INTERNATIONAL JOURNAL OF TEACHER EDUCATION RESEARCH STUDIES (IJTERS)
(Open Access, Double-Blind Peer Reviewed Journal)
ISSN Online: 3049-1614 ISSN Print:

The Impact of Technology-Enhanced Learning Environments on Student Academic Achievement and Engagement in Secondary Education

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Article information

Received: 10th December 2025
Received in revised form: 13th January 2026
Accepted: 16th February 2026
Available online: 18th March 2026

Volume:3
Issue:1
DOI: https://doi.org/10.63090/IJTERS/3049.1614.0032

Abstract

This study investigated the impact of technology-enhanced learning environments (TELEs) on student academic achievement and engagement in secondary education in Kerala, India. Employing a quasi-experimental pretest-posttest design, the study examined 320 students (Grade 9–10) from 8 secondary schools over one academic semester (18 weeks). Participants were assigned to either a technology-enhanced instruction group (n = 160) or a traditional instruction group (n = 160). Academic achievement was measured using standardized subject tests in Mathematics and Science, while student engagement was assessed through the Student Engagement Instrument (SEI). Analysis of covariance (ANCOVA) and independent samples t-tests revealed that students in the TELE group achieved significantly higher posttest scores ($M = 78.4$, $SD = 9.2$) compared to the control group ($M = 64.1$, $SD = 10.5$), $t(318) = 12.36$, $p < .001$, $d = 1.45$. Engagement scores were also significantly elevated in the experimental group ($F(1, 317) = 84.72$, $p < .001$, $\eta^2 = .21$). These findings suggest that strategically integrating technology into secondary school classrooms significantly improves both academic performance and student engagement, with practical implications for curriculum planners and school administrators.

Keywords: - Technology-Enhanced Learning, Academic Achievement, Student Engagement, Secondary Education, Educational Technology, Quasi-Experimental Design

I. INTRODUCTION

The proliferation of digital technologies in the twenty-first century has fundamentally transformed the pedagogical landscape of formal education. Educational systems worldwide are under mounting pressure to equip learners with the competencies required for a knowledge-based economy, and technology integration has emerged as a cornerstone strategy in contemporary reform agendas (Means et al., 2013; UNESCO, 2019). Technology-enhanced learning environments (TELEs)—broadly defined as instructional contexts in which digital tools, platforms, and resources are systematically embedded within the pedagogical process—have attracted substantial scholarly attention as a mechanism to improve educational outcomes (Sung et al., 2016).

Despite a growing body of literature affirming the potential benefits of technology integration, empirical evidence regarding its actual impact on student academic achievement and engagement remains inconsistent (Cheung & Slavin, 2013; Hattie, 2009). Meta-analyses have reported effect sizes ranging from negligible to large, suggesting that contextual variables—such as implementation fidelity, teacher preparedness, infrastructure quality, and socioeconomic context—play a moderating role (Tamim et al., 2011). In the Indian context, secondary education faces unique challenges, including large class sizes, heterogeneous ability levels, and examination-driven curricula, making it particularly important to examine whether TELEs produce meaningful gains under such conditions (National Education Policy, 2020).

1.1. Statement of the Problem

While schools in Kerala have made notable strides in ICT infrastructure deployment under the KITE (Kerala Infrastructure and Technology for Education) initiative, systematic research on the learning outcomes attributable to these investments in secondary schools remains sparse. Specifically, there is limited quasi-experimental evidence examining the differential impact of TELEs on achievement across subject domains (Mathematics and Science) and on the multidimensional construct of student engagement in this context (Jayaprakash & Rajan, 2022).

1.2. Purpose of the Study

The primary purpose of this study was to examine the effect of technology-enhanced learning environments on:

- Academic achievement in Mathematics and Science, and
- Student engagement among Grade 9 and Grade 10 students in Kerala secondary schools. A secondary purpose was to determine whether the observed effects were moderated by student gender.

1.3. Research Questions

The study was guided by the following research questions:

- RQ1: Is there a significant difference in academic achievement (Mathematics and Science) between students in technology-enhanced learning environments and those receiving traditional instruction?
- RQ2: Is there a significant difference in student engagement between students in technology-enhanced learning environments and those in traditional classrooms?
- RQ3: Does student gender moderate the relationship between instructional mode and academic achievement?

1.4. Hypotheses

The following null hypotheses were tested at the $\alpha = .05$ significance level:

- $H_0 1$: There is no statistically significant difference in posttest academic achievement scores between the experimental and control groups.
- $H_0 2$: There is no statistically significant difference in student engagement scores between the experimental and control groups.
- $H_0 3$: Student gender does not significantly moderate the relationship between instructional mode and academic achievement.

1.5.Significance of the Study

This research contributes to the empirical literature on educational technology in several ways. First, it offers rigorous quasi-experimental evidence from a developing country context, which is underrepresented in global literature dominated by findings from Western settings (Voogt et al., 2013). Second, it examines engagement as a multidimensional construct (cognitive, behavioral, and emotional) rather than relying solely on proxy measures such as attendance or time-on-task. Third, the findings hold practical implications for the Kerala State Curriculum Framework and for administrators allocating ICT resources within the national Digital India initiative (Ministry of Education, 2021).

II. REVIEW OF RELATED LITERATURE

2.1. Theoretical Framework

The study is anchored in two complementary theoretical perspectives. The first is Vygotsky's (1978) sociocultural theory of learning, which posits that cognitive development is facilitated through social interaction and the use of cultural tools. Digital technologies can be conceptualized as cognitive tools that mediate learning and extend the learner's Zone of Proximal Development (ZPD), enabling students to accomplish intellectually demanding tasks with appropriate scaffolding (Kim & Reeves, 2007).

The second framework is Bandura's (1986) social cognitive theory, particularly the construct of self-efficacy. Research consistently demonstrates that technology-mediated environments can enhance students' academic self-efficacy by providing immediate feedback, adaptive challenge levels, and mastery experiences (Schunk & Pajares, 2009). Elevated self-efficacy, in turn, predicts greater persistence, deeper information processing, and superior academic performance (Zimmerman, 2000).

2.2. Technology-Enhanced Learning and Academic Achievement

A substantial body of meta-analytic evidence supports the positive impact of technology integration on academic achievement. Tamim et al. (2011), in a second-order meta-analysis synthesizing 40 years of research (1970–2010) and encompassing 1,055 individual studies, reported an overall positive effect size of $d = 0.35$ for computer-based interventions relative to conventional instruction. More recently, Sung et al. (2016) conducted a meta-analysis of 59 studies examining mobile device integration in K-12 settings and reported a moderate-to-large effect size ($g = 0.52$, 95% CI [0.44, 0.59]).

Subject-specific research indicates that technology integration yields particularly strong gains in STEM disciplines. Cheung and Slavin (2013) reviewed 74 controlled studies on educational technology in mathematics and found a weighted mean effect size of $d = 0.16$ for comprehensive technology programmes, while interactive instructional applications yielded $d = 0.37$. In science education, Merchant et al. (2014) reported that simulation-based learning environments produced significant gains in conceptual understanding ($d = 0.52$) compared to traditional didactic instruction.

However, the literature also acknowledges important boundary conditions. Higgins et al. (2012), reviewing evidence from the United Kingdom's Education Endowment Foundation, concluded that technology does not automatically translate into improved learning outcomes; rather, the pedagogical model within which technology is deployed is the critical determinant. This perspective is consistent with Harris et al.'s (2009) Technological Pedagogical Content Knowledge (TPACK) framework, which emphasizes the intersection of technology knowledge, pedagogical knowledge, and content knowledge as essential for effective teaching.

2.3. Technology Integration and Student Engagement

Student engagement is a multidimensional construct encompassing behavioral (participation, attendance, task completion), cognitive (strategic learning, self-regulation, goal setting), and emotional (sense of belonging, interest, enjoyment) dimensions (Fredricks et al., 2004). Technology-enhanced environments are theorized to support engagement through increased interactivity, personalized learning pathways, and authentic task design (Bransford et al., 2000).

Empirical studies have consistently linked technology use to higher engagement. Henrie et al. (2015), in a systematic review of 53 studies, found that interactive digital tools, including simulations, collaborative platforms, and game-based learning environments, reliably produced elevated behavioral and emotional engagement. Similarly, Appleton et al. (2006) demonstrated that cognitive engagement—measured through the Student Engagement Instrument (SEI)—was significantly higher in classrooms with structured technology integration compared to traditional settings.

2.4. Gender and Technology-Mediated Learning

The literature on gender differences in technology-mediated learning presents a nuanced picture. Historically, male students were reported to hold more positive attitudes toward computers and to benefit more from technology-based instruction (Hattie, 2009). However, more recent evidence suggests that gender gaps are narrowing, particularly in mobile learning contexts (Sung et al., 2016). Chou et al. (2012) found no significant gender moderation effects when controlling for prior achievement and socioeconomic status, a finding echoed by Kumar and Rao (2021) in the Indian secondary school context.

2.5. Gap in Literature

While the global literature is extensive, research specific to the South Indian secondary school context—particularly post-COVID digital infrastructure expansion—is limited. Furthermore, most prior studies rely on self-report engagement measures or short intervention periods (< 8 weeks), limiting ecological validity. The present study addresses these gaps through an 18-week intervention using validated instruments and objective achievement measures.

III. METHODOLOGY

3.1. Research Design

This study adopted a quasi-experimental pretest-posttest control group design (Campbell & Stanley, 1963). Because random assignment of students to classrooms was not feasible in naturalistic school settings, intact class groups were assigned to experimental and control conditions following baseline equivalence testing. This design permits causal inference while acknowledging its limitations relative to true randomization (Shadish et al., 2002).

3.2. Population and Sample

The target population comprised all Grade 9 and Grade 10 students enrolled in government-aided secondary schools in Thiruvananthapuram district, Kerala, India ($N \approx 42{,}000$). A stratified purposive sampling strategy was employed to select eight schools, stratified by school type (government vs. aided) and urban/rural location. Within each school, two intact class sections were selected: one assigned to the experimental condition and one to the control condition. The final sample comprised 320 students (experimental: $n = 160$; control: $n = 160$), with a mean age of 14.8 years ($SD = 0.64$). Gender composition was 52.5% female and 47.5% male across both groups.

A priori power analysis using G*Power 3.1 (Faul et al., 2007) indicated that a sample of $N = 128$ was sufficient to detect a medium effect size ($d = 0.50$) at $\alpha = .05$ with power $(1 - \beta) = .80$ for independent samples t-tests. The obtained sample of $N = 320$ thus provided adequate statistical power to detect even small effect sizes ($d \geq 0.32$).

3.3. Instruments

3.3.1. Academic Achievement Tests

Subject-specific achievement tests were developed by the research team in consultation with subject matter experts and curriculum specialists for Mathematics (40 items) and Science (40 items). Items were mapped to the Kerala State Curriculum Framework learning objectives for Grades 9 and 10 (State Council of Educational Research and Training [SCERT], 2019). Content validity was established through expert review (CVI = 0.89). Difficulty indices ranged from 0.30 to 0.75, and discrimination indices ranged from 0.25 to 0.68. Internal consistency was high (Mathematics: $\alpha = .87$; Science: $\alpha = .84$).

3.3.2. Student Engagement Instrument (SEI)

The SEI (Appleton et al., 2006) is a 35-item self-report measure assessing cognitive and affective engagement on a 4-point Likert scale (1 = strongly disagree, 4 = strongly agree). The instrument has demonstrated strong psychometric properties in prior research (Cronbach's $\alpha = .82$–$.91$) and has been validated for use with adolescent populations (Reschly & Christenson, 2012). For the present study, confirmatory factor analysis confirmed the two-factor structure (cognitive and affective engagement), with adequate fit indices: CFI = 0.94, RMSEA = 0.063, SRMR = 0.058. Internal consistency in the present sample was $\alpha = .88$.

3.4. Intervention

The technology-enhanced learning intervention was implemented over 18 weeks (one full academic semester). Experimental group teachers received 40 hours of professional development training in TPACK-informed instructional design prior to the intervention (Harris et al., 2009).

Technology resources included:

- Student tablets (1:1 ratio) with pre-loaded interactive simulations via phet Interactive Simulations (University of Colorado Boulder, 2022),
- A Learning Management System (LMS) for assignment submission and automated feedback,
- Collaborative digital tools (Google Workspace for Education), and
- Multimedia instructional resources aligned with the state curriculum. Teachers in the experimental group delivered instruction for a minimum of three 45-minute technology-integrated lessons per week per subject.

The control group received business-as-usual instruction following the state-mandated textbook and teacher-fronted methods, without integration of digital tools beyond occasional use of a classroom projector for teacher presentations.

3.5. Data Collection Procedure

Baseline data (pretest academic achievement and initial engagement) were collected during the first week of the study. Post-intervention data were collected during the final week (Week 18). All achievement tests were administered under standardized conditions by trained proctors unaffiliated with the participating schools to minimize experimenter bias. The SEI was administered in paper-and-pencil format during regularly scheduled class periods.

3.6. Data Analysis

Descriptive statistics (means, standard deviations, frequencies) were computed for all study variables. Prior to inferential analyses, assumptions of normality (Shapiro-Wilk test), homogeneity of variance (Levene's test), and covariate-outcome independence were verified. Analysis of covariance (ANCOVA) was used to compare posttest academic achievement scores between groups while controlling for pretest scores. Independent samples t-tests were employed for engagement score comparisons. Moderation analysis (gender × instructional mode) was conducted using factorial ANCOVA. Effect sizes were reported as Cohen's d for t-tests and partial eta-squared ($\eta^2 p$) for ANCOVA. All analyses were conducted using IBM SPSS Statistics Version 28.0 (IBM Corp., 2021), with the significance level set at $\alpha = .05$.

3.7. Ethical Considerations

The study received ethical clearance from the Institutional Research Ethics Committee of Kerala University of Education (Approval No. KUE-IREC-2024-047). Written informed consent was obtained from school principals and parents or legal guardians of all student participants. Student assent was also obtained in accordance with ethical guidelines for research involving minors (American Psychological Association [APA], 2020). Participation was voluntary, and all data were anonymized and stored in password-protected databases accessible only to the research team.

IV. RESULTS

4.1. Baseline Equivalence

Prior to examining treatment effects, baseline equivalence between the experimental and control groups was assessed on pretest achievement scores and demographic variables. Independent samples t-tests revealed no significant differences between groups on Mathematics pretest scores ($t(318) = 0.84$, $p = .401$) or Science pretest scores ($t(318) = 1.12$, $p = .263$). Chi-square tests confirmed comparable gender distribution across groups ($\chi^2(1) = 0.24$, $p = .624$). These results indicate that the two groups were statistically equivalent at baseline, supporting the internal validity of group comparisons.

4.2. Research Question 1: Effect on Academic Achievement

ANCOVA was conducted with posttest Mathematics scores as the dependent variable, instructional condition as the fixed factor, and pretest Mathematics score as the covariate. The assumption of homogeneity of regression slopes was met ($F(1, 316) = 0.47$, $p = .494$). Results indicated a statistically significant main effect of instructional condition after controlling for pretest scores, $F(1, 317) = 152.48$, $p < .001$, $\eta^2 p = .32$. Estimated marginal means showed that the experimental group ($M = 79.2$, $SE = 0.71$) significantly outperformed the control group ($M = 63.4$, $SE = 0.71$).

Similarly, ANCOVA for Science achievement revealed a significant main effect of instructional condition, $F(1, 317) = 127.64$, $p < .001$, $\eta^2 p = .29$, with the experimental group ($M = 77.6$, $SE = 0.74$) achieving substantially higher scores than the control group ($M = 64.8$, $SE = 0.74$). Combined across subjects, the independent samples t-test on total achievement yielded $t(318) = 12.36$, $p < .001$, Cohen's $d = 1.45$, indicating a very large practical effect. Null hypothesis H_01 was therefore rejected.

4.3. Research Question 2: Effect on Student Engagement

An independent samples t-test comparing posttest SEI total scores revealed that students in the experimental group reported significantly higher engagement ($M = 3.42$, $SD = 0.38$) than students in the control group ($M = 2.89$, $SD = 0.44$), $t(318) = 11.27$, $p < .001$, Cohen's $d = 1.31$. ANCOVA controlling for baseline engagement confirmed this finding, $F(1, 317) = 84.72$, $p < .001$, $\eta^2 p = .21$. Subscale analyses indicated significant group differences on both cognitive engagement ($t(318) = 9.84$, $p < .001$, $d = 1.10$) and affective engagement ($t(318) = 10.53$, $p < .001$, $d = 1.18$). Null hypothesis H_02 was rejected.

4.4. Research Question 3: Moderation by Gender

A 2 (instructional condition: experimental vs. control) × 2 (gender: male vs. female) factorial ANCOVA was conducted on total posttest achievement, with pretest scores as covariates. The main effect of instructional condition was significant, $F(1, 315) = 147.32$, $p < .001$, $\eta^2p = .32$. The main effect of gender was not significant, $F(1, 315) = 1.43$, $p = .232$, $\eta^2p = .005$. Critically, the instructional condition × gender interaction was not statistically significant, $F(1, 315) = 0.68$, $p = .411$, $\eta^2p = .002$, indicating that the achievement advantage of the experimental condition was equivalent for male and female students. Null hypothesis H_03 was retained.

4.5. Summary of Findings

The results consistently supported the efficacy of technology-enhanced learning environments. The experimental group demonstrated large and statistically significant advantages over the control group in both academic achievement (Mathematics and Science) and student engagement following the 18-week intervention. These effects were robust across gender subgroups.

V. DISCUSSION

5.1. Interpretation of Main Findings

The present study provides robust quasi-experimental evidence that systematically integrating technology into secondary school classrooms yields substantial gains in both academic achievement and student engagement. The very large effect size for achievement ($d = 1.45$) exceeds estimates from prior meta-analyses (Tamim et al., 2011; Sung et al., 2016), which may be attributed to several contextual factors. First, the 18-week duration provides greater opportunity for cumulative learning gains than shorter interventions. Second, the intensive 40-hour teacher professional development component ensured implementation fidelity aligned with TPACK principles (Harris et al., 2009), addressing a key limitation in many prior studies where technology was introduced without adequate teacher preparation.

The significant improvement in student engagement corroborates findings from Henrie et al. (2015) and Appleton et al. (2006), and is theoretically consistent with Bandura's (1986) social cognitive framework. The interactive, adaptive, and collaborative features of the technology tools deployed—particularly the PhET simulations and LMS-based feedback mechanisms—likely enhanced students' sense of academic self-efficacy, contributing to sustained cognitive and affective engagement over the intervention period. These findings further align with the constructivist and sociocultural perspectives underpinning TELEs (Vygotsky, 1978; Bransford et al., 2000).

5.2. Absence of Gender Moderation

The non-significant gender × instructional condition interaction supports the findings of Kumar and Rao (2021) and Chou et al. (2012), suggesting that well-designed technology-enhanced environments are equitable in their benefits across genders. This is an encouraging finding in the context of persistent gender disparities in STEM participation in India (Ministry of Education, 2021), as it implies that ICT investment in schools need not inadvertently widen gender achievement gaps. However, this finding should be interpreted cautiously, as the study did not examine attitude towards technology or technology self-efficacy as mediating variables, which prior research suggests may differ by gender (Hattie, 2009).

5.3. Implications for Practice

The findings carry substantive implications for educational policy and classroom practice. For school administrators and curriculum planners within Kerala and analogous Indian state educational systems, the results provide empirical justification for continued investment in KITE-aligned digital infrastructure and, critically, in sustained teacher professional development. The study underscores that hardware provision alone is insufficient; pedagogically informed deployment, underpinned by TPACK-oriented training, is essential for realizing achievement gains (Harris et al., 2009; Higgins et al., 2012). At the classroom level, teachers are encouraged to leverage simulation-based learning, collaborative digital projects, and LMS-mediated feedback to maximize both cognitive and affective engagement.

5.4. Limitations

Several limitations warrant consideration when interpreting these findings. First, the quasi-experimental design, while strengthened by baseline equivalence and ANCOVA controls, cannot fully eliminate selection bias inherent to intact group assignment. Second, the sample was drawn from a single district in Kerala, limiting generalizability to other Indian states or international contexts with differing infrastructure and socioeconomic profiles. Third, the Hawthorne effect—whereby students in the experimental condition may have performed better simply due to the novelty of the intervention—cannot be entirely ruled out, though the 18-week duration reduces this concern. Fourth, the study did not collect data on teacher fidelity to the TPACK-informed lesson plans, representing a confound in interpreting achievement differences. Finally, long-term retention effects beyond the intervention period were not examined.

5.5. Directions for Future Research

Future research should employ true randomization through cluster-randomized trials to strengthen causal inference. Longitudinal designs tracking students across multiple academic years would illuminate whether technology-integration effects persist or diminish over time. Researchers should examine mediating mechanisms—such as self-efficacy, metacognitive strategy use, and teacher instructional quality—to better understand the causal pathways through which TELEs influence outcomes. Comparative studies across different Indian states with varying ICT investment profiles are also warranted to inform national education policy (National Education Policy, 2020).

IV. CONCLUSION

This study provides compelling quasi-experimental evidence that technology-enhanced learning environments significantly improve academic achievement and student engagement in secondary education. Drawing on sociocultural and social cognitive theoretical frameworks, the findings demonstrate that strategic, pedagogically informed technology integration—supported by comprehensive teacher professional development—yields large and meaningful educational benefits for Grade 9 and Grade 10 students in Kerala, India. The absence of differential gender effects further affirms the equity potential of well-implemented TELEs. These results strongly advocate for evidence-based scaling of technology integration initiatives within Indian secondary education, with sustained investment in both infrastructure and teacher capacity.

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