The Effect of Integrating Moodle LMS and PhET Simulations in Science Instruction on Student Engagement and Academic Performance in Selected Addis Ababa Secondary Schools

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Abstract*: This study investigated the effect of integrating specific digital tools (an interactive Learning Management System - LMS) and online platforms (PhET subject-specific simulations) on student engagement and academic performance among Grade 9 students in two government secondary schools in Addis Ababa, Ethiopia. A quasi-experimental design was employed over one academic semester at Menelik II Secondary School and Bole Comprehensive Secondary School. Two intact classes participated from each school, one assigned as experimental (n = 60) utilizing the LMS and simulations, and one as control (n = 65) receiving traditional instruction, totaling 125 participants. Student engagement was measured using the Student Engagement Instrument (SEI) assessing behavioral, emotional, and cognitive dimensions. Academic performance was assessed via pre- and post-intervention standardized science tests covering Grade 9 content and final course grades. Data analysis included independent samples t-tests and ANCOVA. Results indicated that students in the experimental groups across both schools demonstrated significantly higher levels of cognitive engagement (p = .001) and achieved significantly higher scores on the post-intervention science test (p < .001), controlling for pre-test scores. No significant differences were found for behavioral (p = .410) or emotional engagement (p = .530), or final course grades (p = .380). Findings suggest that targeted technology integration, specifically Moodle and PhET in Science instruction, can positively influence cognitive engagement and specific academic performance indicators within the urban context of Addis Ababa secondary schools, although effects may vary across different engagement dimensions and assessment types. Implications for pedagogical practices, teacher training, and technology deployment within Addis Ababa and similar urban Ethiopian settings are discussed.*

Keywords: technology integration, student engagement, academic performance, secondary education, Addis Ababa, Ethiopia, digital tools, online platforms, LMS, Moodle, PhET simulations, science instruction.

Introduction

The 21st century has witnessed an unprecedented proliferation of digital technologies transforming various aspects of society, including education. In Addis Ababa, Ethiopia's capital and rapidly growing urban center, secondary schools are increasingly incorporating digital tools and online platforms, driven partly by national ICT policies and the aspiration to modernize education (Ministry of Education [Ethiopia], 2015). The expectation is that these technologies will enhance teaching practices, improve student engagement, and ultimately lead to better learning outcomes within this diverse urban educational landscape (Pelgrum & Law, 2003). Technologies such as Learning Management Systems (LMS), interactive simulations like PhET, and online resources offer potential avenues for more personalized and interactive learning experiences, though access and effective utilization can vary significantly even within the city (Sailer & Homner, 2020; Tadesse & Muluye, 2020).

However, the effect of technology integration in education is not without debate. While some studies report positive effects on learning and engagement (Sung et al., 2016), others highlight challenges and mixed results, emphasizing that effective pedagogical integration is key, not just access (Bulman & Fairlie, 2016; Hillmayr et al., 2020; Kirschner & De Bruyckere, 2017). Within the specific resource-constrained urban African settings like Addis Ababa, challenges related to large class sizes, varying levels of digital literacy, inconsistent internet connectivity, and the need for contextually appropriate integration strategies persist (Howard et al., 2021; Tadesse & Muluye, 2020). Understanding the specific interplay between technology, student engagement, and academic performance in this context is crucial for effective educational planning.

Student engagement-encompassing behavioral, emotional, and cognitive aspects is a critical precursor to academic success (Fredricks et al., 2004; Reschly & Christenson, 2012). Technology is often promoted for enhancing engagement (Bond et al., 2020), but specific tools may influence different engagement dimensions differently. This study is theoretically grounded in constructivist learning theories (Vygotsky, 1978; Jonassen, 1999), which suggest that interactive tools and environments can facilitate active knowledge construction, and the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which emphasizes the interplay of technology, pedagogy, and content knowledge for effective technology integration by teachers. Student engagement is conceptualized via Fredricks et al.'s (2004) tripartite model, providing a lens through which to examine how technology

might influence students' involvement in learning. Explicitly linking technology tools like Moodle LMS and PhET simulations to these theoretical perspectives helps explain how technology integration might foster different dimensions of engagement and, consequently, influence academic performance in the specific context of Grade 9 Science classrooms. PhET simulations, for instance, align with constructivism by allowing hands-on exploration and hypothesis testing, potentially boosting cognitive engagement. Moodle LMS can support pedagogical approaches that align with TPACK by providing tools for content delivery, assessment, and interaction.

Research on the effect of specific technology tools on academic performance in science education globally shows promise, particularly with simulations (Sailer & Homner, 2020; Hillmayr et al., 2020). However, robust empirical evidence examining the effect of structured integration of tools like Moodle LMS and PhET simulations on multi-dimensional student engagement and academic performance using rigorous designs within Addis Ababa secondary schools is limited (Tadesse & Muluye, 2020). Existing local studies often focus on broader access issues or tertiary education. This study addresses this gap by examining the effect of a Moodle LMS and PhET simulation intervention in Grade 9 Science within this context.

Therefore, the purpose of this study was to compare the effect of a technology-integrated instructional approach using Moodle LMS and PhET simulations versus traditional teaching methods on student engagement and academic performance among Grade 9 students in selected Addis Ababa secondary schools. Understanding these dynamics is essential for making informed decisions about technology implementation, teacher training, and resource allocation in this key urban educational setting. The study sought to answer the following research questions:

1. Are there significant differences in behavioral, emotional, and cognitive engagement levels between Grade 9 students in selected Addis Ababa schools taught using an LMS and simulations, compared to those taught using traditional methods?
2. Are there significant differences in academic performance (measured by standardized test scores and course grades) between these groups, after controlling for prior knowledge?

This research contributes context-specific evidence relevant to Addis Ababa's educational system. Findings aim to inform pedagogical practices, curriculum adjustments, and policy decisions regarding effective technology integration in the city's secondary schools.

Literature Review

Theoretical Framework

This study is grounded in constructivist learning theories (Vygotsky, 1978; Jonassen, 1999) and the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), applied here to understand effective technology use in the specific context of Addis Ababa secondary classrooms. Constructivism posits that learners actively construct knowledge and meaning, suggesting that interactive tools like PhET simulations and collaborative features within an LMS (Moodle) can support deeper learning by facilitating exploration and interaction rather than passive reception of information. The TPACK framework guides our understanding of how teachers can effectively integrate technology by considering the intersection of their knowledge of the subject matter (Content Knowledge), how to teach (Pedagogical Knowledge), and how to use technology (Technology Knowledge). Effective use of Moodle and PhET in Science instruction, as investigated here, requires teachers to draw upon this integrated knowledge to design lessons that leverage the unique affordances of these tools to support Science learning. Student engagement is conceptualized via Fredricks et al.'s (2004) tripartite model (behavioral, emotional, cognitive), providing a specific lens to examine how these technology-enhanced approaches might influence different dimensions of student involvement in learning, which in turn are theoretically linked to academic performance.

Technology Integration and Engagement

Research suggests technology can enhance behavioral engagement (Bond et al., 2020) and emotional engagement (Sailer & Homner, 2020), potentially valuable in large Addis Ababa classrooms. Cognitive engagement may be promoted via simulations, though potential distractions or superficial use remain concerns, particularly given varying device access and digital literacy levels (Kirschner & De Bruyckere, 2017).

Technology Integration and Academic Performance

Global meta-analyses show mixed results regarding the effect of technology on academic performance (Bulman & Fairlie, 2016; Hillmayr et al., 2020), emphasizing that pedagogical integration, not just access, drives outcomes. Studies focusing on technology use in science, particularly simulations, often report positive effects on conceptual understanding and problem-solving skills (Hillmayr et al., 2020; Sailer & Homner, 2020). Evidence is needed to see how these factors play out within the resource and infrastructure realities of Addis Ababa schools and how integrated use of

specific platforms like Moodle and PhET impacts different measures of academic performance.

The Current Study's Context

While national policies promote ICT (Ministry of Education [Ethiopia], 2015), research specifically linking interventions to multi-dimensional engagement and academic performance using robust designs within Addis Ababa secondary schools is limited. Existing studies often focus on broader access issues or tertiary education (Tadesse & Muluye, 2020). This study aims to fill this specific gap by examining the effect of a Moodle LMS and PhET simulation intervention on student engagement and academic performance in Grade 9 Science within this context.

Methods

Research Design

A quasi-experimental, pre-test/post-test, control group design was employed across two school sites (Shadish et al., 2002). Within each participating school, two intact Grade 9 Science classes were selected; one was assigned to the experimental condition (technology integration) and one to the control condition (traditional instruction).

Participants and Setting

Participants were 125 Grade 9 students from two large public secondary schools in Addis Ababa, Ethiopia: Menelik II Secondary School (located in the Arada sub-city, n = 62 across two classes) and Bole Comprehensive Secondary School (located in the Bole sub-city, n = 63 across two classes). These schools serve diverse student populations typical of urban public schools in the city. The average age was 15.3 (SD = 0.9), with 51% female participants. Schools were selected based on their willingness to participate and logistical feasibility, including having available Grade 9 Science classes. Within each school, existing intact Grade 9 Science classes were purposively selected and randomly assigned to either the experimental or control condition. Selection was also based on the availability of Grade 9 science classes with teachers holding similar qualifications (B.Ed. Science, >5 years experience) and teaching the standard Grade 9 Science curriculum. Informed consent was obtained from school administration, parents/guardians via distributed forms, and student assent was secured. The study took place during the first semester of the 2024-2025 academic year.

Technology Intervention and Materials

The experimental groups (one class at Menelik II, one at Bole Comprehensive) received instruction integrating the Moodle LMS and PhET interactive science simulations as part of their regular Grade 9 Science curriculum. The LMS hosted resources, assignments, quizzes with feedback, and discussion forums accessible via school computer labs or personal devices where available. PhET simulations were used for virtual experiments and conceptual exploration during relevant science units (e.g., circuits, forces, motion). Teachers involved received 12 hours of pedagogical and technical training prior to the semester, focusing on effectively integrating Moodle and PhET simulations into their Grade 9 Science lessons to promote student engagement and conceptual understanding. The control groups (one class at each school) received instruction covering the identical curriculum using traditional methods (lecture, textbook, blackboard notes, standard labs where available, paper assignments). Care was taken to ensure teachers in both conditions had comparable experience levels and covered the same core curriculum content throughout the study period.

Data Collection Instruments

- **Student Engagement Instrument (SEI):** The Student Engagement Instrument (SEI) (adapted from Fredricks et al., 2004), was translated into Amharic and validated for local context. Validation procedures included expert review by educational psychologists and science educators to ensure cultural appropriateness and content relevance, followed by pilot testing with a similar student population. This 18-item instrument uses a 5-point Likert scale (1=Never to 5=Always) to measure three dimensions of engagement. The SEI was administered mid- and end-semester to assess changes in engagement during and at the conclusion of the intervention period. Reliability (Cronbach's alpha) for subscales in this sample were: Behavioral $\alpha = .77$, Emotional $\alpha = .81$, Cognitive $\alpha = .84$.
- **Academic Performance Measures:**
  - **Prior Knowledge (Pre-Test):** An adapted standardized Grade 8 Science Achievement Test (30 items) served as the pre-test, assessing students' baseline knowledge relevant to the Grade 9 Science curriculum. Reliability for this test in the current sample was KR-20 = .76.
  - **Post-Intervention Achievement (Post-Test):** A parallel Grade 9 Science Achievement Test (30 items) covering semester content was administered as the post-test to measure learning gains. Reliability for this test in the current sample was KR-20 = .78.

- **Course Grades:** Final official semester Science grades were collected from school records as a comprehensive measure of academic performance, reflecting various assessment types used by the school.

Procedure

Following ethical approvals from the Addis Ababa educational bureaus and obtaining parental/guardian consent and student assent, the pre-test was administered to all participants. The technology intervention (for experimental groups) and traditional instruction (for control groups) then commenced, running for a duration of 16 weeks, spanning the first semester of the 2024-2025 academic year. Student engagement surveys (SEI) were administered at week 8 (mid-semester) and week 15 (end-semester). The mid-semester administration was conducted to capture potential shifts in engagement during the intervention period, while the end-semester administration assessed the cumulative effect. We acknowledge that a pre-intervention baseline measure of engagement was not included, a limitation of the quasi-experimental design, but baseline equivalence on prior academic knowledge was established. The post-test was administered in the final week (week 16). Fidelity checks (review of teacher logs, Moodle activity reports, and brief classroom observations) were conducted periodically to ensure the intervention was implemented as planned and control group instruction remained traditional.

Data Analysis

Quantitative data analysis was performed using IBM SPSS Statistics version 27. Descriptive statistics, including means and standard deviations, were calculated to summarize sample characteristics and performance on measures. Independent samples t-tests were used to compare baseline characteristics (Age, Pre-Test scores) and end-of-semester engagement scores between the experimental and control groups. Analysis of Covariance (ANCOVA) was employed to compare post-test science achievement scores between the groups, using pre-test scores as a covariate to control for prior knowledge. Independent samples t-tests were also used to compare final course grades. An alpha level of .05 was used for all significance testing.

Ethical Considerations

Approval for the study was obtained from the Addis Ababa educational bureaus and the participating schools. Anonymity and confidentiality of all participant data were maintained throughout the study. Voluntary participation was emphasized, and participants were informed of their right to withdraw at any time without penalty.

Results

Sample Description and Baseline Equivalence

Baseline data (Table 1) showed no significant difference in pre-test science scores between the experimental (M = 10.1, SD = 2.2) and control groups (M = 9.9, SD = 2.1), t(123) = 0.55, p = .582, across the pooled sample from both schools, indicating reasonable baseline equivalence on prior subject knowledge. Similarly, there was no significant difference in age between the experimental (M = 15.2, SD = 0.8) and control groups (M = 15.4, SD = 0.9), t (123) = 0.98, p = .330. The distribution of gender was also comparable between the groups.

Table 1: *Descriptive Statistics and Baseline Comparison (Pooled Sample from Menelik II & Bole Comprehensive)*

Variable	Group	N	Mean	Std. Deviation	t (123)	p-value
Age (Years)	Experimental	60	15.2	0.8	0.98	.330
	Control	65	15.4	0.9		
Pre-Test Score (/30)	Experimental	60	10.1	2.2	0.55	.582
	Control	65	9.9	2.1		
Gender (% Female)	Experimental	60	52%	-	-	-
	Control	65	50%	-	-	-

***Note**: t-tests compared means for Age and Pre-Test Score. p-values > .05 indicate no significant baseline differences between groups.*

Research Question 1: Effect on Student Engagement

As shown in Figure 1 and detailed in Table 2, independent samples t-tests on end-of-semester engagement scores revealed a statistically significant difference in cognitive engagement: the experimental group (M = 4.20, SD = 0.65) scored significantly higher than the control group (M = 3.80, SD = 0.75), t(123) = 3.60, p = .001. No statistically significant differences were found for behavioral engagement *(p = .410) or emotional engagement (p = .530)***.**

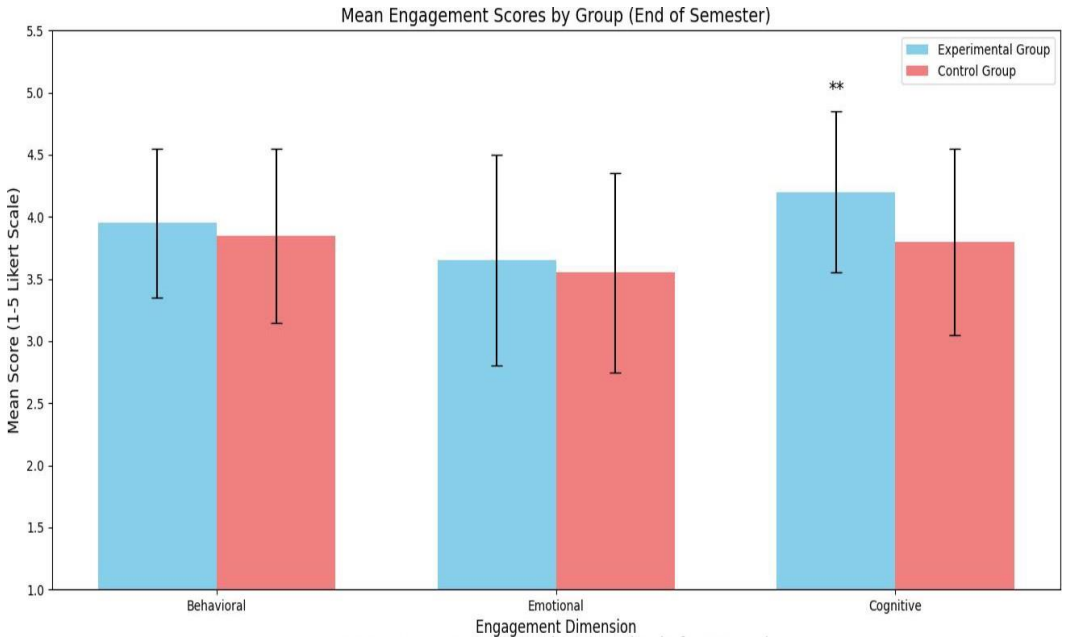

Figure 1. Mean Engagement Scores on a 1-5 Likert Scale by Group.

Table 2: Comparison of Mean Engagement Scores Between Groups (End of Semester, Pooled Sample)

Engagement Dimension	Group	N	Mean	Std. Deviation	t(123)	p-value
Behavioral Engagement	Experimental	60	3.95	0.60	0.82	.410
(Scale 1-5)	Control	65	3.85	0.70		
Emotional Engagement	Experimental	60	3.65	0.85	0.63	.530
(Scale 1-5)	Control	65	3.55	0.80		
Cognitive Engagement	Experimental	60	4.20	0.65	3.60	.001
(Scale 1-5)	Control	65	3.80	0.75		

Note: Engagement measured on a 5-point Likert scale (1=Never, 5=Always). p-value < .05 indicates statistical significance and is bolded.

Research Question 2: Effect on Academic Performance

An ANCOVA revealed a significant effect of the intervention on post-test science achievement scores after controlling for pre-test scores, $F(1, 122) = 13.10$, $p < .001$, partial $\eta^2 = .097$. The experimental group had higher adjusted marginal means (Adj. M = 15.10) than the control group (Adj. M = 13.50). However, an independent samples t-test showed no statistically significant difference was found in final course grades between the experimental (M = 77.8, SD = 8.5) and control groups (M = 76.5, SD = 9.0), $t(123) = 0.88$, $p = .380$.

Discussion

Summary of Key Findings

This study, conducted in two public secondary schools in Addis Ababa, found that integrating the Moodle LMS and PhET interactive simulations significantly enhanced Grade 9 Science students' cognitive engagement and standardized post-test performance compared to traditional methods. However, effects on behavioral engagement, emotional engagement, and final course grades were not statistically significant over the course of one semester.

Interpretation of Findings

The boost in cognitive engagement suggests that the interactive elements, particularly the PhET simulations allowing exploration and the LMS quizzes providing immediate feedback, encouraged deeper mental processing and strategic thinking among students in these Addis Ababa schools. This finding aligns with constructivist principles (Jonassen, 1999) which emphasize active learning and aligns with research suggesting simulations can foster cognitive engagement (Sailer & Homner, 2020). It also supports the notion within the TPACK framework (Mishra & Koehler, 2006) that technology, when integrated pedagogically, can enhance specific aspects of the learning process. This cognitive uplift likely contributed directly to the improved performance on the standardized post-test, which primarily assessed conceptual understanding and application of science principles taught during the semester. This demonstrates a tangible learning benefit in conceptual understanding from this specific technology integration strategy, consistent with studies showing positive effects of simulations on science achievement (Hillmayr et al., 2020). However, the lack of significant difference in course grades, which typically include a broader range of assessments (participation, homework, etc.) beyond conceptual tests, contrasts with some studies and suggests that the benefits of the intervention might have been more narrowly

focused on cognitive gains measured by the standardized test, or that other factors influenced overall course performance.

The lack of significant change in behavioral and emotional engagement within this urban Ethiopian context warrants attention. Behavioral participation (as self-reported via the SEI) might not have changed overtly or significantly enough to be captured, possibly due to the large class sizes typical in these schools making individual behavioral shifts less noticeable. Alternatively, the specific Moodle and PhET tools used, in the manner they were integrated for this intervention, may not have directly targeted or substantially enhanced collaborative or affective aspects of engagement. This contrasts with some literature suggesting technology can boost behavioral and emotional engagement (Bond et al., 2020; Sailer & Homner, 2020), highlighting the crucial role of context and the specific nature of the technology integration. Factors potentially relevant to Addis Ababa schools, such as existing classroom culture, assessment practices emphasizing rote learning over active participation, potentially inconsistent infrastructure outside designated lab times, or varying student digital readiness, likely moderate the impact of technology on behavioral and emotional dimensions (Tadesse & Muluye, 2020). Emotional engagement might require longer-term interventions or technologies focusing more explicitly on personalization, collaboration, or teacher-student interaction features, elements perhaps less central to the specific Moodle/PhET combination implemented. The unchanged course grades could reflect the broader, multi-component assessment methods used in the schools, which might be less sensitive to the specific cognitive gains captured by the standardized post-test, or indicate that improved conceptual understanding did not translate immediately into performance across all assessment types within the semester.

Connection to Literature and Theory

The findings support the TPACK framework (Mishra & Koehler, 2006) by demonstrating that how technology is pedagogically integrated matters significantly; the positive cognitive results were achieved through intentional use of interactive simulations and structured LMS activities aligned with the science curriculum. The positive cognitive results also align with global studies emphasizing the benefits of simulations and structured online environments for conceptual learning (Hillmayr et al., 2020), but the null findings for other aspects highlight the crucial role of context. Factors potentially relevant to Addis Ababa schools, such as large class sizes, existing classroom culture, assessment practices, and potentially inconsistent infrastructure or

varying student digital readiness outside of designated lab times, likely moderate the effect of technology on behavioral and emotional dimensions (Tadesse & Muluye, 2020). The study reinforces the critical link, highlighted by engagement theories (Fredricks et al., 2004), between cognitive engagement and learning, suggesting technology can act as a powerful mediator for this specific dimension.

Implications for Addis Ababa Schools

- **Practical:** Schools in Addis Ababa should consider prioritizing technologies and associated teacher training that demonstrably foster cognitive engagement and conceptual understanding, such as interactive simulations, analytical tools, and platforms offering formative feedback on conceptual tasks. Simply providing access to an LMS or hardware may not be sufficient to impact all desired outcomes, particularly behavioral and emotional engagement. Teacher professional development must focus on pedagogical strategies for integrating these tools effectively to stimulate critical thinking and deep learning within the realities of their classrooms, aligned with the TPACK framework. Furthermore, schools might review assessment practices to ensure they capture gains in conceptual understanding potentially facilitated by technology, supplementing traditional assessment methods with those that measure higher-order thinking.
- **Theoretical:** The study reinforces the critical link between cognitive engagement and **academic performance** in the context of technology integration, suggesting technology can act as a powerful mediator for this specific dimension, even within challenging urban educational environments typical of developing contexts. The findings underscore the need for theoretical models to explicitly account for contextual factors that may moderate the **effect** of technology on different dimensions of engagement and learning outcomes.

Limitations

- The quasi-experimental design limits definitive causal claims compared to a true experiment with random assignment of individuals.
- Findings based on only two government schools in Addis Ababa may not generalize to all schools in the city (**e.g.,** private vs. government, different sub-cities with varying resources) or other parts of Ethiopia.
- The one-semester duration may not capture potential long-term effects on engagement stability or learning consolidation.
- Reliance on self-report measures for engagement may involve inherent biases.

- Potential unmeasured variables (teacher motivation beyond the intervention, detailed home internet access/support, specific classroom dynamics beyond large class size) could have influenced the results.
- Baseline engagement levels were not measured, which could have provided a more complete picture of change.

Suggestions for Future Research

Based on the findings and limitations, future research could:

- Replicate the study across a wider, more representative sample of Addis Ababa schools (government/private, differing resource levels) and potentially other regions in Ethiopia.
- Conduct longitudinal studies tracking students over multiple semesters to provide valuable data on the sustainability of effects and potential lagged impacts on broader academic performance indicators like cumulative GPA.
- Employ mixed-methods research incorporating qualitative data (student/teacher interviews, detailed classroom observations) to understand the nuances of technology use and engagement within the Addis Ababa context, providing richer insights into the observed patterns.
- Conduct comparative studies examining different technology types (e.g., mobile learning apps, collaborative platforms) or integration models relevant to Ethiopian educational goals to identify which approaches are most effective for different outcomes.
- Develop and validate contextually appropriate instruments for measuring engagement and academic performance that capture the specific nuances of the Ethiopian educational system.

Conclusion

This study provides valuable, context-specific evidence from Addis Ababa secondary schools, demonstrating that strategically integrated digital tools-specifically the Moodle LMS combined with PhET interactive simulations can significantly improve Grade 9 Science students' cognitive engagement and performance on standardized tests assessing conceptual understanding. However, affecting behavioral or emotional engagement, and translating these gains into overall course grades, may require different, more comprehensive, or longer-term interventions within the existing educational system. Effective technology use in Addis Ababa necessitates careful

pedagogical planning focused on cognitive activation, substantial teacher support, and alignment with local assessment practices and infrastructure realities. These findings offer practical guidance for educators, school leaders, and policymakers aiming to leverage technology thoughtfully to enhance science teaching and learning in Ethiopia's capital city.

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