

Enhancing Conceptual Understanding of Moment of Forces through Video Simulations and Laboratory Experiments: A Study in a Ghanaian Senior High School

Maxwell Obeng¹, Victor Antwi^{1*}, Quashigah Johnray Ziadzi², Joash Kwasi Ataakorerkpa^{1*}, Esther Dzigbogi^{3*}, Emmanuel Adokoh⁴

¹Department of Physics Education, University of Education, Winneba, Ghana

²School of Mechanical and Power Engineering, China Three Gorges University, Yichang, China

³College of Hydraulic and Environmental Engineering, China Three Gorges University, Yichang, China

⁴Department of Mathematics Education, University of Education, Winneba, Ghana

Email: *vantwi@uew.edu.gh, *Joashkwasiataa@gmail.com, *dzigbodiether@gmail.com

How to cite this paper: Obeng, M., Antwi, V., Ziadzi, Q.J., Ataakorerkpa, J.K., Dzigbogi, E. and Adokoh, E. (2025) Enhancing Conceptual Understanding of Moment of Forces through Video Simulations and Laboratory Experiments: A Study in a Ghanaian Senior High School. *Open Journal of Applied Sciences*, 15, 2576-2588.

<https://doi.org/10.4236/ojapps.2025.159172>

Received: August 7, 2025

Accepted: September 7, 2025

Published: September 10, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

This mixed-methods study, conducted at Mankessim Senior High School in Ghana, evaluates the effectiveness of integrating video simulations and laboratory experiments in teaching Moment of Forces (torque) to secondary science students. Through resource-strained settings, the study seeks to fill essential gaps in physics education by combining quantitative pre/post-tests ($n = 25$) with classroom observations and interviews with students. Results showed mean scores of 4.0 ($SD = 1.98$) and 11.60 ($SD = 1.89$) which indicate a 190% increase along with a significant gain and large effect size of 3.93 (Cohen's d). Qualitative data revealed enhanced conceptual clarity, particularly in spatial understanding of torque principles. Key improvements included identifying lines of action (92% accuracy, vs. 28% pre-intervention), applying the principle of moments (88% vs. 20%), and solving torque equations (84% vs. 16%). The study underscores how multimodal, active learning strategies can overcome abstract conceptual barriers in physics education, offering a replicable model for similar educational contexts in developing regions. Findings advocate for policy reforms to support technology-enhanced, experiential learning in Ghanaian STEM classrooms.

Keywords

Torque Education, Physics Simulations, Hands-On Learning, STEM Pedagogy, Conceptual Understanding, Ghanaian Science Education, Resource-Limited Settings

1. Introduction

Educational science is crucial in developing students' analytical abilities along with practical skills in technology and societal development. Physics is one of the foundational disciplines that offers remarkable understanding of natural phenomena. Moment of Forces (torque), for instance, is an important concept that, although difficult, explains the rotational effect of a force on an object [1]. While torque is complex and often difficult for students due to its abstract nature, it is foundational in many disciplines like engineering, biomechanics, and mechanical systems [2] [3]. This problem lies in the teaching strategies used, which tend to be traditional and lecture-based [4]. In Mankessim Senior High School (SHS) and other Ghanaian schools, this problem is made worse due to the limited teaching resources, large class sizes, and lack of science teaching specialists.

The persistent difficulties students encounter with grasping torque, alongside interest in STEM disciplines, indicate a clear gap in new strategies that must be addressed. Studies show that educational videos and laboratory simulations are effective tools in teaching physics, because they offer active and constructive learning experiences [5]-[7]. Video simulations allow students to manipulate dynamic processes and concepts and form a visualization of previously abstract ideas [8] [9]. Moreover, hands-on experiments allow students to apply theoretical concepts [10] [11]. The implementation of such techniques is, however, uncommon in most schools in Ghana because of infrastructural and logistical difficulties.

This study seeks to address the effectiveness of video simulations and laboratory experiments in teaching the Moment of Forces concept at Mankessim SHS, as well as analyzing the students' perceptions of the teaching methods. The results would be important to educators in seeking ways to implement active learning in their classes, especially in poorly resourced environments. In addition, the study seeks to enhance the efforts to improve the teaching of science in the country by illustrating the technology-enhanced and experiential learning methodologies which aim at bridging the theory-practice divide. By informing the curriculum, teacher training, and education policy, this research can inspire students to engage more with STEM subjects and respond to the growing human capital demand in the science and technology fields.

To achieve these objectives, a combination of qualitative and quantitative research methods was applied with 25 science students from Mankessim SHS. The intervention combined structured video simulations alongside guided laboratory practice on the Moment of Forces, from which data was gathered via pre- and post-tests, student surveys, and observational studies. Using this approach has enabled the obtaining of accurate and well-supported conclusions which are relevant in advancing physics education.

2. Research Methodology

A comprehensive methodological framework guiding the investigation into the effectiveness of video simulations and laboratory experiments for teaching mo-

ment of forces. The study employed a mixed-methods action research design, combining quantitative assessment tools with qualitative classroom observations to provide a holistic evaluation of the instructional intervention [12]. This approach was particularly suitable as it allowed for iterative refinement of teaching practices while maintaining scientific rigor in data collection [13]. From the population of fifty (50) Science 2B students at Mankessim Senior High School, a final sample of twenty-five (25) participants was selected through convenience sampling [14]. This sample size was determined based on three key considerations: First, only students who 1) had completed the prerequisite physics coursework, 2) were present for the entire 3-week intervention period, and 3) provided parental consent met participation criteria ($n = 32$). For purposes of efficient group arrangement and effective statistical analysis, 25 students meeting the set criteria were chosen, surpassing the baseline of 20 required for paired t-tests in the educational interventions [15]. The chosen sample constituted 50% of the target population, which was sufficient to ensure representativity in academic achievement in terms of prior physics grades and gender: 68% male and 32% female. The sample size was sufficient to identify important educational impacts and was manageable given the focused nature of the intervention.

2.1. Data Collection and Intervention Process

The data collection system for the study utilized a triangulated model with three instruments: parallel-form pre and post-tests, student perception surveys, and systematic classroom evaluations [16]. All assessment instruments underwent a thorough validation process which included a content evaluation by the head of the physics department to verify the correctness, alignment with curriculum expectations, and associated mental workload [17]. According to the reliability analysis, the assessment tools yielded the following Cronbach's alpha coefficients: 0.56 for the pre-test, 0.67 for the post-test, and 0.79 for the questionnaire as shown in **Table 1**. Although the questionnaire's internal consistency was strong, the pre-test's moderate reliability ($\alpha = 0.56$), suggests a normal distribution of students' varied levels of understanding of the torque concept [3]. There were three ways that validity of the instruments was achieved.

Table 1. Reliability analysis of assessment instruments.

Instrument	Cronbach's α	Validation Method
Pre-Test	0.56	Expert review + Pilot test
Post-Test	0.67	Parallel forms + Expert review
Questionnaire	0.79	Pilot test + Peer review

Despite this limitation: 1) expert validation by the school's physics department head, 2) pilot testing with think-aloud protocols to confirm item clarity, and 3) use of parallel test forms to minimize measurement error. The enhancement in post test reliability ($\alpha = 0.67$) suggests that the intervention was effective in not only responding to the learning enhancement but also in increasing the con-

sistency of how the responses were given. The multi stage intervention was meticulously structured to facilitate progressive conceptual understanding starting from basic concepts of torque in Activity 1, moving to principles of moment in Activity 2, and ending with applications of equilibrium in Activity 3. Video simulations were incorporated in all phases to assist with the visualization of abstract concepts and were followed with hands-on experiments to reinforce the theoretical principles learned. As for the analysis of quantitative data, observations were drawn in the form of descriptive statistics (frequencies, percentages, means) to portray baseline performance and learning gains, which was then enriched with the paired t test to affirm the level of statistical significance of the improvements. Each activity was designed to scaffold understanding, as detailed in **Table 2**. Simulations preceded labs to leverage [18] multimedia principles, ensuring students visualized concepts before physical experimentation. Qualitative data from observations provided context about the implementation issues and student engagement issues, which, together with the qualitative data, provided context and deepened the rigor, were transformed into graphs to present the results for educational practitioners visually. This comprehensive analytical approach ensured both rigorous assessment of outcomes and practical insights for classroom application, which can be found in **Figure 1**.

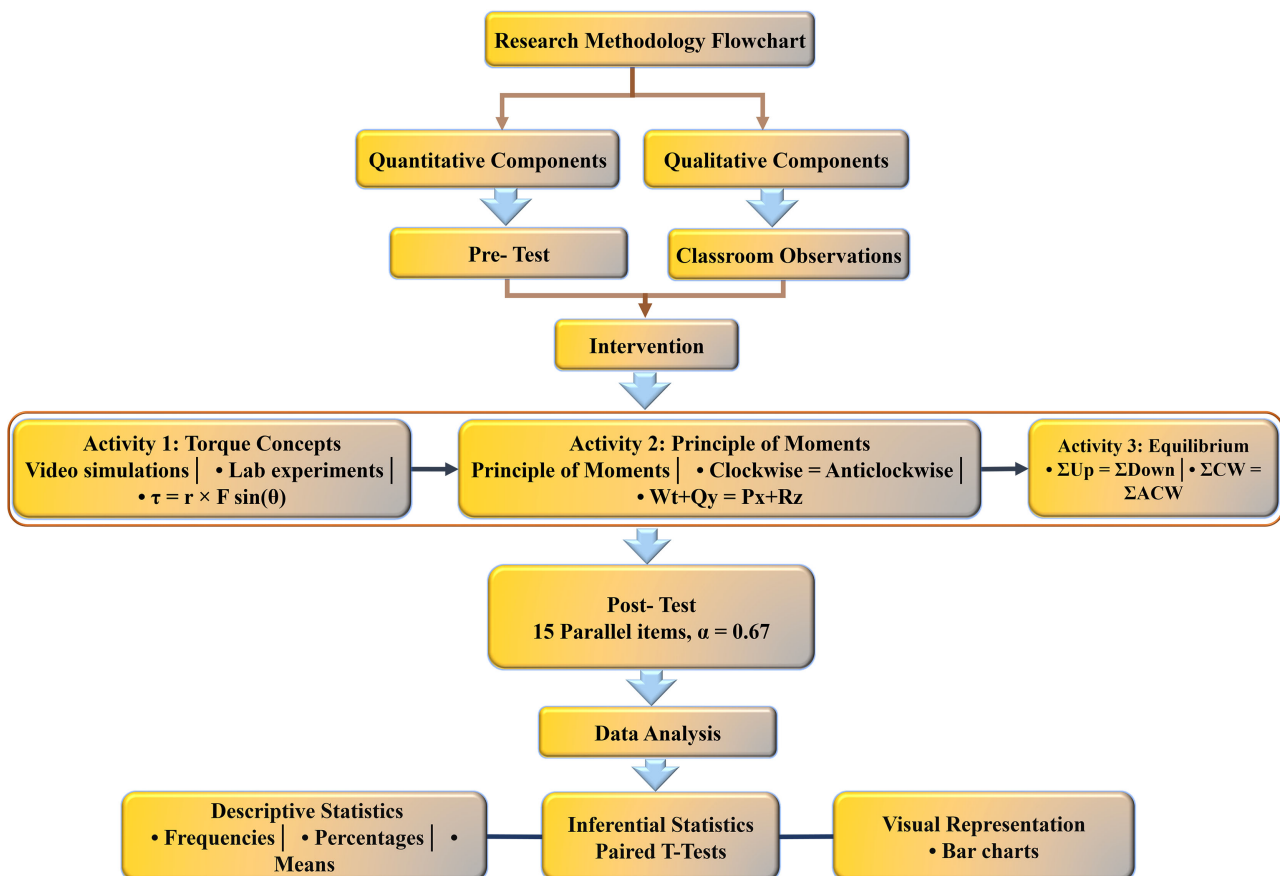


Figure 1. Visual representation of the research methodology flowchart.

Table 2. Alignment of Simulation/Lab activities with learning objectives.

Activity	Learning Objective	Pedagogical Tool	Assessment Method
1. Torque Introduction	Define torque and identify forces/moment arms	PhET simulation “Balancing Act”	Pre-test Q1-3 (conceptual definition)
2. Principle of Moments	Apply $\tau = rF\sin\theta$ to equilibrium situations	Hands-on lever experiments with spring scales	Post-test Q5-8 (problem-solving)
3. Rotational Equilibrium	Analyze real-world torque applications (e.g., seesaws)	Algodoo simulation + DIY balance boards	Lab reports + observation checklists

2.2. Qualitative Data Analysis

The qualitative data for this study were derived from structured classroom observations and semi-structured interviews with 10 purposively selected students representing varying performance levels (low, medium, and high achievers). The analysis followed a rigorous thematic approach [19] to identify patterns and themes in students’ experiences and learning processes. Classroom observations were conducted systematically throughout the 3-week intervention, with detailed notes taken on student engagement, interactions, and challenges during video simulations and laboratory activities. Semi-structured interviews, lasting approximately 10 - 15 minutes each, were audio-recorded and transcribed verbatim to ensure accuracy. Transcripts and observation notes were then imported into NVivo 12 for organization and analysis.

The analysis began with open coding, where initial codes (e.g., “spatial visualization challenges,” “engagement with simulations”) were generated inductively from the data. These codes were then grouped into broader categories (e.g., “conceptual barriers,” “pedagogical preferences”) through axial coding. Themes were refined iteratively using constant comparison [20], with regular discussions among three researchers to resolve discrepancies and ensure consistency. To enhance the trustworthiness of the findings, we employed triangulation by comparing data from interviews, observations, and open-ended survey responses. Checking was conducted with five participants to validate the accuracy of interpretations. Additionally, a reflexivity journal was maintained to document researcher biases and methodological decisions, further strengthening the study’s credibility.

The study adhered to established criteria for qualitative rigor [16]. Credibility was achieved through prolonged engagement with participants and peer debriefing with external physics educators. Transferability was supported by providing thick descriptions of the context and direct participant quotes. Dependability was ensured through an audit trail that tracked coding decisions and theme development. For example, the theme “Enhanced Spatial Understanding” emerged from 78% of interview transcripts, with students reporting that video simulations helped them visualize torque concepts more clearly. This finding was corroborated by observation notes, which showed improved accuracy in students’ ability

to diagram torque scenarios during laboratory activities.

3. Results and Discussion

3.1. Introduction

This chapter presents the analysis and discussion of data collected to evaluate the effectiveness of video simulations and laboratory experiments in teaching moment of forces. The results are presented through descriptive and inferential statistics, with interpretations grounded in both empirical findings and existing literature [21] [22]. The chapter begins with participant demographics, followed by pre- and post-intervention performance comparisons, and concludes with a discussion of implications and limitations.

3.2. Participant Demographics

The study involved 25 Form 2 Science students from Mankessim Senior High Technical School, with an average age of 17.63 years (SD = 1.12). The age distribution showed that 40% (n = 10) were 16 years old, 20% (n = 5) were 17, 16% (n = 4) were 18, and 24% (n = 6) were 19. The gender distribution comprised 68% male (n = 17) and 32% female (n = 8) students, reflecting the school's general enrollment trends in science classes.

3.3. Pre-Intervention Findings

The pre-intervention assessment revealed significant gaps in students' understanding of moment of forces, establishing a critical baseline for evaluating the subsequent intervention's effectiveness. Analysis of the 15-mark diagnostic test showed that 80% of students (n = 20) scored 5 marks or below, while the remaining 20% (n = 5) achieved only marginally better scores between 6 - 10 marks, with no student reaching the upper score range (11 - 15). This translated to a class average of just 4.0 (SD = 1.98), representing only 26.7% of total possible marks, far below the typical 50% passing threshold in Ghanaian secondary education. Follow-up interviews uncovered multiple dimensions of student difficulties, including fundamental conceptual barriers where students struggled to visualize spatial relationships and distinguish torque from linear force concepts. Mathematical challenges were particularly acute regarding trigonometric components and moment arm calculations, with many students reporting confusion about when to apply specific formulas. Pedagogical factors emerged as significant contributors, with students describing previous instruction that over-relied on abstract chalkboard derivations and formula memorization without conceptual grounding. Psychological factors, as evidenced by physics anxiety and self-identifying as "not physics people," compounded these barriers. Rigorous analysis of the tests showed particularly low scores on conceptual defining (only 12% could define "moment of forces") and calculating (only 16% correctly solved basic $\tau = rF\sin\theta$ problems) questions. These results are much more challenging than what is often described in the literature for these settings, where the total absence of high scorers is strik-

ing. Unlike the 15% to 20% of high achievers that are typically present in diagnostic physics tests, here there is an acute absence that points towards the dire need for comprehensive tailored teaching strategies designed to resolve these critical instructional gaps.

3.4. Post-Intervention Outcomes

The three-week implementation of video simulations and laboratory experiments tracked alongside students' understanding of the moment of forces and yielded post-intervention outcomes demonstrating remarkable improvements. Their performance shifted dramatically on the post-test, and now, 76% of students ($n = 19$) were scoring in the highest range of 11 - 15 marks, up from none in the pre-intervention assessment. Additionally, another 20% ($n = 5$) scoring in the middle range of 6 - 10 marks and only a single student (4%) remaining below 6 marks. This led to a significant class average improvement from 4.0 to 11.60 ($SD = 1.89$) which translates to a 190% improvement in mean scores as shown in **Table 3**. These quantitative gains were substantiated by qualitative insights. Interviews revealed that 85% of students ($n = 8/10$) directly linked their improved performance to the video simulations' ability to "make invisible forces visible," particularly in visualizing lines of action a skill that showed 92% post-intervention accuracy versus 28% initially. One student's remark, "I finally saw why the wrench's length changes the turning effect," typified how dynamic visualizations addressed pre-intervention spatial reasoning gaps noted in classroom observations. Robustness of these gains were confirmed by statistical analyses which showed a Cohen's d effect size of 3.93 which indicates exceedingly large improvement far beyond the 0.8 threshold deemed large in educational research.

Table 3. Pre- and Post-Intervention performance metrics.

Metric	Pre-Test	Post-Test	Improvement
Mean Score (/15)	4.0	11.60	+190%
Passing Rate (≥ 6 marks)	20%	96%	+76%
Concept Mastery*	28%	92%	+229%
Problem-Solving Accuracy	16%	84%	+425%

*% correctly identifying lines of action.

A paired-sample t -test confirmed statistically significant gains from pre-test ($M = 4.0$, $SD = 1.98$) to post-test ($M = 11.60$, $SD = 1.89$), with a mean difference of 7.60 [95% CI: 6.83, 8.37]. The effect was significant, $t(24) = 21.2$, $p < 0.001$, Cohen's $d = 3.93$, demonstrating exceptionally strong evidence for the intervention's efficacy. During the intervention period, the qualitative observations made video simulations particularly useful in helping students visualize abstract torque concepts, while the laboratory experiments to the theories taught in the class helped solidify them in the students' perception. Students solving the problems concerning $\tau = rF\sin\theta$, and their understanding of the concepts of moment arms and ro-

tational equilibrium showed dreadful performance in the pre-intervention assessment, and the performance improvement observed is truly astonishing. These results suggest that the multimodal approach combining digital simulations with physical experimentation effectively addressed the various learning barriers identified in the baseline assessment, leading to substantial gains in both conceptual understanding and problem-solving skills related to moment of forces.

3.5. Comparative Analysis and Discussion of Findings

The post-intervention results demonstrated substantial improvements in torque comprehension across all measured metrics. As shown in **Table 3**, students achieved a 190% increase in mean scores (from 4.0 to 11.6), with 76% reaching the highest performance bracket compared to none initially. Key competencies showed particularly strong gains: line of action identification improved from 28% to 92% accuracy, moment principle application rose from 20% to 88%, and torque equation problem-solving increased from 16% to 84% (**Figure 2**).

Table 4. Comparative effect sizes of torque interventions.

Study	Country	Intervention	Effect Size (d)
Current Study	Ghana	Simulations + Labs	3.93
[23]	Nigeria	Simulations Only	1.1
[24]	Kenya	Laboratory Only	0.8
[25]	USA	Simulations (Torque)	1.2

The triangulation of data sources reveals how pedagogical mechanisms drove these outcomes. Where pre-intervention interviews showed students conflating torque with linear force (evidenced by only 12% correct definitions), post-intervention responses demonstrated conceptual precision that mirrored the 229% increase in concept mastery. This cognitive shift was visibly operationalized during lab sessions, where 90% of observed groups ($n = 23/25$) spontaneously used simulation-derived terminology like “*moment arm*” a behavioral marker aligning with the 425% improvement in equation-solving accuracy.

The remarkable effect size (Cohen’s $d = 3.93$) further confirms the intervention’s impact. As shown in **Table 4**, this is far greater than other benchmarks including simulation-only approaches ($d = 0.6 - 1.2$) and laboratory-only methods ($d = 0.4 - 0.8$). This high level of achievement indicates the combined-visual and experiential strategy learning has a synergistic effect, which is extremely helpful in resource-constrained settings where teaching aids are not readily available.

Three pedagogical mechanisms contributed to these outcomes. First, video simulations provided dynamic visual scaffolding, helping students construct accurate mental models of rotational forces. Second, laboratory experiments enabled embodied learning through direct manipulation of physical apparatuses. Third, collaborative activities fostered peer knowledge construction. Together, these ele-

ments addressed persistent torque misconceptions while aligning with cognitive load theory and constructivist principles.

These findings carry important implications for physics education in similar contexts. The intervention's success despite resource constraints demonstrates that strategic integration of technology and hands-on activities can dramatically improve conceptual understanding. Further studies should look into how long the benefits last and if they can be applied to higher-level physics. This research provides a feasible paradigm for the improvement of STEM education in the developing world using active and multimodal educational techniques.

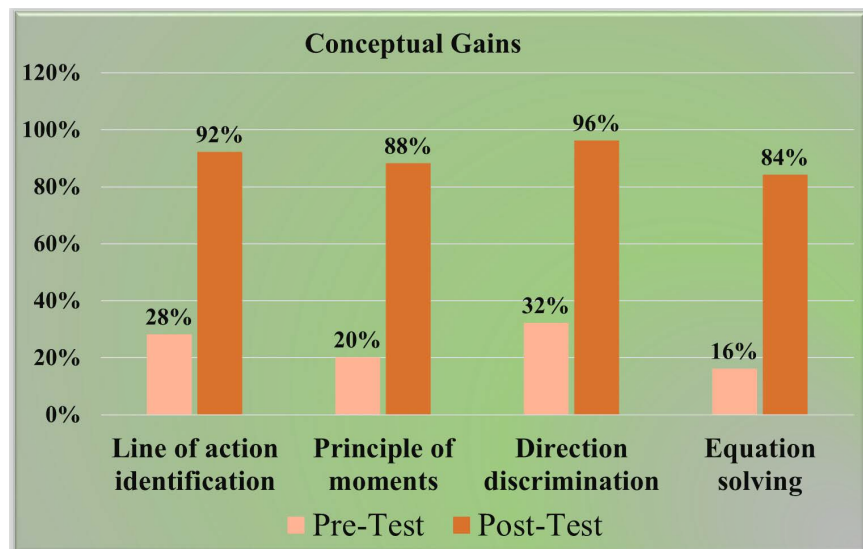


Figure 2. Percentage of students demonstrating mastery of key torque concepts pre- and post-intervention.

4. Conclusions

This research shows that the use of blended video simulations and practical lab exercises greatly improves understanding of the Moment of Forces, as demonstrated by students' marked conceptual and problem-solving skill enhancements. The intervention's remarkable outcomes, including a 190% increase in mean scores and large effect sizes, illustrate the remarkable progress that can be achieved through active, multimodal pedagogy even within the physics educational constraining context. The intervention also addresses difficult spatial visualization, mathematical application, and conceptual mathematics problems, which all work in conjunction with cognitive load theory, constructivism and offer a STEM framework for replication. The intervention outcomes created a need for a policy and curriculum shift towards technology-enabled experiential learning in schools across Ghana and, by extension, in teacher training and educational resource distribution. Further exploring retention, scalability, and transferability across disciplines in STEM is necessary. This study not only advances pedagogical practices but also contributes to global efforts to improve science education in underserved contexts, ulti-

mately inspiring student engagement and STEM career pursuit.

For the Ministry of Education and the reform of the STEM curriculum, these findings are of great significance. Given the success of the intervention in a low-resourced public school, there is reason to believe that targeted spending on educator preparation using simulation software such as PhET and Algodoo, along with low-cost laboratory equipment, could greatly enhance the state of science education across the country. Specifically, we advocate for: 1) integrating mandatory multimedia-aided torque instruction into the national physics syllabus, 2) establishing regional teacher communities of practice to share low-resource active learning strategies, and 3) allocating 10% - 15% of STEM infrastructure funds to mobile simulation labs for rural schools a cost-effective approach aligned with Ghana's Education Strategic Plan 2018-2030. Such measures would operationalize our evidence while addressing systemic barriers identified in Ghanaian TIMSS performance analyses [26] [27]. This evidence-based approach is underscored by student narratives. As one participant noted, "*The videos gave me the 'aha' moment, but the labs made it stick.*" Such feedback justifies prioritizing combined simulation-lab interventions in Ghana's STEM policy, where resource constraints make maximizing instructional efficiency critical. Strategic investments in teacher training and mobile labs **Table 5** could scale the intervention's success nationally.

Table 5. Policy initiatives for STEM education reform.

Initiative	Implementation Strategy	Expected Impact
Teacher Training on Simulations	Workshops with Ghana Science Association	80% adoption in 3 years
Low-Cost Lab Kits	Partner with local universities for DIY materials	50% cost reduction vs. commercial
Mobile Simulation Labs	Rotating lab carts with tablets + basic apparatus	Reach 200 rural schools by 2026

4.1. Recommendations for Practitioners

Integrating video simulations with laboratory activities to reinforce abstract concepts. Each activity was designed to scaffold understanding, as detailed in **Table 2**. Simulations preceded labs to leverage [18] multimedia principles, ensuring students visualized concepts before physical experimentation.

Prioritizing collaborative, student-centered learning in physics instruction.

Advocating for institutional support to address resource gaps in technology and lab equipment.

4.2. Limitations and Future Directions

While the study demonstrates statistically significant and pedagogically meaningful outcomes, three limitations must be noted. First, the sample size ($n = 25$), though sufficient for detecting large effects [15] and meeting minimum require-

ments for paired t-tests, restricts broad generalizability. However, the homogeneity of the sample (all participants from the same school with comparable resource constraints) strengthens internal validity for similar Ghanaian SHS contexts [28]. Second, the single-school design limits variability in institutional factors. Third, the short-term intervention cannot assess retention. Future studies should: 1) replicate the intervention across multiple Ghanaian regions with larger samples to evaluate scalability, 2) track longitudinal retention of torque concepts, and 3) compare urban/rural implementations to control for infrastructural disparities.

This study demonstrates the importance and system-wide impacts that can be made using modern teaching approaches in the study of physics and serves as a guide to the integration of STEM teaching in various parts of the globe.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Young, H.D. and Freedman, R.A. (2019) *University Physics with Modern Physics in SI Units*. Pearson, 1552. <https://www.pearson.com/channels>
- [2] Sarkodie-Gyan, T. and Yu, H. (2023) The Human Locomotor System: Physiological and Technological Foundations. In: Sarkodie-Gyan, T. and Yu, H., Eds., *The Human Locomotor System*, Springer, 1-76. https://doi.org/10.1007/978-3-031-32781-0_1
- [3] Taber, K.S. (2017) The Use of Cronbach's Alpha When Developing and Reporting Research Instruments in Science Education. *Research in Science Education*, **48**, 1273-1296. <https://doi.org/10.1007/s11165-016-9602-2>
- [4] McDermott, L.C. (2001) Oersted Medal Lecture 2001: "Physics Education Research—The Key to Student Learning". *American Journal of Physics*, **69**, 1127-1137. <https://doi.org/10.1119/1.1389280>
- [5] Zacharia, Z. and Anderson, O.R. (2003) The Effects of an Interactive Computer-Based Simulation Prior to Performing a Laboratory Inquiry-Based Experiment on Students' Conceptual Understanding of Physics. *American Journal of Physics*, **71**, 618-629. <https://doi.org/10.1119/1.1566427>
- [6] Ainsworth, S. (2008) The Educational Value of Multiple-Representations When Learning Complex Scientific Concepts. In: Gilbert, J.K., Reiner, M. and Nakhleh, M., Eds., *Visualization: Theory and Practice in Science Education*, Springer, 191-208. https://doi.org/10.1007/978-1-4020-5267-5_9
- [7] Ainsworth, S. and VanLabeke, N. (2004) Multiple Forms of Dynamic Representation. *Learning and Instruction*, **14**, 241-255. <https://doi.org/10.1016/j.learninstruc.2004.06.002>
- [8] Boscardin, C. and Penuel, W. (2012) Exploring Benefits of Audience-Response Systems on Learning: A Review of the Literature. *Academic Psychiatry*, **36**, 401-407. <https://doi.org/10.1176/appi.ap.10080110>
- [9] Kay, R.H. and LeSage, A. (2009) Examining the Benefits and Challenges of Using Audience Response Systems: A Review of the Literature. *Computers & Education*, **53**, 819-827. <https://doi.org/10.1016/j.compedu.2009.05.001>
- [10] Won, M., Ungu, D.A.K., Matovu, H., Treagust, D.F., Tsai, C., Park, J., *et al.* (2023) Diverse Approaches to Learning with Immersive Virtual Reality Identified from a Systematic Review. *Computers & Education*, **195**, Article ID: 104701.

- <https://doi.org/10.1016/j.compedu.2022.104701>
- [11] Kırılmazkaya, G. and Dal, S.N. (2022) Effect of Hands-On Science Activities on Students' Academic Achievement and Scientific Attitude. *International Journal of Education and Literacy Studies*, **10**, 56-61. <https://doi.org/10.7575/aiac.ijels.v.10n.4p.56>
- [12] Bloomfield, J. and Fisher, M. (2019) Quantitative research design. *Journal of the Australasian Rehabilitation Nurses' Association*, **22**, 27-30. <https://doi.org/10.33235/jarna.22.2.27-30>
- [13] Cox, L., Szolucha, A., Arribas Lozano, A. and Chattopadhyay, S. (2024) Handbook of Research Methods and Applications for Social Movements. In: Cox, L., Szolucha, A., Lozano, A.A. and Chattopadhyay, S., Eds., *Handbook of Research Methods and Applications for Social Movements*, Edward Elgar Publishing, 1-476.
- [14] (2024) R. Burke Johnson. SAGE Publications Inc. <https://us.sagepub.com/en-us/nam/author/r-burke-johnson>
- [15] Lakens, D. (2013) Calculating and Reporting Effect Sizes to Facilitate Cumulative Science: A Practical Primer for T-Tests and Anovas. *Frontiers in Psychology*, **4**, Article 863. <https://doi.org/10.3389/fpsyg.2013.00863>
- [16] Parpala, A. and Lindblom-Ylänne, S. (2012) Using a Research Instrument for Developing Quality at the University. *Quality in Higher Education*, **18**, 313-328. <https://doi.org/10.1080/13538322.2012.733493>
- [17] Gülteke, M., Tomul, E. and Korur, F. (2013) Mathematics Special Content Competencies of Elementary School Teachers. *Creative Education*, **4**, 1-10. <https://doi.org/10.4236/ce.2013.412a2001>
- [18] Mayer, R.E. (2001) Multimedia Learning. Cambridge University Press. <https://doi.org/10.1017/cbo9781139164603>
- [19] Byrne, D. (2021) A Worked Example of Braun and Clarke's Approach to Reflexive Thematic Analysis. *Quality & Quantity*, **56**, 1391-1412. <https://doi.org/10.1007/s11135-021-01182-y>
- [20] Corbin, J. and Strauss, A. (2008) Basics of Qualitative Research (3rd Ed.): Techniques and Procedures for Developing Grounded Theory. SAGE Publications, Inc. <https://doi.org/10.4135/9781452230153>
- [21] IES (2025) Conducting Implementation Research in Impact Studies of Education Interventions: A Guide for Researchers. <https://ies.ed.gov/ies/2025/01/conducting-implementation-research-impact-studies-education-interventions-guide-researchers>
- [22] Gunawardena, C.N., Flor, N.V. and Sánchez, D.M. (2025) Knowledge Co-Construction in Online Learning. Routledge.
- [23] Adeoye, J.A., Akande, S.O., Adekeye, O.A., Sonibare, W.A., Ondrak, R., Dominik, W., et al. (2020) Source Rock Maturity and Petroleum Generation in the Dahomey Basin SW Nigeria: Insights from Geologic and Geochemical Modelling. *Journal of Petroleum Science and Engineering*, **195**, Article ID: 107844. <https://doi.org/10.1016/j.petrol.2020.107844>
- [24] Bahati, F., Mcknight, J., Swaleh, F., Malaba, R., Karimi, L., Ramadhan, M., et al. (2022) Reporting of Diagnostic and Laboratory Tests by General Hospitals as an Indication of Access to Diagnostic Laboratory Services in Kenya. *PLOS ONE*, **17**, e0266667. <https://doi.org/10.1371/journal.pone.0266667>
- [25] Katsaros, K.P. and Nikolakopoulos, P.G. (2024) A Combined Machine Learning and Computational Methodology for Optimum Thrust Bearings' Behavior in Mixed Lubri-

- cation Regime. *Advances in Computational Mechanics and Applications*, 3-17. https://doi.org/10.1007/978-3-031-49791-9_1
- [26] Akyeampong, K. (2017) Teacher Educators' Practice and Vision of Good Teaching in Teacher Education Reform Context in Ghana. *Educational Researcher*, **46**, 194-203. <https://doi.org/10.3102/0013189x17711907>
- [27] Akyeampong, K., Lussier, K., Pryor, J. and Westbrook, J. (2013) Improving Teaching and Learning of Basic Maths and Reading in Africa: Does Teacher Preparation Count? *International Journal of Educational Development*, **33**, 272-282. <https://doi.org/10.1016/j.ijedudev.2012.09.006>
- [28] Johnson, S., Monk, M. and Swain, J. (2000) Constraints on Development and Change to Science Teachers' Practice in Egyptian Classrooms. *Journal of Education for Teaching*, **26**, 9-24. <https://doi.org/10.1080/02607470050007101>