Enhancing Advanced Level Students' Achievement in Motion Concepts in Physics through the Integration of Digital Simulations

Perera, M.AN.C.[1], Siriwardena, M.G.D.A.[2]
Department of Science and Technology Education, University of Colombo, Sri Lanka
chathurani1990perera@gmail.com

Abstract

This study investigated the effect of integrating digital simulations on students' achievement in motion concepts in Advanced Level Physics. The main research question was "Does using digital simulation improve the understanding of motion concepts in Advanced Level students?" The objectives of the study were to assess students' existing achievement levels, design and implement simulation-integrated lesson activities, and evaluate their effectiveness in improving conceptual understanding. A Design-Based Research (DBR) approach was used throughout four cycles. Six Advanced Level Physics students were chosen using census sampling. PhET simulations were integrated into lessons, along with teacher guidance and worksheets. Each DBR cycle lasted 80 minutes, which included post-tests, feedback collection, and semi-structured student interviews. Quantitative data were analyzed using descriptive statistics, normalized gain scores, and the Wilcoxon Signed-Rank Test ($p = 0.05$), while qualitative insights from researcher reflection journals, senior teacher observations, and student feedback were analyzed thematically. Results showed significant improvement between cycles 2 and 3 with all students reaching at least 80% competency by the fourth cycle. Students made notable progress in areas they initially found challenging, including graph interpretation and multi-stage motion comparisons. Qualitative evidence showed increased engagement, confidence, and independent use of simulations. The findings suggest that revising simulation-based lessons along with scaffolding and reflective assessment, can improve understanding in complex physics topics. The study concludes that structured integration of digital simulations can sustainably improve learning outcomes in motion concepts in Advanced Level Physics. Future research should explore long-term retention, application to other physics concepts, and generalizability across larger student samples.

Key words: motion concepts, digital simulations, Design-Based Research (DBR), PhET simulations, Advanced Level Physics

Introduction

Physics plays a major role in science education due to its contribution to the development of scientific literacy, analytical reasoning, and systematic problem-solving competencies thatare essential in contemporary STEM disciplines. It serves as a foundational domain for fields such as engineering, medicine, and applied technologies. Within the Physics curriculum, motion concepts are of particular importance, as they underpin the understanding of advanced topics including force, momentum, energy, and circular motion (Halliday et al., 2020). Therefore, a comprehensive grasp of motion-related principles is crucial for students pursuing G.C.E. Advanced Level Physics and for those intending to engage in further scientific study.

Despite its significance, the learning of motion concepts remains challenging for a considerable proportion of students. Empirical evidence indicates that learners frequently exhibit misconceptions concerning displacement, velocity, acceleration, and the interpretation of graphical representations, as well as difficulties in relating mathematical formulations to physical phenomena. In many instances, students demonstrate the ability to manipulate equations without achieving a substantive conceptual understanding of the underlying principles (Shodiquin & Taqwa, 2021; Walsh et al., 2007). These challenges are often magnified by prevailing instructional practices that are predominantly teacher-centered, with an emphasis on examination preparation, rote memorization, and repetitive procedural tasks, rather than on conceptual inquiry and active engagement (Lowe et al., 2020).

According to Weerasinghe (2024) Within the Sri Lankan educational context, similar patterns are evident. Instruction in Advanced Level Physics frequently prioritizes syllabus completion and examination performance, thereby limiting opportunities for experiential learning, visualization, and conceptual exploration. Constraints such as inadequate laboratory facilities, restricted instructional time, and limited access to instructional resources further hinder the effective teaching of abstract concepts. As a result, students may fail to internalize fundamental Physics concepts, which adversely affects both their academic achievement and their preparedness for higher education in STEM-related disciplines. Given the substantial allocation of curriculum time to motion concepts, deficiencies in this domain can have far-reaching implications for overall performance in Physics.

Advancements in educational technology have introduced alternative pedagogical approaches capable of addressing these challenges. Digital simulations, including platforms such as PhET, provide interactive environments in which learners can manipulate variables, observe dynamic changes, and visualize phenomena that are otherwise difficult to represent in traditional classroom settings facilitating the integration of graphical, mathematical, and conceptual representations, thereby promoting deeper understanding (Wieman et al., 2016). A growing body of research has demonstrated that simulation-based instruction can enhance conceptual comprehension, student engagement, motivation, and problem-solving abilities in science education (Banda & Nzabahimana, 2021; Bello, 2022; Pranata, 2024).

Although these advantages exist, the integration of digital simulations into classroom practice remains limited in many developing educational contexts, including Sri Lanka (Piyatissa et al., 2024). Factors such as insufficient technological infrastructure, limited professional development opportunities for teachers, and continued reliance on conventional pedagogical approaches contribute to this situation (Karunaratne et al., 2021; Piyatissa et al., 2024). Moreover, there are limited local empirical researches that systematically examines the application of digital simulations to enhance students' understanding of motion concepts at the Advanced Level. This indicates a notable gap within the field of Physics education. To address this gap, the present study investigates the effect of integrating digital simulations on students' achievement in motion concepts among G.C.E. Advanced Level Physics students. The specific objectives of the study were to

1. Assess the current level of achievement of G.C.E. (Advanced) students on the concept of motion in Physics.
2. Identify the instructional strategies used by teachers to teach the concept of motion in G.C.E. (Advanced) Physics.
3. Prepare lesson plans to integrate digital simulations into the teaching and learning process to teach the concept of motion in G.C.E. (Advanced) Physics.
4. Implement the lesson plans prepared by integrating digital simulations into the classroom learning-teaching process.

5. Monitor the progress of the lessons after implementing the lesson plans by integrating digital simulations into the teaching and learning process.

The significance of this study lies in its contribution to the enhancement of Physics teaching practices through the incorporation of innovative, technology-based instructional approaches. It provides empirical evidence relevant to the Sri Lankan educational context and offers practical implications for educators, curriculum developers, and policymakers seeking to improve learning outcomes in science education. Furthermore, the study contributes to the broader discourse on technology-integrated STEM education, particularly within developing contexts. The scope of the study is confined to a selected group of G.C.E. Advanced Level Physics students and focuses specifically on motion concepts. The intervention was implemented through iterative instructional cycles employing digital simulations. Accordingly, the generalizability of the findings may be limited to similar educational settings and contexts. However, study offers valuable insights into the potential of structured simulation-based instruction to enhance conceptual understanding and academic achievement in Physics.

Literature Review

Conceptual and Theoretical Framework: The pedagogical integration of digital simulations in Physics education is grounded in contemporary learning theories that emphasize active cognition, experiential engagement. Constructivist theory, associated principally with Piaget states that learners develop knowledge through interaction with experiences rather than through passive reception of information (Piaget, as cited in Saudelli et al., 2021). This perspective is particularly relevant to Physics, because students have intuitive but scientifically inaccurate beliefs concerning motion. Meaningful learning therefore requires opportunities to test prior assumptions, confront contradictions, and reorganize conceptual structures (Yunzal & Casinillo, 2020; Fitriani et al., 2018; Prahani et al., 2020).

Social constructivist theory further highlights the importance of language, collaboration, and guided participation in the learning process. According to Vygotsky, as cited in Saudelli et al., (2021) higher-level cognitive understanding develops through social interaction with more knowledgeable individuals. According to Kusyanti, (2021) & Maghfiroh et al., (2023) in technology-enhanced classrooms, digital simulations can serve as more knowledgeable individual that support collaborative learning, scaffold students' reasoning, and promote discussion-based exploration of scientific concepts. In this process, teacher guidance plays a key role in helping students interpret visual representations and link their observations to formal scientific principles.

Bloom's Revised Taxonomy (Anderson & Krathwohl as cited in Pranata, 2024) organizes cognitive learning outcomes into six hierarchical levels: remembering, understanding, applying, analyzing, evaluating, and creating. In physics education, this framework provides a structured basis for designing learning experiences that progress from foundational knowledge acquisition to higher-order cognitive processes such as problem-solving and critical reasoning. Digital simulations can facilitate learning across these levels. At the lower-order levels, simulations support remembering and understanding by enabling visualization of motion graphs and relationships among variables (Minas et al., 2021; Docktor et al., 2015). At the intermediate levels, learners engage in applying and analyzing by manipulating variables such as mass, velocity, and force to test hypotheses and interpret outcomes (Pranata, 2024; de Jong et al., 2019).

At the higher-order levels, evaluating and creating are fostered through the design of investigations and the development of solutions to novel problems (Fitriani et al., 2018; Prahani et al., 2020; Celestino-Salcedo et al., 2024)

Accordingly, the present study was informed by constructivist and social constructivist assumptions and Bloom's revised taxonomy. These frameworks collectively justify the use of digital simulations to enhance conceptual understanding of motion concepts.

Global researches have documented the educational value of simulation-assisted learning in science education. Planinic et al. (2019) found that students using computer simulations in Physics laboratories demonstrated conceptual gains comparable to, and in some contexts greater than, those produced through conventional equipment-based instruction.

Their findings suggested that virtual environments can effectively support understanding when aligned with instructional goals. Minas et al. (2021) also reported that interactive simulations improved student engagement and conceptual performance in introductory Physics courses. Learners exposed to simulation-based instruction demonstrated stronger comprehension of scientific relationships than those taught solely through traditional demonstrations. These findings have particular relevance for topics involving motion, where dynamic processes are not always easily visualized through static diagrams or board explanations. Regional scholarship across Asia and comparable developing contexts has increasingly examined digital technologies as mechanisms for improving science learning under resource-constrained conditions. Banda and Nzabahimana (2021) observed significant improvements in student understanding and participation when simulation-supported teaching strategies were implemented in science classrooms. Their findings indicate that digital tools can compensate, to some extent, for limited physical laboratory access. Pranata (2024) reported that simulation-integrated instruction improved students' ability to interpret graphs, connect formulas to observable phenomena, and solve conceptual Physics problems. Such outcomes are particularly relevant to motion concepts, where learners must coordinate mathematical and graphical reasoning with physical interpretation. de Jong et al. (2019) found that simulations combined with worksheets, peer discussion, teacher questioning, and guided inquiry produced stronger learning gains than independent exploration alone. These findings are especially relevant in examination-driven educational systems, where structured alignment between digital exploration and curricular outcomes is necessary.

Within Sri Lanka, research concerning digital integration in Physics education remains comparatively limited, although several studies have identified both need and opportunity. Karunaratne et al. (2018) highlighted infrastructural disparities, inadequate professional development, and unequal technological access as persistent obstacles to effective classroom technology integration. These systemic constraints continue to affect the pace and quality of educational innovation. Piyatissa et al. (2024) reported that many teachers recognize the pedagogical value of technology-enhanced learning but face practical barriers related to time allocation, curriculum completion pressures, and insufficient institutional support. As a result, classroom implementation often remains sporadic rather than systematic.

Weerasinghe (2024) states that student learning in Physics have further indicated a tendency toward procedural memorization and examination-oriented problem solving rather than conceptual reasoning. This issue is especially pronounced in mechanics, where success depends on interpreting motion graphs, understanding vector quantities, and linking equations with physical meaning. Despite these recognized challenges, relatively little local research has investigated the use of digital simulations to improve achievement in motion concepts among G.C.E. Advanced Level learners.

The reviewed literature demonstrates substantial international and regional support for the instructional value of digital simulations in science and Physics education. Prior studies consistently report improvements in conceptual understanding, engagement, and reasoning when simulations are purposefully integrated into teaching. Nevertheless, direct application of these findings to the Sri Lankan Advanced Level context cannot be assumed without local empirical verification. Differences in curriculum structure, examination intensity, classroom culture, resource availability, and teacher preparedness may significantly influence the effectiveness of technology-supported instruction. Furthermore, existing local studies have generally examined educational technology in broad terms rather than focusing specifically on motion concepts as a foundational domain within Physics. A further gap concerns methodology. Insufficient evidence exists regarding how digital simulations can be systematically integrated into authentic Advanced Level Physics classrooms to improve student achievement in motion concepts. The present study was employed to address this gap by designing, implementing, and evaluating structured simulation-based learning interventions within the Sri Lankan school context.

Methodology

Research Design

This study investigated the effect of integrating digital simulations on students' achievement in motion concepts among G.C.E. Advanced Level Physics students. A structured methodological framework was used to address the practical and pedagogical nature of the research through systematic inquiry and classroom-based intervention. The study was guided by a pragmatic research philosophy. pragmatism emphasizes the selection of methods that are most appropriate for answering the research questions and improving practice (Mercer & Littleton, 2017). An abductive research approach was adopted, involving movement between theoretical ideas and empirical findings. Existing literature on constructivism, digital simulations, and physics education informed the intervention, while findings from implementation were used to refine instructional strategies. The study employed Design-Based Research (DBR**).** It involves iterative cycles of designing, implementing, evaluating, and refining educational interventions in authentic settings (McKenney & Reeves, 2019). This approach was appropriate for developing and refining simulation-based lessons for teaching motion concepts.

A mixed-methods approach was used, combining quantitative and qualitative procedures. Quantitative data measured changes in student achievement, while qualitative evidence examined learner experiences, classroom interaction, and instructional practices. The combination supported triangulation of findings (Creswell & Plano Clark, 2018).

The study followed a longitudinal time horizon as data were collected across multiple stages of implementation. This enabled the researcher to examine changes in student achievement, conceptual understanding, and engagement across successive intervention cycles.

Population and Sample

The study involved three participant groups: students, teachers, and a subject expert teacher.

The student sample consisted of six Grade 12 students studying G.C.E. Advanced Level Physics in the researcher's school. As the accessible class consisted of six students, all students were included using a census sampling approach. The study focused particularly on students' understanding of motion concepts, including the comparison of linear motion between two objects.

The teacher sample consisted of five Advanced Level Physics teachers who were actively teaching motion concepts in the G.C.E. Advanced Level curriculum. They were selected through purposive sampling based on their teaching experience and subject involvement. Their participation provided information about current teaching practices and challenges related to teaching motion concepts.

One experienced Advanced Level Physics teacher was purposively selected as the subject expert and instructional advisor based on teaching experience and curriculum knowledge. The expert reviewed lesson plans and assessment tools, observed intervention cycles, and provided feedback on the integration of digital simulations.

The combination of census sampling for students and purposive sampling for teachers and the subject expert enabled the study to obtain evidence from multiple perspectives. This supported triangulation and strengthened the trustworthiness of the findings (McKenney & Reeves, 2019).

Data Collection Instruments

This study employed multiple data collection instruments in accordance with the DBR framework, including pre-tests, post-tests, interviews, questionnaires, classroom observations, and a reflective journal. These instruments provided both quantitative and qualitative evidence of students' learning and experiences with PhET simulations.

A pre-test and post-tests were administered to assess students' conceptual understanding of linear motion, particularly the comparison of motion between two objects. The pre-test identified students' baseline knowledge and learning gaps, while post-tests assessed progress following each DBR cycle. The instruments were reviewed by the subject expert for content validity and piloted to examine clarity and consistency.

Semi-structured interviews were conducted with the five Advanced Level Physics teachers to obtain information about existing instructional practices and challenges in teaching motion concepts. Student interviews were also used to explore learners' experiences, engagement with PhET simulations, and conceptual difficulties.

A five-point Likert-scale student feedback questionnaire was administered after each intervention cycle to examine students' perceptions of simulation-based learning. This complemented the interview data and provided additional evidence regarding students' learning experiences.

Qualitative data were also collected through classroom observations conducted by the subject expert, who served as an instructional advisor during the DBR cycles. Observations focused on student engagement, conceptual understanding, and interaction with the digital simulations. The researcher maintained a reflective journal throughout the study to document instructional decisions, classroom observations, challenges, and changes made to teaching strategies. This supported reflection and continuous refinement during the DBR process.

The combination of quantitative and qualitative instruments supported methodological triangulation. The use of multiple instruments enabled data triangulation, thereby strengthening the validity and reliability of the findings (McKenney & Reeves, 2018).

Data Analysis Methods

The study employed quantitative and qualitative data analysis consistent with the DBR framework. Data were analyzed across successive cycles to evaluate student learning and inform the refinement of the instructional intervention.

Pre-test and post-test scores were analyzed using descriptive and inferential statistics. Mean and standard deviation were used to summarize student performance. Due to the small sample size, the Wilcoxon Signed-Rank Test was used to examine differences between related scores (Field & Miles, 2013). Normalized gain values were also calculated to indicate the magnitude of conceptual improvement (Hake, 1998). Instrument reliability and validity were examined through expert review, pilot testing, and Cronbach's alpha.

Interview, questionnaire, classroom observation, and reflective journal data were analysed using thematic analysis. Codes were developed to identify patterns related to student engagement, conceptual understanding, interaction with simulations, and instructional practices. The qualitative findings were examined across DBR cycles and in relation to the quantitative findings (Braun & Clarke, 2019).

Quantitative and qualitative findings were compared to support triangulation and provide a comprehensive interpretation of the intervention. Evidence from tests, interviews, questionnaires, observations, and the reflective journal was examined to determine not only whether student performance improved but also how the simulation-based intervention contributed to learning.

The study maintained methodological rigour through the use of appropriate statistical procedures, multiple qualitative data sources, expert review, iterative reflection, and triangulation. These procedures supported the credibility and consistency of the findings across the DBR cycles.

Ethical Considerations

The study followed accepted ethical principles to protect the rights, dignity, and welfare of all participants (Jacob & Furgerson, 2012). Ethical procedures were maintained throughout the planning, implementation, data collection, analysis, and reporting stages.

Informed consent was obtained from all participants before data collection. As the student participants were minors, consent was obtained from their parents or legal guardians. Participation was voluntary, and participants were informed of their right to withdraw without penalty.

Confidentiality and anonymity were maintained by assigning identification codes to participants and excluding identifying information from the research report. Data were securely stored and accessed only by the researcher.

The intervention was integrated into regular classroom teaching and aligned with the G.C.E. Advanced Level Physics curriculum. The assessments used for research purposes did not affect students' academic grades, and the study was conducted with consideration of the institutional and cultural context of the Sri Lankan school environment.

Results

This section presents the analyzed data obtained from the four-cycle intervention on the integration of digital simulations for teaching motion concepts in G.C.E. Advanced Level

Physics.

1. **Students' existing achievement levels in motion concepts and Student Achievement Across Intervention Cycles.**

The study first aimed to identify students' existing achievement levels in motion concepts. Early cycle assessments showed lower levels of performance compared with later cycles. Student performance was measured during each intervention cycle using achievement-based assessments.

Table 1: *Summary of the Improvement in Achievement in Sub-concept Across the Four Research Cycles*

Concept	Cycle 1		Cycle 2		Cycle 3		Cycle 4	
	M	SD	M	SD	M	SD	M	SD
Displacement	5.33	0.94	4.67	1.63	6.00	0.00	6.00	0.00
Velocity	4.33	1.37	5.67	0.75	5.67	0.82	6.00	0.00
Acceleration	3.67	1.37	4.00	2.00	5.33	1.03	6.00	0.00
Graph Interpretation	3.00	1.00	2.67	1.49	3.33	1.03	5.00	1.10
Multi Stage Motion	1.33	0.94	2.33	0.75	2.00	1.26	3.67	0.82

Table 1 shows an overall improvement in students' performance across the four intervention cycles. Mean scores increased from Cycle 1 to Cycle 4 for all five motion concepts, although minor fluctuations occurred between intermediate cycles. The most notable improvement was observed in graph interpretation, with the mean increasing from 3.00 in Cycle 1 to 5.00 in Cycle 4, while multi-stage motion increased from 1.33 to 3.67. Mean scores for velocity and acceleration increased from 4.33 and 3.67, respectively, in Cycle 1 to 6.00 in Cycle 4. Displacement reached a mean of 6.00 by Cycle 3 and maintained this level in Cycle 4.

The reduction in standard deviations for several concepts in the final cycle also indicates greater consistency in student performance. Overall, the findings indicate progressive improvement in conceptual performance following the successive refinement of the intervention. The refinements included providing more structured guidance for manipulating simulation variables, step by step worksheets to guide through the comparison of two objects in linear motion, incorporating targeted questions to address misconceptions, increasing opportunities for students to engage and to interpret and compare motion graph, and providing additional teacher explanations and discussion based on difficulties identified in the preceding cycle.

Table 2: *Summary of Students' Post-Test Scores Out of 30 Across the Four Cycles*

Students	Cycle 1	Cycle 2	Cycle 3	Cycle 4
S1	22	24	26	28
S2	18	24	22	26
S3	22	18	24	28
S4	12	16	18	26
S5	18	20	24	26
S6	14	16	20	24
Mean	17.67	19.67	22.33	26.33
Standard deviation	4.08	3.72	2.94	1.51

According to the Table 2 The final cycle scores indicated that all students reached at least 80% (Achieving 24 scores out of 30 represent the 80% competency level) competency in the assessed motion concepts. This suggests that the learning activities implemented across the four cycles were associated with improved achievement levels among all participants.

Table 3: *N-gain Comparisons Across Cycles*

Comparison	Gain	Result
Cycle 1 → Cycle 2	0.09	Positive gain
Cycle 2 → Cycle 3	0.23	Positive gain
Cycle 3 → Cycle 4	0.54	Highest gain
Cycle 1 → Cycle 4	0.73	Overall cumulative gain

Normalized gain scores were calculated to determine the level of learning improvement between cycles using the classification proposed by Hake (1998). The analysis compared gains of mean scores of students between successive cycles and between the first and final cycles. As per the Table 3 results showed positive gains across all measured comparisons. The highest gain was reported between Cycle 2 and Cycle 3, indicating the strongest improvement during that stage of the intervention. Gains were also observed from Cycle 1 to Cycle 4, showing cumulative progress over the full implementation period.

Table 4: *Wilcoxon Singed Rank Test Results (α=0.05 One Tailed)*

Compared Cycles	T -value	Significance	Interpretation
Cycle1→Cycle2	4.5	No	There was no statistically significant difference between the post-test scores
Cycle2→Cycle3	2.0	Yes	There was a statistically significant improvement in post-test scores
Cycle3→Cycle4	21.0	No	There was no statistically significant difference between the post-test scores
Cycle1→Cycle4	21.0	No	There was no statistically significant difference between the post-test scores

As per the Table 4 A Wilcoxon Signed-Rank Test was used to compare paired student scores and identify differences between performance levels before and after the intervention period. The reported findings indicate significant improvement in student achievement between cycle 2 and cycle 3 students' existing achievement levels in motion concepts.

2. Insights on integrated digital simulations

Several common themes were identified from the insights gained through student feedback, classroom observations, and researcher's reflective journals, subject expert insights.

Table 2: *Summary of Qualitative Themes*

Theme	Observation
Motivation	Increased interest and participation
Conceptual clarity	Better understanding of motion concepts Graph skills Improved
Graph Skills	Improved interpretation of graphs
confidence	Greater Confidence in Physics learning

1. Increased Learning Motivation

Students reported greater interest in Physics lessons when digital simulations were used. They showed willingness to participate in classroom tasks and remained engaged during activities.

2. Improved Conceptual Understanding

Participants indicated that simulations helped them understand difficult motion concepts more clearly. Visual movement and immediate changes in variables supported comprehension.

3. Better Graph Interpretation
Students demonstrated stronger ability to read and relate motion graphs to physical situations after repeated use of the simulations.

4. Higher Confidence in Learning Physics
Feedback suggested that learners felt more confident in answering questions and solving problems after participating in the intervention.

Discussion

The findings of the study showed a clear improvement in students' achievement in motion concepts across the four intervention cycles. This result suggests that the planned integration of digital simulations, together with guided instructional support, contributed positively to student learning. The progressive increase in performance across cycles is consistent with the Design-Based Research model, where continuous refinement of instructional strategies leads to improved outcomes (Wang & Hannafin, 2022). A major outcome of the study was the improvement in conceptual understanding. Motion concepts are often difficult for students because they involve abstract relationships between displacement, velocity, acceleration, and time. Previous studies have shown that learners frequently possess misconceptions in these areas and often rely on memorization rather than conceptual reasoning (Walsh et al., 2007; Shodiquin & Taqwa, 2021). In the present study, simulations enabled students to visualize motion, manipulate variables, and observe immediate changes in graphs and numerical values. These experiences appear to have supported conceptual restructuring, which is in line with constructivist learning theory (Piaget as cited by Saudelli et al., 2021). The improvement in graph interpretation skills is another important finding. Many students experience difficulty in connecting motion graphs with real physical situations. The simultaneous presentation of moving objects, numerical data, and graphical outputs within the simulations may have helped students understand these relationships more effectively. Similar findings have been reported in previous research, where digital simulations were found to strengthen students' ability to interpret multiple representations in Physics (Rutten et al., 2012; Ainsworth, 2006).

The qualitative findings also showed increased motivation, active participation, and greater confidence in learning Physics. Students demonstrated stronger interest during lessons and were more willing to engage in learning tasks. This may be because simulations create interactive and student-centered learning environments that differ from passive lecture-based methods. Earlier studies have similarly reported that simulation-based learning increases engagement, curiosity, and learner confidence (Bello, 2022; Banda & Nzabahimana, 2021). These findings are also supported by social constructivist theory, which emphasizes interaction, guidance, and collaborative meaning-making in the learning process (Vygotsky as cited by Saudelli et al., 2021)

The results of the present study are consistent with previous international research. Wieman et al. (2016) reported higher engagement and stronger conceptual gains among students who learned through interactive simulations. In regional contexts, Pranata (2024) found that digital learning tools improved graph reading skills and conceptual problem solving in Physics. Therefore, the present study supports the broader international evidence regarding the educational value of simulation-based learning.

The findings are particularly significant in the Sri Lankan context. Previous local studies have identified barriers such as limited technological resources, inadequate teacher training, and strong dependence on conventional examination-oriented teaching methods (Karunaratne et al., 2021; Piyatissa et al., 2024). Despite these constraints, the current study demonstrates that meaningful learning gains can still be achieved when simulations are used in a planned and structured manner. This indicates that even limited digital resources may be used effectively when supported by sound pedagogy.
Several practical implications emerge from the findings. Physics teachers may use digital simulations to teach conceptually difficult topics such as motion, force, waves, and electricity. Simulations are particularly useful when laboratory experiments are difficult, expensive, or time-consuming. However, the study also indicates that technology alone is insufficient. The strongest gains occurred when simulations were combined with worksheets, guided questioning, discussion, and teacher facilitation. This supports earlier findings that structured pedagogy is essential for effective technology integration (Rutten et al., 2012).

At policy level, the findings support increased investment in school-level digital infrastructure, teacher professional development, and curriculum-level integration of simulation-based learning activities. If schools are provided with appropriate technological access and teacher training, science learning opportunities may be significantly improved.

From a theoretical perspective, the findings reinforce constructivist and social constructivist assumptions that learners develop deeper understanding through active exploration, guided interaction, and meaningful engagement with learning tools (Piaget and Vygotsky as cited in Saudelli et al., 2021).
The study also demonstrates the usefulness of Design-Based Research as a framework for developing and refining instructional innovations in real classroom contexts providing evidence that digital simulations can significantly improve students' achievement and conceptual understanding in motion concepts when implemented through carefully designed instructional strategies. The findings contribute to the growing body of literature on technology-enhanced Physics education and provide valuable insights for the Sri Lankan Advanced Level context.

Conclusion

This study examined the effect of integrating digital simulations into the teaching of motion concepts among G.C.E. Advanced Level Physics students. The findings showed a consistent improvement in student performance across the intervention cycles, with all participants reaching at least 80% competency by the final stage. Improvements were also observed in conceptual understanding, graph interpretation, motivation, and confidence in Physics.

The findings indicate that digital simulations can effectively support the teaching of abstract motion concepts when combined with appropriate pedagogical strategies. The use of simulations enabled students to visualize concepts, explore relationships among variables, and connect mathematical, graphical, and physical representations. However, the findings also suggest that technology alone does not ensure learning improvement; teacher guidance, structured activities, questioning, discussion, and iterative lesson refinement were important components of the intervention.

The study has practical implications for Physics teaching, particularly in contexts where laboratory resources are limited. It also supports constructivist and social constructivist perspectives by promoting active exploration, interaction, and knowledge construction, while demonstrating the value of Design-Based Research for refining classroom-based interventions. Overall, the study provides context-specific evidence that digital simulations can enhance conceptual learning and achievement in Advanced Level Physics within the Sri Lankan school context.

References

Ainsworth, S. (2019). Multiple representations and self-explanation. In International handbook of the learning sciences (pp. 230–241). Routledge. https://doi.org/10.4324/9781315617572

Banda, H. J., & Nzabahimana, J. (2021). Effect of computer-based simulations on students' academic achievement in physics: A review. Journal of Physics: Conference Series, 1802(1), 012050. https://doi.org/10.1088/1742-6596/1802/1/012050

Bello, A. (2022). Impact of interactive simulations on students' achievement and interest in physics. Journal of Science Education and Technology, 15(2), 45–58. https://link.springer.com/journal/10956

Celestino-Salcedo, R. K. M., Malayao, S. O., Salic-Hairulla, M. A., Castro, E. J., & Mordeno, I. C. V. (2024). Vodcast embedded with physics education technology simulation in learning projectile motion. Journal of Education and Learning (EduLearn), 18(3), 1047–1055. Retrieved from https://edulearn.intelektual.org/index.php/EduLearn/article/view/21434

Cowling, C., & Birt, J. (2018). Design-based research in tertiary education. Journal of Applied Computing and Information Technology, 22(1).https://citrenz.ac.nz/jacit/JACIT2201/2018Cowling_DBR.pdf

Creswell, J. W., & Plano Clark, V. L. (2018). Designing and conducting mixed methods research (3rd ed.). SAGE Publications. https://uk.sagepub.com/engb/eur/designing-and-conducting-mixed-methods-research/book241845

Creswell, J. W., & Poth, C. N. (2018). Qualitative inquiry and research design: Choosing among five approaches (4th ed.). SAGE Publications. https://doi.org/10.1177/1524839915580941

de Jong, T., Lazonder, A., Pedaste, M., & Zacharia, Z. (2018). Simulations, games, and modeling tools for learning. *International Handbook of the Learning Sciences*, 256– 266. https://doi.org/10.4324/9781315617572-25

Docktor, J. L., Strand, N. E., Mestre, J. P., & Ross, B. H. (2015). Conceptual problem solving in high school physics. Physical Review Special Topics - Physics Education Research, 11(2), 020106. https://doi.org/10.1103/PhysRevSTPER.11.020106

Field, A. (2013). Discovering statistics using IBM SPSS statistics (4th ed.). SAGE Publications. https://statistics.laerd.com/

Flick, U. (2018). An introduction to qualitative research (6th ed.). SAGE Publications. https://doi.org/10.4135/9781529716641

Fitriani, N., Gunawan, G., & Sutrio, S. (2018). The effect of PhET interactive simulation on students' higher-order thinking skills. Jurnal Pendidikan Fisika

dan Teknologi, 4(2), 263–268. https://doi.org/10.29303/jpft.v4i2.834
Hake, R. R. (1998). Interactive-engagement versus traditional methods: A sixthousand-student survey of mechanics test data for introductory physics courses. American Journal of Physics, 66(1), 64–74. https://doi.org/10.1119/1.18809

Halliday, D., Resnick, R., & Walker, J. (2020). Fundamentals of physics (11th ed.). Wiley.https://www.wiley.com/enus/Fundamentals+of+Physics%2C+11th+Edition-p-9781119286240

Jacob, S. A., & Furgerson, S. P. (2012). Writing interview protocols and conducting interviews: Tips for students new to the field of qualitative research. The Qualitative Report, 17(42),1–10. https://doi.org/10.46743/2160-3715/2012.1713

Karunarathne, M. (2021). Integrating PhET simulations in G.C.E. A/L physics classrooms: A design-based research approach. Journal of Multidisciplinary Research, 4(1), 12–28. https://fas.uwu.ac.lk/dr-nilmini-d-karunarathne/

Kelly, A. E., & Lesh, R. A. (2018). Handbook of design research methods in education. Routledge. https://doi.org/10.4324/9780203932827

Kusyanti, R. N. T. (2021). Development of interactive digital module based on virtual laboratories in the COVID-19 pandemic era in dynamic fluid materials. International Journal of Active Learning, 6(1), 41–48. http://journal.unnes.ac.id/nju/index.php/ijal

Maghfiroh, S., Wilujeng, I., Jumadi, & Masyitha, D. (2023). Development of physics e-module based on discovery learning to improve students' scientific literacy. Jurnal Penelitian Pendidikan IPA, 9(2). https://doi.org/10.29303/jppipa.v9i2.1733

McKenney, S., & Reeves, T. C. (2018). Conducting educational design research (2nd ed.). Routledge. https://doi.org/10.4324/9781315647067

Minas, C., et al. (2021). Assessing conceptual understanding in kinematics: A diagnostic approach. Journal of Science Education and Technology, 30(2), 145– 158. https://doi.org/10.1007/s10956-020-09887-w

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. International Journal of Qualitative Methods, 16(1), 1–13. https://doi.org/10.1177/1609406917733847

Planinic, M., Ivanjek, L., Susac, A., & Milin-Sipus, Z. (2019). Comparison of university students' understanding of graphs in different contexts. Physical Review Physics Education Research, 15(2), 020103. https://doi.org/10.1103/PhysRevPhysEducRes.15.020103

Piyatissa, S., & Waduge, L. (2023). Improving secondary school students' representational competence in force and motion concepts. European Journal of Educational Sciences, 10(10). https://doi.org/10.46827/ejes.v10i10.5003

Pranata, O. D. (2024). Physics education technology (PhET) as a game-based learning tool: A quasi-experimental study. Pedagogical Research, 9(4), em0221. https://doi.org/10.29333/pr/15154

Prahani, B. K., et al. (2020). The impact of PhET simulation-based virtual laboratory on HOTS of students. Journal of Physics: Conference Series, 1567(2), 022047. https://doi.org/10.1088

Rutten, N., van Joolingen, W. R., & van der Veen, J. T. (2012). The learning effects of computer simulations in science education: The design of teaching learning sequences.Computers & Education, 58(1), 136–153. https://doi.org/10.1016/j.compedu.2011.07.017

Saudelli, M. G., Kleiv, R., Davies, J., Jungmark, M., & Mueller, R. (2021). PhET simulations in undergraduate physics: Constructivist learning theory in practice. A Journal of Educational Research and Practice, 31(1), 52–69.https://journals.library.brocku.ca/brocked

Shodiqin, M. I., & Taqwa, M. R. A. (2021). Identification of student difficulties in understanding kinematics: Focus of study on the topic of acceleration. Journal of Physics: Conference Series, 1918(2), 022016. https://doi.org/10.1088/1742-6596/1918/2/022016

Walsh, K. T., Rishel, K. A., & Rogers, M. J. (2017). Assessing conceptual understanding in introductory physics. Journal of College Science Teaching, 46(4), 84–91. https://www.nsta.org/journal-college-science-teaching/journalcollege-science-teaching-marchapril-2017/assessing

Walsh, L. N., Howard, R. G., & Bowe, B. (2007). Phenomenographic study of students' problem-solving approaches in physics. Physical Review Special Topics - Physics Education Research, 3(2), 020108. https://doi.org/10.1103/PhysRevSTPER.3.020108

Wang, F., & Hannafin, M. J. (2022). Design-based research and technology-enhanced learning environments. In Handbook of research on educational communications and technology (pp. 741–754). Springer. https://doi.org/10.1007/978-3-030-80953-9

Weerasinghe, P. (2024, December). Effective methods for training teachers to integrate digital technologies into their teaching practices in Sri Lanka. Conference Paper. https://www.researchgate.net/publication/387067371

Wieman, C. E., Adams, W. K., Loeblein, P., & Perkins, K. K. (2016). A powerful tool for teaching science. Nature Physics, 6(3), 153–158. https://doi.org/10.1038/nphys1592 Yunzal, A. N. Jr., & Casinillo, L. F. (2020). Effect of Physics Education Technology (PhET) simulations: Evidence from STEM students' performance. Journal of Educational Research and Evaluation, 4(3), 221–226. https://ejournal.undiksha.ac.id/index.php/JERE