online or digital learning activities in a planned and integrated way (Aigerim Shapiyeva et al., 2025) but this approach is not possible for distant learners due to limited access of time. Recent advances in mobile technology have positioned smartphones as viable tools for experimental physics instruction (Yiping Zhao, 2025, Endra Putra Raharja et al., 2024). Modern smartphones integrate sensors such as accelerometers, gyroscopes, magnetometers, microphones, and high-resolution cameras, enabling them to function as portable measurement devices (Romain Guidoux 2024). Smartphone-based laboratories thus provide a promising approach to technology-enhanced learning by combining accessibility, flexibility, and inquiry-based pedagogy. Previous studies have demonstrated the pedagogical value of smartphone-based experiments across multiple physics domains (Oprea and Cristina Miron, 2014) In addition, mobile laboratories have been shown to positively influence students' attitudes toward physics by emphasizing real-world relevance and hands-on exploration. However, challenges such as sensor variability across devices and the need for teacher professional development remain active areas of research. The present article investigates the effectiveness of Technology-Enhanced physics laboratories (Smartphone-based experiments) by adopting a quasi-experimental methodology using descriptive statistics and paired t – test.

METHODOLOGY

1. Research Design

A quasi-experimental pre-test and post-test design was employed to evaluate the effectiveness of smartphone-based physics laboratories. Two groups were compared:

- Experimental Group (EG): Smartphone-based laboratory instruction (N=20)
- Control Group (CG): Traditional laboratory instruction (N=20)

2. Participants

Participants included undergraduate physics students (N=20) enrolled in an introductory mechanics course at the department of Physics and Astronomy, Navoi State University, Navoi, Uzbekistan. The students of both the groups are selected not randomly but a careful observation of age, skills and practical knowledge were analyzed properly and maintained a careful discipline in making the two groups of students almost having equal performance and efficiency. Both groups were taught by the same instructor (expert in both traditional and IT based laboratory training) from the department of Physics and Astronomy, Navoi State University to minimize instructional variability.

3. Instructional Intervention

The EG conducted laboratory activities using smartphones and freely available applications (sensor-based data collection and video analysis). Activities included experiment on simple harmonic oscillations. The CG completed equivalent experiments using standard laboratory equipment.

DATA AND METHODOLOGY

1. Conceptual Understanding Test *(pre and post test):* To measure the improvement in students' conceptual understanding, pre-test and post-test were conducted. The scores were collected through HEMIS platform. The scores were analyzed and the mean gain and normalized gains were measured. The mean gain was calculated as the difference between the mean post-test score and the mean pre-test score. This measure represents the absolute improvement in students' performance following instruction.

$$\textbf{Mean gain} = X_{post} - X_{pre}$$

where X_{pre} and X_{post} are the mean scores of the pre-test and post-test, respectively.

The value of g is found to be 0.58. This value represents a medium gain indicating a moderate level of improvement, suggesting that learners have made noticeable progress but have not reached the upper limits of potential achievement. This level of gain reflects meaningful learning outcomes that go beyond minimal improvement but still leaving the process for further development.

Since mean gain does not account for differences in students' initial knowledge levels, the normalized gain was also computed. Normalized gain represents the proportion of the maximum possible improvement that was achieved as a result of smartphone-based instruction.

$$\langle g\rangle = \frac{Xpost - Xpre}{Xmax - Xpre}$$

where X_{max} is the maximum possible score on the test.

A medium normalized gain of 0.52 is measured indicating that the learners achieved approximately one-third to two-thirds of the available learning improvement.

Medium gain alongside medium normalized gain provides a balanced perspective on learning effectiveness. Together, these measures indicate that the intervention produced is consistent and meaningful learning improvements across participants, supporting its value while encouraging continued optimization.

2. Science Process Skills Rubric

Science Process Skills (SPS) Rubric that is commonly used in science education to assess students' practical and inquiry-based skills and is adapted for EG and CG groups. After completion of the experiments by both groups, the students SPS is measured through inquiry by a special committee of faculty. Five important SPS rubric (Observation, measuring numbers, formulating hypothesis, experimenting, interpreting data and outcomes) was analyzed and the performance level was estimated as level 3 (indicating clear demonstrations and correct understanding independently). Descriptive statistics were used to determine students' science process skills as demonstrated through smartphone-based laboratory performance. The science process skills instrument showed good internal consistency (Cronbach's $\alpha = 0.82$). The normalized gain analysis indicated a medium normalized gain ($g = 0.52$), reflecting moderate improvement in students' science process skills.

Further, paired-samples t-test was conducted to compare students' science process skills before and after the smartphone-based laboratory. There was a significant increase in scores from pre-test ($M = 46.3$, $SD = 7.5$) to post-test ($M = 73.8$, $SD = 6.2$), $t(19) = 34.84$, $p < 0.001$. The normalized gain was $g = 0.52$, indicating a medium level of learning improvement.

DISCUSSION

The findings support previous research indicating that smartphone-based laboratories can effectively act as an alternative to traditional physics laboratory. The portability and familiarity of smartphones enable flexible experimentation and repeated practice, which contribute to deeper conceptual understanding. Additionally, smartphone-based labs promote learner-centered and inquiry-driven instruction, aligning with contemporary pedagogical frameworks.

However, careful instructional planning and teacher training are essential to address challenges related to device variability and data accuracy.

CONCLUSION

This study demonstrates that smartphone-based laboratories represent a viable and effective model for technology-enhanced physics education. By reducing equipment costs and increasing accessibility, these laboratories offer scalable solutions for diverse educational contexts. Future work should explore integration with artificial intelligence-supported feedback and augmented reality environments to further enhance experimental learning. The authors focus on more statistical analysis evidencing the validity of IT based physics laboratory trainings over traditional hands-on training. Rigorous data and analysis of students of different practical skills, learning environment, age-groups and maturity levels need to be addressed.

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