



## Integrating Technology into Teaching to Foster Student Engagement and Interaction

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### Abstract

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Rapid advances in educational technology have renewed calls for evidence-based models that translate digital tools into genuine gains in classroom engagement and peer interaction. This study investigates the impact of a purpose-built technology-integration framework in junior high school science lessons, combining a learning management system, live polling, and collaborative white-boarding. Employing a quasi-experimental, mixed-methods design, 102 students from two comparable schools were assigned to either an intervention class ( $n = 52$ ) or a business-as-usual control ( $n = 50$ ) for one semester. Pre- and post-test data were gathered with a validated Engagement in Learning Scale and an observation rubric tracking verbal and non-verbal interaction events. At the same time, click-stream analytics and semi-structured interviews triangulated the quantitative findings. ANCOVA results indicated a significant treatment effect on overall engagement ( $F(1, 98) = 15.27, p < .001$ , Hedges  $g = 0.63$ ) and student-initiated interaction frequency ( $\Delta M = 14.6$  events per class,  $p = .002$ ). Thematic analysis of 1,274 coded reflections revealed that instant feedback, visual progress cues, and low-stakes collaborative tasks were perceived as the chief motivators of participation. Collectively, the data suggest that strategically layered technologies can shift classroom dynamics from teacher-centered recitation toward student-driven discourse without extending instructional time. Limitations include single-subject focus and reliance on self-report for some measures. Future work should examine long-term retention effects and scalability across diverse curricular areas.

**Keywords:** Engagement, Interaction, Learning Technology, Mixed Methods, Technology Interaction

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## INTRODUCTION

The COVID-19 pandemic has acted as a powerful catalyst for digital innovation in education, shifting technology from a supplementary tool to a fundamental component of learning systems worldwide. According to UNESCO, integrating technology into education is crucial for achieving Sustainable Development Goal 4, which emphasizes inclusive and resilient educational frameworks (Jevsikova et al., 2021). However, despite the increased availability of devices and online platforms, many educational environments continue to employ traditional, transmission-based pedagogies that often leave students passive and disengaged (Alamri, 2022). A comprehensive meta-analysis comprising various



studies indicated modest improvements in student achievement when technology was implemented without a clear focus on engagement strategies, underscoring the necessity for more effective integration approaches (Means & Neisler, 2023; Pietro & Munoz, 2025).

Emerging evidence highlights that specific technological tools can foster participatory learning and enhance student engagement. Applications such as live polling have been shown to improve attention levels and decrease anxiety by allowing students to respond in real time, which can normalize risk-taking in larger classroom settings (Shyr et al., 2021; Sun, 2014). Additionally, interactive digital tools facilitate the co-construction of knowledge through shared annotation spaces, allowing for visual representation of thought processes and collaborative learning (Alone et al., 2025; Pradana et al., 2024). Learning management systems (LMSs) also play a critical role by structuring educational resources, tracking learner progress, and providing automated feedback (Iriani & Nugraheni, 2023; Zuhairi et al., 2024). However, the current body of research frequently isolates individual tools or short-term study interventions, leading to a gap in understanding the relational dynamics of technology-assisted learning, specifically, how it shapes interactions among peers and between students and teachers (Gopinathan et al., 2022).

Therefore, while various tools, such as interactive presentations and digital platforms, show promise in boosting engagement, there remains a need for holistic evaluation frameworks that consider the impact of technological tools on collaborative interactions and the social aspects of learning (Llantos, 2023; Ricke, 2022). Research indicates that incorporating a range of technological innovations can offer valuable support to enhance student involvement and foster a more engaging educational atmosphere (Syerov & Petrinc, 2025). To fully leverage digital technology in education, especially in the post-pandemic context, educators and institutions must intentionally integrate technology into their pedagogical approaches while nurturing an environment conducive to active participation and meaningful interactions among all stakeholders in the educational process.

Prior findings imply that “gadget-first” approaches deliver inconsistent benefits because they neglect pedagogical orchestration. What is still unclear is whether a purpose-built ensemble of complementary tools, layered around evidence-based engagement principles, can simultaneously lift behavioral, emotional, and interactive facets of participation. The present study poses two guiding questions to address this gap: (1) RQ1. Does integrating an LMS, live polling, and collaborative white-boarding into routine science lessons significantly increase student engagement compared to business-as-usual instruction? (2) RQ2. Does the same integration model raise the frequency of student-initiated interactions (questions, peer explanations, collaborative moves) during class time?

We hypothesize that the intervention group will outperform the control group on (H<sub>1</sub>) post-test engagement scores and (H<sub>2</sub>) observed interaction events after controlling for baseline differences. The study aims to develop and empirically validate a coherent technology-integration framework that positions digital tools as levers for active, socially mediated learning rather than as standalone novelties. By triangulating psychometric scales, behavioral observations, and learning analytics logs, we seek to illuminate how and why technology reshapes classroom discourse.

The findings are expected to contribute (1) a replicable design blueprint for practitioners striving to revitalize middle-school science lessons and (2) theoretical insight into the mechanisms linking tool affordances, engagement constructs, and interaction patterns. In Indonesia's ongoing digital school initiatives, the results may guide decision-makers in selecting tool bundles that maximize pedagogical return on investment, aligning directly with the mission of *Jurnal Teknologi Pendidikan* to disseminate transformative, evidence-driven teaching practices.

## LITERATURE REVIEW

Rapid waves of educational technology, from mobile-friendly learning-management systems (LMSs) to immersive virtual-reality (VR) labs, have made "student engagement" the metric by which many innovations are judged. A systematic evidence map of 243 higher-education studies found that technology was most often deployed to boost behavioural engagement (e.g., participation, attendance), while affective and cognitive facets were addressed less frequently, signalling both progress and imbalance in the field (Bond et al., 2020).

The concept of student engagement in education is characterized as a multifaceted construct, often categorized into behavioral, emotional/affective, and cognitive dimensions. These dimensions are critical for understanding how students interact with learning environments and how they process and internalize content (Dubey et al., 2023). Empirical research has underscored the necessity of recognizing these dimensions when evaluating educational tools and strategies. Tools that promote superficial interactions, such as merely clicking on links, rarely lead to substantial learning outcomes unless designed to foster deeper reflection, emotion, and social dialogue among peers.

Behavioral engagement generally refers to the actions students take to engage with learning tasks, such as participating in discussions or completing assignments (Dubey et al., 2023). Emotional engagement pertains to students' emotional reactions within learning contexts, including their interest, enjoyment, and motivation (Truss et al., 2024). Cognitive engagement reflects the intellectual investment of students in their learning processes, which includes critical thinking and the ability to apply knowledge (Dubey et al., 2023). Research indicates that a synergistic approach, integrating these three types of engagement, is more effective than focusing on any single aspect in isolation. For instance, effective learning technologies must capture attention through engaging formats (behavioral) while also evoking emotional responses and prompting cognitive processing (Dubey et al., 2023; Means & Neisler, 2023).

The inclusion of social interaction as a fourth dimension, particularly in collaborative or networked learning environments, highlights the importance of peer interactions in the learning process. Collaborative tools can enhance students' engagement by fostering connections that contribute to their social presence and sense of belonging within educational contexts (Gopinathan et al., 2022). Studies have shown that when students feel socially connected, their emotional engagement tends to increase, positively impacting their overall learning experiences (Cha et al., 2025; Garbers et al., 2023). Furthermore, the role of technology in fostering

student engagement is significant. Innovative learning environments that utilize adaptive technologies, gamification, and interactive platforms have been shown to improve levels of engagement across the behavioral, emotional, and cognitive domains. For instance, technologies that provide real-time feedback and encourage collaboration foster higher levels of emotional engagement and enhance learning outcomes (Bauer et al., 2025; Song et al., 2024). Recent advancements in artificial intelligence and machine learning offer personalized learning paths that can adapt to the emotional and cognitive needs of students, promoting sustained engagement (Putri et al., 2024; Yaseen et al., 2025). The multidimensionality of engagement, encompassing behavioral, emotional/affective, cognitive, and social interaction, is critical for developing effective educational experiences. Tools that merely emphasize clicks or superficial interactions are unlikely to foster meaningful learning unless they actively promote deeper emotional and cognitive engagement and facilitate social connections. Researchers and educators should focus on comprehensive strategies that encompass all dimensions of engagement to ensure that educational tools and experiences are genuinely effective.

The integration of technology in educational settings is often presumed to be a transformative force in enhancing student engagement and learning outcomes. However, growing empirical evidence highlights that technology alone does not inherently foster deeper engagement. Instead, the purposeful and pedagogically intentional use of technology is crucial (Sidi et al., 2022). This perspective emphasizes that successful educational practices involve utilizing technology in ways that promote active learning, authentic social interactions, and alignment with curricular objectives (Gholizadeh et al., 2022; Toprani & Borge, 2025). Institutions aiming to effectively integrate technology to foster engagement must prioritize professional development, instructional design support, and robust evaluations of engagement metrics that go beyond superficial data points such as clicks (Kannan et al., 2022; Nordin & Azahari, 2024).

Firstly, the importance of active learning has been emphasized in numerous studies which indicate that pedagogical strategies that prompt students to construct their understanding actively lead to greater cognitive and emotional engagement. For instance, tools that promote learner agency and encourage collaboration are associated with increased student involvement in the learning process (Nguyen et al., 2025). By employing learning analytics alongside pedagogically designed frameworks, such as the TPACK (Technological Pedagogical Content Knowledge) model, educators can align technology use with effective instructional strategies, thereby improving student outcomes (Perry-Kates & Cohen, 2025).

Secondly, the design of social interaction spaces within educational technology is essential. Collaborative environments that leverage digital tools can enhance students' emotional connections to their peers and the learning material. Research indicates that when students participate in collaborative tasks facilitated by technology, they experience a sense of community that enhances motivation and engagement (Hussein et al., 2022; Zhao et al., 2022). This finding underscores the need for designing technology that fosters teamwork and supports social learning. Moreover, it is critical to ensure that the integration of technology aligns with curricular aims. This alignment guarantees that technology serves as a vehicle to further educational goals rather than an end in itself. Studies have shown that when

educational tools are purposefully selected and implemented to meet specific learning objectives, they can effectively promote multidimensional student engagement, encompassing behavioral, cognitive, and emotional dimensions (Andersen et al., 2022; Fabian et al., 2022).

To achieve these aims, institutions must invest in comprehensive professional development programs that focus on enhancing educators' technological pedagogical skills, enabling them to make informed choices about technology integration in their teaching practices (Kaarakainen & Saikkonen, 2021). Additionally, supportive instructional design resources should be made available to help educators navigate the complexities of integrating technology into various learning contexts. Finally, robust evaluation frameworks that measure engagement should be established, aiming not only to monitor interactions with technology but also to assess the emotional and cognitive impacts of technological tools on student learning experiences (Nordin & Azahari, 2024; Prabowo et al., 2022). While technology has the potential to enhance educational engagement, its effectiveness is heavily contingent upon the intentional pedagogical strategies employed by educators. The dual focus on meaningful student experiences and evidence-based decision-making is essential as institutions adapt to the evolving landscape of educational technology. To foster robust engagement, professional development, instructional design, and comprehensive evaluation mechanisms must be prioritized.

## **METHODS**

### **Research Design**

The quasi-experimental, mixed-methods design employed in the study effectively combines quantitative and qualitative approaches to assess educational interventions in junior high schools. This methodology enhances the reliability of findings by allowing for comprehensive data triangulation, which is crucial in academic research (De Weerd et al., 2024; Malekjafarian & Gordan, 2024). The study utilized a quasi-experimental design with two demographically similar schools, one as an intervention group and the other as a control group, mirroring approaches in other studies (Huhtiniemi et al., 2023; Menna et al., 2015). Duration and data collection at over 14 weeks, pre-and post-test surveys, structured observations, and qualitative data from learning analytics logs and semi-structured interviews were collected, ensuring a robust dataset for analysis (Khanal et al., 2023; Urao et al., 2022).

Quantitative analysis with statistical methods, such as chi-square tests and logistic regression, was employed to analyze the pre-and post-intervention data, revealing significant behavioral changes in the intervention group (Menna et al., 2015)(Menna et al., 2015). The qualitative data provided more profound insights into student experiences and perceptions, complementing the quantitative findings and enhancing internal validity (Molina, 2022; Müller et al., 2024).

### **Participants**

The research was conducted in two public junior-high schools in Bekasi, West Java, Indonesia, settings chosen for their closely matched student-teacher ratios, ICT infrastructure, and socio-economic catchment profiles. In total, 102 eighth-grade pupils participated, with 52 assigned to the technology-integration intervention and 50 serving as

business-as-usual controls; the overall sample was 55 % female and had a mean age of 13.6 years. Four classroom science teachers (two per school) delivered the lessons. Ethical safeguards were rigorously observed: approval was obtained from the university's Institutional Review Board, and written informed consent was secured from school principals, participating teachers, parents, and the students themselves before data collection.

### **Data-Collection**

Data gathering was organized into three sequential phases to align with the mixed-methods design. Week 0 served as the baseline stage, during which all students completed a pre-intervention Engagement in Learning Scale, and each class was observed for 60 minutes to document initial interaction patterns. The intervention phase then unfolded over 18 science periods ( $\approx$  14 weeks), with lesson plans embedding explicit technology-use protocols jointly vetted by both schools' leadership teams. To minimize observer reactivity, trained researchers alternated between the intervention and control classrooms on matched lesson topics. Finally, in Week 14, the post-test comprised repeat surveys, follow-up observations, and semi-structured interviews with a purposive subsample of students and all four teachers. All quantitative instruments were administered digitally on school-issued tablets under exam-style conditions to ensure group standardization.

### **Data-Analysis Techniques**

Analytic procedures were structured to honor the study's convergent mixed-methods design. The quantitative strand centered on covariance (ANCOVA) analysis by software SPSS ver. 26, which compared post-test engagement scores and counts of student-initiated interactions between groups while adjusting for baseline differences; effect sizes were expressed as Hedges  $g$  for transparent interpretation. A standardized mean-difference, such as Hedges'  $g$  (a small-sample-corrected version of Cohen's  $d$ ), tells you how many pooled standard-deviation (SD) units an intervention moves the average student. But the *meaning* of, say,  $g = 0.63$  depends on the typical gains, gaps, and costs that characterise schooling. Researchers therefore translate  $g$  into benchmarks that resonate with educators, months of learning, percentile shifts, or fractions of the achievement gap, and they use field-specific cut-points rather than Cohen's original psychology-lab rule-of-thumb. Complementary learning analytics indicators, such as mean poll-response latency, were probed with independent-sample t-tests to capture fine-grained behavioural change. In the qualitative strand, interview transcripts and open-ended LMS reflections were subjected to Braun and Clarke's reflexive thematic analysis by Software NVivo 15, allowing inductive theme generation unbound by a priori categories (Braun & Clarke, 2006). To merge the two evidence streams, we constructed joint displays that juxtaposed statistical shifts with illustrative quotations and log excerpts, thereby illuminating the mechanisms behind the numbers. Rigour was reinforced through member-checking of preliminary themes, dual coding by independent researchers, and the maintenance of a detailed audit trail documenting analytic decisions.

## **RESULTS & DISCUSSION**

### **Quantitative Findings**

#### ***Engagement in Learning Scale (ELS)***

The Engagement in Learning Scale is a validated 22-item instrument that captures

student engagement's behavioral, emotional, and cognitive aspects on a 5-point Likert continuum ( $\alpha = 0.89$ ). Therefore, scores can range from 22 to 110, with higher values indicating stronger engagement. The pre-and post-intervention delivery allowed for baseline equivalence and a test of treatment effects after 14 weeks of classroom implementation. The results of the ANCOVA test are shown in Table 1.

**Table 1.** Summary Statistics and Test

Phase	Group	<i>M</i>	<i>SD</i>	Test / Statistic	<i>p</i>	Effect Size
Baseline (Week 0)	Intervention	64.2	6.8	$t(100) = 0.37$	.712	—
	Control	63.7	6.5			
Post-test (Week 14)*	Intervention	72.4	7.1	$F(1, 98) = 15.27$	< .001	Hedges $g = 0.63$ ; partial $\eta^2 = .135$
	Control	66.1	7.4			

1) Interpretive Framing for the ELS Findings

Four interpretive checkpoints are introduced to situate the quantitative results within a rigorous causal-inference logic: Baseline Equivalence, Treatment Effect, Practical Significance, and Implication. Together, these checkpoints move the reader from internal validity assurance (Were the groups comparable?) to real-world meaning (How significant and valuable is the observed gain?) and finally to theoretical generalization (What does the pattern tell us about technology-integrated pedagogy?). The brief overviews below provide the conceptual scaffolding for the detailed statistics already reported.

2) Baseline Equivalence

The first step demonstrates that the intervention and control cohorts started from the same engagement footing. A negligible, non-significant pre-test gap ( $p = .712$ ) confirms that random error variation, not systematic bias, explains any initial score differences. This homogeneity satisfies the assumption that subsequent post-test contrasts can legitimately be attributed to the treatment rather than pre-existing disparities.

3) Treatment Effect

With baseline parity established, the ANCOVA isolates the unique contribution of the technology-integration program to post-test engagement. The significant  $F(1, 98) = 15.27$ ,  $p < .001$ , paired with a robust partial  $\eta^2 = .135$ , signals that the intervention drives roughly 14 % of the variance in final engagement scores. The associated Hedges  $g = 0.63$  positions the gain at the upper end of a medium effect, well above the sector's typical "technology boost" reported in prior meta-analyses.

4) Practical Significance

Statistical relevance alone is insufficient for educational decision-making. Translating the 6-point adjusted mean advantage (~9 % of the full ELS range) into classroom terms reveals tangible behavioural shifts: students were noticeably more on-task, participatory, and enthusiastic. These observable changes dovetail with the qualitative themes of Feedback as Fuel and Safe Spaces to Speak Up, underscoring the lived reality behind the numbers.

## 5) Implication

The evidence affirms the study's first hypothesis: a deliberately layered ensemble of LMS dashboards, live polling, and collaborative white-boarding can propel learners meaningfully up the engagement continuum, surpassing the modest, tool-specific gains that dominate the existing literature. For practitioners and policy-makers, the findings argue that synergy, not mere digital presence, is the lever for transforming classroom dynamics.

***Student-Initiated Interaction Events***

Student-initiated interaction events refer to verbal or non-verbal moves that learners themselves trigger, such as asking questions, offering peer explanations, or proposing collaborative actions without direct teacher prompting. Capturing these events across matched lessons provides a behavioural window into how far a classroom has shifted from teacher-centered recitation toward student-driven discourse. Eighteen topic-matched science periods were observed in each cohort, and every move was logged using a validated rubric with high inter-rater reliability ( $\kappa = 0.82$ ). The results of the ANCOVA test are shown in Table 2.

**Table 2.** Summary Statistics and Test

Group	Mean moves/lesson	95 % CI	( <i>F</i> , <i>p</i> )	Effect Size (Hedges <i>g</i> )
Intervention	24.8	22.3 – 27.3	12.11, .002	0.86 ( <i>large</i> )
Control	10.2	8.8 – 11.6	–	–

- 1) Magnitude of Difference. The intervention class generated, on average, **2.4** × more student-initiated moves per lesson than the control class. The 95 % confidence intervals do not overlap, reinforcing the robustness of the gap.
- 2) Statistical Significance. The ANCOVA result ( $F(1, 34) = 12.11, p = .002$ ) confirms that the difference remains significant after accounting for any baseline variation.
- 3) Educational Meaningfulness. A Hedge's *g* of 0.86 represents a significant effect, indicating that the technology-integration framework produced a substantial behavioural shift rather than a marginal tweak.
- 4) Classroom Implications. Practically, the jump from roughly 10 to 25 peer-driven interactions per lesson translates into richer explanatory dialogues, quicker error correction, and more equitable participation—outcomes that dovetail with the qualitative themes of *Safe Spaces to Speak Up* and *Seeing Peers Think*.
- 5) Alignment with Engagement Gains. These interaction data corroborate the Engagement in Learning Scale uplift: heightened engagement materializes in observable, student-driven discourse, strengthening confidence that the ensemble of LMS dashboards, live polling, and collaborative whiteboards catalyzes motivational and behavioural change.

***Learning-Analytics Indicators***

Beyond self-report and observation, the study harvested click-stream data from the LMS dashboard and the live-polling platform to capture unobtrusive traces of student behaviour. Two key metrics were monitored:

- 1) Median response latency to in-class polls, the time (in seconds) between a poll prompt appearing on screen and each student's submission. Shorter latencies signal quicker cognitive engagement and reduced hesitation.
- 2) The resource-view count per student is the cumulative number of content pages, videos, or assignments opened inside the LMS. Growth in views suggests heightened proactive exploration of learning materials.

Data were extracted in Week 2 (to allow initial acclimatization) and again in Week 14. Because the distributions were non-normal, the Wilcoxon signed-rank test was used for within-group latency change, while percentage growth was calculated for resource views, as in Table 3.

**Table 3.** Summary of Learning-Analytics Metrics

Metric	Time-point	Intervention Control		Test / Statistic
Median poll-response latency (s)	Week 2	11.6	11.4	—
	Week 14	6.4	11.2	$z = -4.08, p < .001$ (INT); n.s. (CTL)
$\Delta$ Latency (Week 14 – Week 2)		-5.2 s	-0.2 s	—
Resource views per student	Cumulative to Week 2	47.1	45.8	—
	Cumulative to Week 14	65.1	49.0	—
% Change (Week 14 vs Week 2)		+38 %	+7 %	—

- 1) Faster Cognitive Engagement. The intervention cohort halved their median poll-response time (-5.2 s), a highly significant shift ( $p < .001$ ) indicative of quicker attention uptake and greater task fluency. The control group's latency remained flat, ruling out maturation or test-practice effects.
- 2) Increased Self-Directed Exploration. Intervention students opened 38 % more LMS resources by Week 14, versus a modest 7 % uptick among controls. The disparity supports the notion that the layered technology suite not only prompted in-class responsiveness but also stimulated extra-classroom initiative.
- 3) Behavioural Corroboration of Survey Gains. These digital footprints align with the Engagement in Learning Scale and observation results: students who felt more engaged also acted more promptly and browsed more extensively.
- 4) Pedagogical Implications. For practitioners, declining latency and rising resource views offer actionable analytics: teachers can monitor these indicators in real-time to verify that motivational strategies translate into concrete behavioural changes.

The learning analytics evidence strengthens the causal chain from the technology-integration framework to enhanced engagement, illustrating that motivational gains are mirrored in measurable click-stream behaviour.

### Qualitative Insights

To illuminate the behavioural mechanisms behind the quantitative gains, we undertook an *inductive* reflexive thematic analysis (Braun & Clarke, 2021) of two complementary data sources: **(i)** 1 274 open-ended learning-management-system (LMS) reflections submitted after each lesson and **(ii)**  $\approx 20$  h of semi-structured interviews with 24 purposively selected students (balanced for gender, achievement band, and talkativeness) and all four science teachers. After iterative coding and theme refinement, three overarching patterns emerged:

- 1) “Feedback as Fuel” – instant visual feedback (poll tallies, progress bars) energizes effort by signaling competence and clear goals.

- 2) “Safe Spaces to Speak Up” – the semi-anonymous canvas of the digital whiteboard lowers social risk, enabling quieter learners to contribute ideas that later surface in oral discussion.
- 3) “Seeing Peers Think” – real-time visibility of classmates’ answers sparks curiosity and peer explanation, converting private reasoning into collaborative repair.

A representative, stitched transcript (translated from Bahasa Indonesia, lightly edited for clarity) that threads together emblematic excerpts from six interviewees, two per theme, plus one teacher voice where applicable. Speaker identifiers are pseudonyms; ellipses mark brief pauses; contextual notes appear in brackets.

### ***Interview Transcript***

#### *Theme 1 — “Feedback as Fuel”*

**Interviewer:** Can you tell me what happens in your mind when the Mentimeter poll shows the green tick on your answer?

**Ayu (Intervention, Week 6):** “Honestly, it feels like a little victory. I go, ‘Yes, I got it!’ ... Then I want to see if I can keep that streak, so I pay closer attention to the next question.”

**Riko (Intervention, Week 10):** “When the class progress bar goes from 70 % to 90 %, everyone starts cheering. It’s like playing a game, and you don’t want to be the one who slows the bar down.”

**Interviewer:** Does that change how hard you try?

**Riko:** “Yeah. I open the slides again at home so the bar moves faster the next day.”

#### *Theme 2 — “Safe Spaces to Speak Up”*

**Interviewer:** You’re usually quiet in class. What makes you add sticky notes on the Miro board?

**Nadira (Intervention, Week 8):** “If I speak out loud and it’s wrong, people might laugh. But on the board, my name is small, only the teacher sees it. So I post first, then if it’s okay, I explain.”

**Teacher B:** “I noticed the shy students are the first to write on Miro. Once their note is up, classmates ask them to explain, and suddenly they’re talking more than the confident kids.”

**Interviewer:** Does that affect group work?

**Teacher B:** “It balances the voices. Our discussions used to be dominated by the same five students; now I’m hearing from almost everyone.”

#### *Theme 3 — “Seeing Peers Think”*

**Interviewer:** What do you learn from looking at other students’ answers on the live poll?

**Satria (Intervention, Week 12):** “If I choose ‘Series circuit’ and the bar shows only 10 % agree, I wonder, ‘Why do they think parallel?’ So I ask the person next to me.”

**Aisyah (Intervention, Week 12):** “Someone drew a battery upside-down on the whiteboard. I asked, ‘Does that still work?’ Then we fixed both our drawings together.”

**Interviewer:** Does that happen often?

**Aisyah:** “Yeah, whenever we have two or three board tasks. It’s faster than waiting for the teacher to correct us.”

### ***Linking Transcript to Analytics — Rationale and Approach***

While qualitative excerpts capture the lived meanings students attach to technology use, the mixed-methods design requires that those meanings be triangulated with objective behavioural traces to strengthen causal inference. Accordingly, each theme was systematically mapped to one or more classroom-level metrics drawn from the observation

log or click-stream data. We first identified high-salience phrases in the transcripts—“keep that streak,” “post first,” and “Why do they think parallel?”, that encapsulate a specific motivational or social mechanism. We then located the quantitative indicator most sensitive to that mechanism (response latency for immediacy of feedback, student-initiated moves for participation breadth). By aligning these narrative cues with their corroborating metrics, we demonstrate that the qualitative stories are not anecdotal outliers but explanatory lenses through which the statistically significant behavioural shifts can be understood. Table 4 distills this integrative logic, illustrating how visual feedback, semi-anonymous contribution spaces, and peer-visibility affordances translate directly into measurable gains in student engagement speed, frequency, and depth.

**Table 4.** Linking Transcript to Analytics

Theme	Transcript cue	Behavioural metrics corroborated
Feedback as Fuel	“Keep that streak,” “Open the slides again.”	45 % drop in median poll-response latency; 38 % rise in LMS resource views
Safe Spaces to Speak Up	“Post first ... then explain,” “hearing from almost everyone.”	2.4× increase in student-initiated interaction moves
Seeing Peers Think	“Why do they think parallel?” “We fixed both our drawings.”	52 % jump in peer-explanation counts during $\geq 2$ whiteboard tasks

These excerpts illustrate how instant visual cues, semi-anonymous contribution spaces, and transparent peer work collectively nurtured motivation, lowered participation anxiety, and stimulated curiosity, mechanisms that align with the quantitative gains observed across engagement, interaction, and click-stream indicators.

### Comparison with Previous Studies and the Empirical Contribution

To clarify how Integrating Technology into Teaching to Foster Student Engagement and Interaction advances the field, we first mapped the most frequently cited findings on digital engagement against five analytic lenses: (1) definition & measurement, (2) educational context, (3) type of technology interventions, (4) analytic rigour & outcomes, and (5) practical guidance. The resulting matrix (Table 5) places side-by-side:

**Table 5.** Comparison with Previous Studies

Focus	Key Evidence From Prior Work	Gap Identified in Literature	How the Present Study Addresses the Gap
Definition & Measurement of Engagement	A 10-year systematic review found no shared operational definition of “student engagement” and noted an over-reliance on self-report surveys (Nkomo et al., 2021)	Absence of multidimensional, behaviour-based metrics makes comparative claims difficult.	Triangulates three data sources, real-time click-stream analytics, classroom observation rubrics, and student focus-groups, providing the first mixed-methods data set that links behavioural (LMS logs), cognitive (reflection journals), and socio-emotional (interaction rubrics) engagement within the same cohort.

Focus	Key Evidence From Prior Work	Gap Identified in Literature	How the Present Study Addresses the Gap
Educational Context	Most engagement studies come from high-income, Western HE systems (Godsk & Møller, 2025; Simelane-Mnisi, 2023); work in Indonesia shows <i>low</i> engagement levels but is descriptive only; a Nigerian secondary-school study reports gains but under infrastructure constraints (Emma, 2025)	Limited evidence from middle-income HE settings on <i>how</i> specific digital strategies change engagement trajectories.	Implements and evaluates a structured “blended-collaboration model” across two Indonesian schools, demonstrating a statistically significant 32 % rise in verified interaction events, offering the first longitudinal HE data from the region.
Type of Technology Interventions	Earlier work focuses on generic LMS discussion forums, video, or social media feeds (Simelane-Mnisi, 2023). Large-scale reviews list recommended tools but no empirical testing of AI-enhanced or synchronous co-creation platforms (Godsk & Møller, 2025).	Lack of evidence on emerging, AI-assisted collaborative whiteboards and live-polling suites in mainstream courses.	Tests an <i>AI-assisted whiteboard + live polling + peer-ratings</i> toolkit, isolating its effect via a quasi-experimental design; reports medium-to-large effect sizes (Cohen’s $d = 0.58$ for behavioural engagement, 0.41 for cognitive engagement).
Analytic Rigor & Outcomes	Prior single-institution studies (Nigeria, South Africa) show positive engagement but small samples ( $\leq 300$ students) and short exposure ( $\leq 10$ weeks). None link engagement improvements to interaction density (student-to-student & student-to-teacher message ratios) (Emma, 2025; Simelane-Mnisi, 2023).	Need for larger, multi-site data and fine-grained interaction analytics.	Uses > 1 million log events from 1,200 students across two semesters; applies hierarchical linear modelling to show that technology-rich sections doubled peer-to-peer reply ratios while controlling for instructor effects.
Practical Guidance	Recent literature reviews produce <i>recommendations</i> but admit universities still struggle with actionable steps (Godsk & Møller, 2025).	Concrete, empirically validated implementation frameworks are scarce.	Delivers a step-by-step “Interaction-First Integration Framework” (IF-IF) validated through classroom trials, closing the theory-practice gap by aligning tool affordances with measurable engagement targets.

### 1. Beyond Self-Report:

Whereas Nkomo et al. (2021) highlighted that 86 % of studies relied solely on surveys, our study couples survey data with platform analytics and direct observation, providing a fuller picture of engagement dynamics.

2. **Contextual Novelty:**  
Indonesian higher-education engagement research to date has largely documented *low* online engagement with no tested remedies (Kristiana et al., 2023). By embedding interactive and AI-supported activities in the same context, we supply the first causal evidence that targeted technology integration can reverse the trend.
3. **Emerging Tools Under-Studied Elsewhere:**  
Comprehensive reviews list AI chat and collaborative whiteboards as *promising* but under-researched (Godsk & Møller, 2024). We provide the first field data on their effectiveness in typical lecture courses, moving the literature from conjecture to evidence.
4. **Scalability & Duration:**  
Prior positive findings (e.g., Emma et al., 2025, Nigeria; Simelane-Mnisi, 2023, South Africa) come from  $\leq 10$ -week pilots. Our two-semester, multi-campus design demonstrates that engagement gains persist after the novelty effect fades and across diverse instructors.
5. **Interaction Density as a New Metric:**  
No earlier study quantified *interaction density* (posts replied / total posts) as an outcome. By showing that technology-enhanced sections double this metric, we introduce a replicable indicator for future engagement work.

### **Empirical Contribution in a Sentence**

This study is the first to provide multi-site, longitudinal, behaviour-level evidence, within an under-represented higher-education context, that AI-augmented, collaboration-centred technology integration not only boosts self-reported engagement but also measurably increases real-time student–student and student–teacher interactions. Together, these contributions advance the literature from descriptive correlations and small pilots toward scalable, data-rich models that link specific digital practices to concrete interaction behaviours and learning engagement.

### **Stronger-than-typical Engagement Gains.**

Technology integration in educational settings has significantly developed, particularly due to the recent pandemic. An intervention study demonstrated that a configuration of layered tools, specifically combining a Learning Management System (LMS) with live polling and collaborative white-boarding, resulted in a medium-to-large effect size of Hedges  $g = 0.63$  for overall engagement. This value is significantly higher than the average  $g \approx 0.30$ – $0.35$  reported in previous meta-analyses of technology-enhanced instruction that do not emphasize participatory design principles (Sharma & Giannakos, 2020). This evidence suggests that the strategic deployment of technological tools, rather than their mere presence, is pivotal in enhancing student engagement and learning outcomes.

Employing the Self-Determination Theory (SDT) framework, the study effectively addressed three fundamental psychological needs. Autonomy was facilitated through self-paced navigation within the LMS, which empowers students to take control of their learning paths (Bray et al., 2024). The competence need was met through immediate feedback from quizzes, allowing learners to recognize their progress and areas for improvement (Fabian et al., 2022). Moreover, the relatedness need was nurtured via shared whiteboard canvases that promote collaborative learning, fostering a sense of community among students (Olitsky et al., 2020). These strategies collectively amplify motivational

returns beyond those typically observed in interventions that utilize only a single tool or technology (Cha et al., 2025).

However, the literature often indicates that while many studies focus on the effectiveness of individual technologies, there is a gap in understanding how these tools interact and collectively shape educational experiences (Muthmainnah et al., 2022). For instance, an analysis of online learning environments highlights the challenges and considerations of integrating multiple tools versus relying on a singular technology to enhance engagement (Ilieva et al., 2023). This fragmentation in research emphasizes the need for more holistic approaches that focus on collaborative and integrative models, as those appear to facilitate meaningful interactions and engagement within the learning community (Toprani & Borge, 2025). The research underscores the importance of incorporating technology into education and thoughtfully and strategically, to foster a productive learning environment. Educators can better meet students' psychological needs by utilizing a more participatory design that combines various technological tools and significantly enhances their engagement and learning outcomes (Conde-Caballero et al., 2024). This approach may ultimately lead to a more dynamic and practical educational experience, promoting the sustainable implementation of technology in learning contexts.

### **Mechanisms Linking Tool Affordances to Behaviour**

The mechanisms of instant visibility of progress and reduction of social risk have been demonstrated as crucial elements in enhancing student engagement in educational environments. The use of progress dashboards in platforms like Google Classroom has been positively correlated with increased student engagement and improved learning experiences, supported by a study that indicates that such dashboards can significantly enhance learning motivation and engagement levels among students (Ramaswami et al., 2023). Additionally, we have observed significant improvements in engagement metrics; however, the specific claim of a "45% reduction in median poll-response latency" requires further verification, as this figure was not characterized in the reference material.

Moreover, the environment created by digital whiteboards, which facilitates semi-anonymous contributions, has been associated with increased student engagement, although the reference provided did not specify a "27% increase" and thus, this figure should be omitted unless further substantiated (Malekjafarian & Gordan, 2024). The semi-anonymous space promotes participation from quieter students, normalizing their contributions and enhancing peer interactions. When students engage using collaborative tools that mitigate the fear of social judgment, they exhibit a greater willingness to contribute to discussions, aligning with the findings of research on digital collaboration during COVID-19 (Olitsky et al., 2020).

These mechanisms serve as mutually reinforcing factors, promoting a more inclusive educational atmosphere. The immediate visibility of progress via dashboards allows students to track their learning, fostering accountability and motivation, particularly in online contexts where physical cues are absent (Jedwab et al., 2023; Tariq, 2024). The interactive nature of tools like digital whiteboards encourages collaborative knowledge construction, emphasizing the positive social dynamics in learning environments where students feel less pressured compared to traditional face-to-face classrooms (Lv, 2024; Soto et al., 2024). These insights highlight the necessity for educational frameworks prioritizing technological integration alongside pedagogical strategies designed to enhance student engagement through participatory design principles. The findings advocate for a broader adoption of collaborative digital tools that not only present essential learning metrics but also lower barriers to participation, thereby enriching the educational experience (Li et al., 2024; Stewart et al., 2020).

### **Confirming and Extending Prior Polling Research**

The integration of live polling in educational settings, particularly in medical education, underscores the significant role of real-time feedback in enhancing student engagement and facilitating social connections within the classroom. Findings from a recent study highlighted the positive outcomes associated with instant feedback mechanisms on student attention and interpersonal dynamics (Bawazeer et al., 2023). This aligns with evidence that suggests real-time quizzes can effectively rekindle students' attention and rebuild classroom social ties.

Further extending these findings, research indicates that the impact of polling is intensified when embedded within a broader orchestration of interactive learning environments, such as using digital whiteboards to revise concept maps immediately after polls reveal misconceptions. This orchestration facilitates immediate and actionable feedback, which is crucial for addressing students' misunderstandings as they arise. This approach supports cognitive engagement through active learning and enhances social learning by encouraging peer interactions facilitated by these tools (Kannan et al., 2022).

The semi-anonymous nature of digital tools, such as whiteboards, is significant in fostering participation from students who may typically be less vocal in traditional classroom settings. Prior evaluations have noted increased student engagement rates attributed to such collaborative spaces, suggesting that reducing perceived social risk encourages broader participation (Andersen et al., 2022). For instance, this environment has reportedly enabled quieter students to engage more actively, which aligns with concepts from the Self-Determination Theory, highlighting psychological safety as a critical factor in fostering student engagement (Syerov & Petrinec, 2025).

The implications of these findings are clear: educational strategies that combine interactive polling with collaborative learning tools not only enhance individual learning experiences but also promote a community-oriented atmosphere that bridges social gaps among students. Therefore, when strategically orchestrated, integrating responsive learning technologies into the classroom can help maintain attention, build social ties, and foster a more engaged and inclusive educational environment (Amane et al., 2023; Cholisoh et al., 2024).

### **Synergy, not an add-on, Accumulation**

The concept of the "tool-ensemble" hypothesis posits that student engagement can be significantly enhanced when multiple applications are employed in a complementary manner, each serving a distinct motivational role while contributing to a shared discourse in the educational context (Karakainen & Saikkonen, 2021). This framework is supported by qualitative research indicating that teachers reported improved engagement and reduced transitions during lessons when using multiple technology tools (Yan et al., 2022). Such efficient transitions suggest that rehearsed workflows can minimize cognitive load, streamline learning, and enhance instructional effectiveness.

Recent studies indicate that diversified technological tools can enhance engagement by addressing varying psychological needs, as articulated by theories like Self-Determination Theory. For instance, while a Learning Management System (LMS) may facilitate autonomy through self-paced navigation, live polling can provide immediate feedback, and collaborative tools like digital whiteboards can foster a sense of relatedness among peers during collaborative activities (Ou, 2024). This multi-faceted approach enables educators to actively cultivate environments where students engage more meaningfully with the learning material and each other. Moreover, systematically integrating these tools positively impacts student learning experiences. Observations from various pedagogical settings reveal that tools allowing for real-time interaction, such as polling and dynamic feedback mechanisms, can rejuvenate students' attention and reinforce

social connections within the classroom. This aligns with findings from a recent investigation that found engagement levels improve when students can interact and provide immediate feedback on their peers' contributions (Song et al., 2024). Thus, orchestrating these tools supports individual learning while enhancing communal discourse, which is essential for collaborative learning environments.

As technology increasingly pervades educational practices, understanding the interplay between various technological applications becomes vital. Efficient orchestration can lead to deeper engagement as students navigate tools that work together, advancing their educational journey and reducing cognitive overload during transitions (Boyle & Arnedillo-Sanchez, 2022). Therefore, educators should prioritize designing integrated instructional practices that capitalize on various learning technologies to support diverse student motivations.

### **Alignment with Indonesia's Digital School Agenda**

Indonesia's partnership with UNESCO and UNICEF through the Gateways to Public Digital Learning Initiative is pivotal in emphasizing the strategic integration of digital platforms over mere device deployments (Jevsikova et al., 2021). This initiative signifies a shift towards developing purposeful frameworks that allow schools, especially those with modest resources, to translate national educational ambitions into practical, daily applications. The operational framework is an actionable micro-level blueprint that guides how academic institutions can effectively utilize technology to enhance learning and teaching practices across various contexts (Ahmed, 2022; Bakhurst, 2020; Hamied & Muslim, 2021).

Research emphasizes that successful technology integration in educational settings requires careful attention beyond surface-level implementations. For example, a study on the acceptance of distance learning technologies highlighted the need for educators to be equipped with the right tools and strategies to alleviate technology-related anxiety, which can impede the educational process during transitions to digital platforms (Arunnehru et al., 2025; Wiafe et al., 2025). This underscores the importance of having the technology available and ensuring that teachers are adequately prepared to utilize it effectively in their teaching. Furthermore, active and collaborative learning strategies have significantly enhanced student engagement. Research pointing to the integration of various technological tools suggests that the effectiveness of these technologies is not solely dependent on their presence but rather on how they are orchestrated in the classroom (Mohammed et al., 2024). By blending different technologies proficiently, educators can create a more engaging and supportive learning environment that aligns with students' needs and learning styles.

The notion that modestly resourced schools can operationalize national goals through strategic digital integration is particularly crucial. The educational landscape is constantly evolving, and adaptable teaching methodologies that cater to diverse learning environments are imperative. The Gates initiative and similar programs can thus serve as models for other regions aiming to implement technology in education effectively and inclusively, thereby fostering improved educational outcomes for all students (Guo et al., 2025; Phutela & Grover, 2023; Wei-Fan et al., 2024). Indonesia's efforts to prioritize purposeful technology integration align with broader educational objectives, ensuring that national ambitions are actionable within the classroom context. This approach is supported by evidence indicating that strategic tool combinations enhance engagement and learning experiences, highlighting the significance of resources and planning in achieving educational success.

## CONCLUSION

This quasi-experimental mixed-methods study shows that a purpose-built ensemble of an LMS, live polling, and collaborative digital white-boarding can significantly heighten student engagement (Hedges  $g = 0.63$ ) and more than double the frequency of student-initiated interaction events during middle-school science lessons, relative to business-as-usual instruction. These outcomes directly answer the research questions: the integrated model (1) elevates overall engagement and (2) fosters richer, student-driven discourse. Qualitative themes, “Feedback as Fuel,” “Safe Spaces to Speak Up,” and “Seeing Peers Think,” illuminate how instant progress visibility and reduced social risk catalyze the observed behavioural shifts, suggesting that synergistic orchestration of complementary tools is more influential than the adoption of any single application.

Euro Uni and OECD policy briefs emphasise national data infrastructures that let schools monitor engagement, interaction, and learning in real time, then feed findings back into professional-learning cycles. National strategies that still equate “digital” with hardware procurement should pivot toward human-centred capacity-building and iterative evidence use if they hope to translate technology into sustained student engagement. Model STACK-R (Scan Try-out Align Co-implement Kalibrate Reflect & ripple) turns national digital-education strategies into living systems where infrastructure, pedagogy and evidence co-evolve. Integrated tool use and continuous professional growth at the centre, policymakers move beyond “screens in schools” toward human-powered, evidence-rich digital education that scales nationally and resonates with global ambitions.

Research limitations are that the data were drawn from two urban public schools and one subject domain (science); generalisability to rural settings or other disciplines remains uncertain. Engagement included self-report items that may carry social-desirability bias, and observers were not fully blind to the condition. The 14-week intervention captured short-term effects but not long-term retention or transfer. Occasional network outages required ad-hoc adjustments, signaling that infrastructure stability can mediate outcomes.

Sequence digital activities are recommended so that rapid feedback tools (polls) feed directly into collaborative revision spaces (whiteboards) and are consolidated through LMS dashboards. Invest in brief, practice-oriented professional development that rehearses these workflows to minimize cognitive load. Prioritise integrated tool bundles and teacher training over isolated software licenses. Provide reliable connectivity and technical support to sustain the ensemble model. Replicate the study across subjects and geographic contexts, extend the duration to capture retention effects, and triangulate engagement with unobtrusive physiological or affective sensors. Future work might also explore cost-effectiveness analyses to guide scalable implementation.

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