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Impact of digital learning tools on numeracy, motivation, and engagement in elementary education

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Abstract: This study investigated the effects of digital technology–integrated mathematics instruction on elementary students' numeracy achievement, learning motivation, classroom engagement, and technology acceptance. A quasi-experimental non-equivalent control group design was employed involving two Grade VI classes (N = 50) from an elementary school in Tanah Tidung Regency, Indonesia. Data were collected using numeracy pretests and posttests, an ARCS-based learning motivation questionnaire, a Technology Acceptance Model (TAM) questionnaire, a classroom engagement observation sheet, and an implementation fidelity checklist. Prior to hypothesis testing, data were examined using the Shapiro–Wilk and Levene's tests. The data were subsequently analyzed using independent samples t-tests, analysis of covariance (ANCOVA), normalized gain (N-Gain), and Cohen's d effect size. The results showed that the experimental group achieved significantly higher numeracy performance than the control group, as reflected by higher posttest scores, a greater normalized gain (0.57 vs. 0.26), and a very large effect size (d = 1.99). ANCOVA further confirmed that the improvement remained significant after controlling for students' initial numeracy ability. Students in the experimental group also demonstrated significantly higher learning motivation across all ARCS dimensions, stronger classroom engagement, and high levels of technology acceptance. These findings indicate that integrating digital technology into mathematics instruction enhances students' cognitive achievement while simultaneously promoting positive motivational and behavioral learning outcomes. The study provides practical evidence supporting the implementation of technology-enhanced mathematics instruction in elementary education, particularly in rural school contexts.

Keywords: Digital technology, learning with technology, mathematics instruction

Abstrak: Penelitian ini mengkaji pengaruh pembelajaran matematika terintegrasi teknologi digital terhadap kemampuan numerasi, motivasi belajar, keterlibatan kelas, dan penerimaan teknologi siswa sekolah dasar. Penelitian ini menggunakan desain kuasi-eksperimen dengan model *non-equivalent control group* yang melibatkan dua kelas VI (N = 50) di salah satu sekolah dasar di Kabupaten Tanah Tidung, Indonesia. Data dikumpulkan melalui pretest dan posttest numerasi, angket motivasi belajar berbasis ARCS, angket *Technology Acceptance Model* (TAM), lembar observasi keterlibatan siswa, dan lembar fidelity implementasi. Sebelum pengujian hipotesis, data dianalisis menggunakan uji Shapiro–Wilk dan Levene. Selanjutnya, data dianalisis menggunakan independent samples t-test, analysis of covariance (ANCOVA), normalized gain (N-Gain), dan ukuran efek Cohen's d. Hasil penelitian menunjukkan bahwa kelompok eksperimen memperoleh capaian numerasi yang secara signifikan lebih tinggi dibandingkan kelompok kontrol, ditunjukkan oleh skor posttest yang lebih tinggi, N-Gain yang lebih besar (0,57 dibandingkan 0,26), serta ukuran efek yang sangat besar (d = 1,99). Hasil ANCOVA juga menegaskan bahwa peningkatan tersebut tetap signifikan setelah mengontrol kemampuan numerasi awal siswa. Siswa pada kelompok eksperimen juga menunjukkan motivasi belajar yang lebih tinggi pada seluruh dimensi ARCS, keterlibatan kelas yang lebih kuat, dan tingkat penerimaan teknologi yang tinggi. Temuan ini menunjukkan bahwa integrasi teknologi digital dalam pembelajaran matematika dapat meningkatkan capaian kognitif siswa sekaligus mendukung aspek motivasional dan perilaku belajar. Penelitian ini memberikan bukti praktis bagi penerapan pembelajaran matematika berbasis teknologi di sekolah dasar, khususnya pada konteks sekolah di wilayah rural.

Kata kunci: Teknologi digital, pembelajaran dengan teknologi, pengajaran matematika

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INTRODUCTION

Elementary mathematics instruction in Indonesia has traditionally relied on non-technological, teacher-centered practices such as lectures, rote memorization, and repetitive workbook exercises. These conventional methods often limit students' opportunities to explore mathematical ideas actively or engage in meaningful problem-solving (Purnomo et al., 2022). As a result, many students struggle to make sense of mathematical concepts, experience low participation, and develop negative perceptions toward mathematics. The absence of visual representations, contextualized tasks, and interactive activities contributes to decreased motivation and engagement during learning, which ultimately hinders the development of essential mathematical skills.

To overcome these limitations, mathematics learning at the elementary level should be designed to be more student-centered, interactive, and contextual. Instruction needs to support conceptual understanding, encourage inquiry, and connect abstract mathematical ideas to students' real-life experiences. Approaches such as Realistic Mathematics Education (RME) emphasize situating mathematical tasks in meaningful contexts to foster deeper reasoning and enhance students' interest (Fauzan et al., 2024; Laurens et al., 2018; Van den Heuvel-Panhuizen & Drijvers, 2020). In addition, effective instruction should consider affective and behavioral dimensions, ensuring that students feel motivated, confident, and actively engaged in the learning process.

Numeracy is widely understood as a core twenty-first-century competence that extends far beyond basic computation, encompassing the ability to apply mathematical concepts to analyze, interpret, and solve real-world problems (Randy et al., 2024). Despite its critical importance, Indonesian students' numeracy performance remains low. Results from PISA 2022 place Indonesia at 68th out of 81 countries in mathematics, indicating significant gaps in mathematical literacy and application (Widyaningrum et al., 2024). These gaps reflect long-standing structural issues, particularly the overreliance on conventional pedagogies that fail to cultivate higher-order thinking, reasoning, and contextual problem-solving (Kalaitzidis, 2026; Othman & Mazlan, 2026; Purnomo et al., 2022).

Low numeracy outcomes are closely intertwined with motivational challenges. According to the ARCS model (Attention, Relevance, Confidence, Satisfaction), learning motivation is essential for sustaining persistence and engagement (Damopolii, 2025). Yet many elementary students experience mathematics as difficult, irrelevant, or intimidating, leading to reduced attention, low confidence, and disengagement. Previous studies suggest that when learning activities lack relevance or fail to provide constructive feedback, students' motivation diminishes, which directly affects their numeracy performance and willingness to solve mathematical problems. Student engagement, behavioral, emotional, and cognitive, is another critical factor influencing numeracy development. Engagement reflects students' participation in tasks, persistence in solving challenges, collaboration with peers, and willingness to explore mathematical ideas (Handaryani et al., 2026). However, traditional instruction offers limited opportunities for active engagement, resulting in passive learning, minimal interaction, and reduced exploration (Kalifah et al., 2025; Runniarsiti et al., 2025; Siregar et al., 2025). As noted by Jiawen et al. (2024), students' numeracy engagement is shaped by both instructional practices and contextual supports; in Indonesia, these supports are often insufficient.

Digital learning tools have emerged as a promising solution to these interconnected challenges. Interactive learning technologies such as GeoGebra, Prodigy, game-based platforms, and simulation-based applications provide multimodal representations, immediate feedback, and opportunities for exploratory learning. Studies show that neuroscience-based games enhance mathematical understanding by stimulating attention and interaction (Procópio et al., 2024), while game-based platforms improve motivation and performance through continuous feedback loops (Decker et al., 2023). Digital tools can visualize abstract concepts, contextualize problem situations, and promote hands-on exploration, thereby supporting both cognitive and affective aspects of mathematics learning (Hidayah et al., 2022; Georgiou & Ioannou, 2021; Ochogboju & Díez-Palomar, 2025).

The integration of digital learning tools has been shown to positively affect numeracy development by enabling students to manipulate representations, practice problem-solving through interactive tasks, and receive real-time corrective feedback. Beyond cognitive gains, digital environments significantly enhance motivation by capturing students' attention, making tasks more relevant, and building confidence through scaffolded challenges (Hidayanthi et al., 2024). Likewise, engagement is strengthened as students become more active, collaborative, and persistent during digital learning activities. Busyairi and Kusuma (2024) highlight that immediate feedback fosters self-regulation and perseverance, while Choi et al. (2022) emphasize that digital literacy supports students' readiness to participate in technology-mediated learning.

Despite these promising findings, research assessing digital learning tools in the Indonesian elementary school context particularly in rural regions such as Tanah Tidung remains limited. Existing studies often focus primarily on cognitive outcomes and overlook motivational, engagement, and technology acceptance dimensions, which are crucial for comprehensive learning improvement. To address this gap, the present study investigates the impact of digital learning tools on numeracy, student motivation (ARCS), engagement, and technology acceptance (TAM) among Grade VI students. The aim is to provide empirical evidence on how technology-enhanced instruction can holistically improve mathematics learning and offer practical implications for strengthening numeracy education in Indonesian elementary schools.

METHOD

Research design

This study employed a quasi-experimental design using a non-equivalent control group model. Two intact Grade VI classes from an elementary school in Tanah Tidung were assigned as the experimental and control groups. The experimental group received mathematics instruction integrated with digital learning tools, whereas the control group received conventional instruction consisting of lectures and paper-based exercises. Both groups completed pretests and posttests to measure changes in numeracy skills. The overall design is summarized in Table 1. This design was selected because intact classes could not be randomly reassigned, and quasi-experimental models are appropriate for maintaining ecological validity in school-based interventions where randomization is impractical.

Table 1. Non-equivalent control group design

Group	Pretest	Treatment (X)	Posttest
Experimental	O1	Digital technology–integrated instruction	O2
Control	O1	Conventional instruction (lecture & exercises)	O2

Participants

The study population included all sixth-grade students at a public elementary school in Tanah Tidung, Indonesia. Two intact classes were purposively selected. One class (n = 25) served as the experimental group, and the other (n = 25) served as the control group, meeting the minimum sample size requirement for parametric analysis (≥ 30 total participants). Group equivalence was examined using pretest numeracy scores prior to treatment implementation. Permission and informed consent were obtained from school administrators and parents before the study commenced.

Research instruments

Numeracy test (Pretest–Posttest).

A researcher-developed 20-item numeracy test was used to assess students' mathematical performance, consisting of 15 multiple-choice and 5 short-answer items. The instrument measured number operations, contextual problem solving, measurement and geometry, data interpretation, and mathematical reasoning. Content validity was established through expert evaluation involving three validators with expertise in mathematics education and educational assessment. Each validator independently reviewed item relevance, clarity, and alignment with learning indicators. The results of the validation showed that all items met acceptable validity criteria, with an average Content Validity Index (CVI) score of 0.87. Minor revisions were made to wording and contextual clarity as recommended by the validators. Reliability testing was conducted through a pilot study at a comparable school outside the research sample. Using Cronbach's Alpha, the internal consistency coefficient for the numeracy test was 0.79, which falls within the acceptable range (≥ 0.70), indicating that the instrument demonstrates stable and reliable measurement properties. Thus, the numeracy test was deemed suitable for use as pretest and posttest instruments in the main study.

Motivation and technology perception questionnaires.

Student motivation was measured using a 12-item ARCS (Attention, Relevance, Confidence, Satisfaction) questionnaire on a 5-point Likert scale, including two reverse-coded items. In addition, the Technology Acceptance Model (TAM) questionnaire, consisting of 8 items measuring perceived usefulness, ease of use, and attitudes toward digital learning, was administered to the experimental group. Both questionnaires underwent expert validation by three validators specializing in educational technology and psychology. Based on the validation process, the items demonstrated strong content relevance and theoretical alignment, resulting in a mean CVI score of 0.89 for the ARCS scale and 0.91 for the TAM scale, confirming high content validity. Several items received recommendations for refinement in wording clarity, which were implemented prior to field use. Reliability testing was conducted using Cronbach's Alpha through a preliminary try-out with students outside the study sample. The ARCS questionnaire produced a reliability coefficient of 0.83, while the TAM scale yielded a coefficient of 0.81. These values exceed the minimum reliability threshold of 0.70, indicating both instruments possess high internal consistency and are suitable for measuring student motivation and technology perception in the main study.

Observation sheet (Engagement)

A structured 10-item observational checklist was developed to capture student engagement during learning activities, focusing on indicators such as focus, participation, collaboration, persistence, and appropriate use of digital tools. Each indicator was rated using a 1–4 scale. The observation instrument was validated by three experts specializing in classroom instruction and behavioral assessment. The resulting mean CVI score was 0.88, indicating strong content validity. Prior to data collection, inter-rater reliability was examined through practice scoring sessions among three trained observers. The reliability agreement score (Cohen's Kappa = 0.82) reflected a high level of scoring consistency.

Fidelity Checklist

To ensure the consistency of treatment implementation, a fidelity checklist was applied across sessions covering availability of resources, sequence of activities, use of feedback, and teacher facilitation.

Research procedures

The study was implemented through a sequence of structured data collection activities designed to compare the effectiveness of digital technology–integrated mathematics instruction with conventional teaching. At the beginning of the study, students in both the experimental and control groups completed an identical numeracy pretest to determine their initial level of mathematical competence and to verify the equivalence of the two groups before the intervention.

The instructional intervention was subsequently conducted over four to six classroom meetings, each lasting approximately 70 minutes. During these lessons, students in the experimental group learned mathematics using interactive digital learning tools, including applications such as GeoGebra, Prodigy, and comparable educational platforms. The instructional activities emphasized visual representations, exploratory learning, interactive problem-solving, and immediate digital feedback to support students' conceptual understanding of mathematical ideas. In contrast, students assigned to the control group received mathematics instruction through conventional classroom practices consisting primarily of teacher explanations, textbook-based learning, and paper-and-pencil exercises without the assistance of digital technology. To ensure that the intervention was implemented consistently across all meetings, implementation fidelity was monitored continuously using a structured fidelity checklist.

Upon completion of the instructional phase, all participants completed the same numeracy assessment as a posttest to evaluate changes in learning achievement. Students' motivational responses toward mathematics learning were subsequently measured using the ARCS Motivation Questionnaire, which was administered to both groups. In addition, students in the experimental group completed the Technology Acceptance Model (TAM) questionnaire to evaluate their perceptions of the usefulness, ease of use, and acceptance of the digital learning tools employed during the intervention.

Students' classroom engagement was documented throughout the intervention using a structured observation protocol that captured behavioral indicators such as attention, participation, collaboration, persistence, and initiative. To improve the consistency of observational data, all observers followed standardized scoring guidelines during every classroom session. Prior to the commencement of the study, permission to conduct the research was obtained from the school administration, and written informed consent was secured from students' parents or legal guardians. As an ethical consideration, students in the control group were provided with opportunities to access the digital learning resources after the completion of the research.

Data analysis

The statistical analysis was conducted in several stages to address the research objectives comprehensively. Initially, descriptive statistics were generated to describe students' numeracy performance in both groups. These descriptive measures included the mean, standard deviation, and normalized gain (N-Gain), providing an overview of students' achievement before and after the instructional intervention.

Before conducting the inferential analyses, the suitability of parametric statistical procedures was evaluated by examining the underlying assumptions. The distribution of the data was assessed using the Shapiro–Wilk test, whereas the equality of variances between the experimental and control groups was evaluated through Levene's test. Only after these assumptions had been satisfied were parametric statistical analyses applied.

Group differences in numeracy achievement were examined using independent samples *t*-tests for both the pretest and posttest scores. The same analytical procedure was employed to compare students' learning motivation, including each of the four ARCS dimensions Attention, Relevance, Confidence, and Satisfaction as well as the composite motivation score. These analyses were intended to determine whether students exposed to digital technology–integrated instruction differed significantly from those receiving conventional mathematics instruction.

To obtain a more rigorous estimate of the instructional effect, an Analysis of Covariance (ANCOVA) was performed using the posttest numeracy score as the outcome variable while controlling for students' pretest numeracy performance. By adjusting for baseline differences, this procedure provided a more precise evaluation of the contribution of the instructional intervention to students' numeracy achievement. The practical significance of the intervention was further assessed through Cohen's *d* effect size, with values interpreted according to the conventional criteria proposed by Cohen (2004), namely 0.20 (small), 0.50 (medium), and 0.80 (large).

Responses to the Technology Acceptance Model (TAM) questionnaire and the classroom engagement observation data were analyzed descriptively. Mean scores and standard deviations were calculated for each dimension to describe students' perceptions of the digital learning environment and their behavioral engagement during the instructional activities. These findings served as complementary evidence for interpreting the quantitative results on numeracy achievement and learning motivation. All analyses were performed using IBM SPSS Statistics, and statistical significance was determined at the 5% level ($\alpha = .05$).

RESULTS AND DISCUSSION

Numeracy test results

To determine whether parametric statistical procedures could be appropriately applied, the distributional characteristics of the numeracy data were examined before testing the research hypotheses. The evaluation focused on two statistical assumptions: the normality of score distributions and the equality of variances between the experimental and control groups. Normality was assessed using the Shapiro–Wilk test, whereas Levene's test was employed to evaluate homogeneity of variances. These analyses were conducted for both the pretest and posttest numeracy scores. The outcomes of the assumption testing are summarized in Table 1.

Table 1. Assumption tests for numeracy scores

Test	Variable	Experimental (n = 25)	Control (n = 25)	Decision
Shapiro–Wilk	Pretest	W = 0.972, p = 0.721	W = 0.965, p = 0.563	Normal
Shapiro–Wilk	Posttest	W = 0.981, p = 0.903	W = 0.975, p = 0.786	Normal
Levene's Test	Pretest	F = 0.083	p = 0.775	Homogeneous
Levene's Test	Posttest	F = 0.247	p = 0.622	Homogeneous

The assumption testing demonstrated that the numeracy data satisfied the requirements for parametric statistical analysis. Across both groups, the Shapiro–Wilk test produced probability values above the .05 criterion for the pretest and posttest scores, indicating that the score distributions did not deviate significantly from normality. Likewise, the results of Levene's test showed no statistically significant differences in variance between the two groups for either measurement occasion, suggesting that the assumption of homogeneous variances was also fulfilled.

Because both statistical assumptions were satisfied, the subsequent comparison of students' numeracy achievement was conducted using parametric procedures. Descriptive statistics were first calculated to summarize students' performance before and after the intervention. These descriptive results, including the pretest and posttest means, standard deviations, and normalized gain (N-gain) scores for both groups, are presented in Table 2.

Table 2. Descriptive statistics of numeracy scores

Group	N	Pretest Mean (SD)	Posttest Mean (SD)	N-Gain (Mean)
Experimental	25	58.40 (7.85)	82.20 (6.95)	0.57
Control	25	57.80 (8.10)	68.60 (7.20)	0.26

Table 2 summarizes students' numeracy performance before and after the instructional intervention. Prior to treatment, both groups demonstrated comparable levels of numeracy, with very similar mean pretest scores (58.40 for the experimental group and 57.80 for the control group). Following the intervention, the experimental group achieved a substantially higher mean posttest score (82.20) than the control group (68.60). Likewise, the normalized gain was more pronounced among students who experienced digital technology–integrated instruction (0.57) than among those who received conventional instruction (0.26), indicating greater improvement in numeracy achievement during the intervention period.

To examine whether these observed differences were statistically meaningful, inferential analyses were subsequently performed. Independent samples t-tests showed no significant difference between the two groups before the intervention ($t(48) = 0.27$, $p = 0.79$), confirming that both groups started from an equivalent level of numeracy achievement. In contrast, the posttest comparison revealed a statistically significant advantage for the experimental group ($t(48) = 6.98$, $p < 0.001$).

To account for potential baseline differences, an Analysis of Covariance (ANCOVA) was conducted using pretest scores as the covariate. After controlling for students' initial numeracy performance, the adjusted posttest scores remained significantly higher for the experimental group ($F(1, 47) = 47.35$, $p < .001$), indicating that the instructional treatment exerted a significant effect on students' numeracy achievement. The magnitude of this effect was substantial, as reflected by a large effect size (Cohen's $d = 1.99$). The detailed results of the independent samples t-tests are presented in Table 3.

Table 3. Independent samples t-test for numeracy scores

Variable	**t**	**df**	**p**	**Interpretation**
Pretest	0.27	48	0.789	Not Significant
Posttest	6.98	48	< 0.001	Significant

The independent samples t-test was conducted to compare numeracy achievement between the experimental and control groups before and after the intervention. As shown in Table 3, no statistically significant difference was identified in the pretest scores ($t(48) = 0.27$, $p = 0.789$), indicating that the two groups were comparable at the beginning of the study. Following the intervention, however, the posttest comparison demonstrated a statistically significant difference ($t(48) = 6.98$, $p < 0.001$), with students in the experimental group obtaining higher numeracy scores than those in the control group.

To determine whether this difference remained after accounting for students' initial numeracy performance, an Analysis of Covariance (ANCOVA) was subsequently performed. The corresponding results, together with the estimated effect size, are presented in Table 4.

Table 4. ANCOVA and Effect Size Results

Analysis	**Value**	**Interpretation**
ANCOVA	F(1,47) = 47.35	p < 0.001
Cohen's d	1.99	Very Large Effect

After adjusting for pretest numeracy scores, the ANCOVA analysis continued to show a statistically significant difference between the two instructional groups ($F(1, 47) = 47.35$, $p < .001$). This finding indicates that the observed posttest difference was not attributable to students' initial numeracy ability. The magnitude of the treatment effect was also substantial, with a Cohen's *d* value of 1.99, which corresponds to a very large effect according to conventional effect size criteria.

Motivation (ARCS Questionnaire)

To determine the appropriate statistical procedure for comparing students' learning motivation, the distribution of the ARCS motivation scores was first evaluated. Normality was assessed separately for each motivation dimension Attention, Relevance, Confidence, Satisfaction—as well as for the overall motivation score using the Shapiro–Wilk test. The results of these analyses are summarized in Table 5.

Table 5. Assumption tests for students' learning motivation scores

Dimension	Group	Shapiro–Wilk (W)	p	Decision
Attention	Experimental	0.975	0.786	Normal
	Control	0.968	0.612	Normal
Relevance	Experimental	0.982	0.914	Normal
	Control	0.973	0.751	Normal
Confidence	Experimental	0.971	0.689	Normal
	Control	0.979	0.864	Normal
Satisfaction	Experimental	0.977	0.823	Normal
	Control	0.966	0.571	Normal
Total Motivation	Experimental	0.984	0.947	Normal
	Control	0.978	0.841	Normal

The normality analysis indicated that all motivation variables followed an approximately normal distribution in both groups. Across all ARCS dimensions and the overall motivation score, the obtained probability values exceeded the .05 criterion, indicating no significant deviation from normality. These findings supported the use of parametric statistical analyses for subsequent group comparisons. Before conducting the comparison of motivation scores, the equality of variances between the experimental and control groups was also evaluated using Levene's test. The outcomes of the homogeneity analysis are presented in Table 6.

Table 6. Homogeneity test for students' learning motivation scores

Dimension	Levene Statistic	p	Decision
Attention	0.312	0.579	Homogeneous
Relevance	0.184	0.670	Homogeneous
Confidence	0.526	0.472	Homogeneous
Satisfaction	0.298	0.587	Homogeneous
Total Motivation	0.411	0.524	Homogeneous

The results presented in Table 6 indicate that the variances of all learning motivation dimensions were homogeneous across the experimental and control groups. Levene's test produced significance values greater than .05 for Attention (p = 0.579), Relevance (p = 0.670), Confidence (p = 0.472), Satisfaction (p = 0.587), and the overall learning motivation score (p = 0.524). These findings indicate that the assumption of homogeneity of variance was satisfied for all variables. Since both the normality and homogeneity assumptions were met, the data fulfilled the requirements for parametric analyses. Therefore, independent samples *t*-tests were subsequently conducted to compare students' learning motivation between the experimental and control groups.

Table 7. Motivation scores by group

Dimension	**Experimental (M ± SD)**	**Control (M ± SD)**	***t*(48)**	***p***
Attention	12.6 ± 1.8	10.8 ± 1.9	3.56	<0.01
Relevance	12.1 ± 1.7	10.9 ± 1.5	2.59	<0.05
Confidence	11.9 ± 1.5	10.2 ± 1.6	3.67	<0.01
Satisfaction	12.0 ± 1.6	10.2 ± 1.4	3.95	<0.001
Total	48.6 ± 5.2	42.1 ± 4.9	3.89	<0.001

The analysis of students' motivation based on the ARCS model revealed clear and consistent differences between the experimental and control groups. As shown in Table 7, the experimental group achieved significantly higher mean scores across all four motivational dimensions—Attention, Relevance, Confidence, and Satisfaction indicating that the integration of digital learning tools positively influenced students' affective engagement with mathematics.

Students in the experimental group reported higher levels of Attention, suggesting that the interactive features embedded in the digital tools—such as animations, visual models, and gamified elements—were successful in capturing their curiosity and maintaining their focus throughout the lessons. The dimension of Relevance also scored higher, implying that the technology-enhanced activities enabled students to perceive mathematics as more meaningful and connected to real-life contexts, an aspect often lacking in conventional instruction.

The Confidence scores indicate that students using digital platforms felt more capable of solving mathematical problems independently. This improvement can be attributed to the immediate feedback provided by the applications, which helped clarify misconceptions and reinforced correct procedures. Moreover, the experimental group's significantly higher Satisfaction scores illustrate that students not only felt more successful but also enjoyed the learning experience, which is aligned with previous findings showing that digital tools enhance learners' emotional engagement and sense of accomplishment.

Taken together, these motivational gains suggest that digital technology does not merely enhance cognitive outcomes but also plays a vital role in strengthening students' internal drive to learn. Increased motivation likely contributed to the large improvements in numeracy performance observed in the experimental group, consistent with the ARCS model's assertion that motivation is a key determinant of sustained effort and academic achievement.

Technology Acceptance Model (TAM) – Experimental group only

The Technology Acceptance Model (TAM) results provide additional insight into how students perceived the digital learning tools used during the intervention. As summarized in Table 8, students in the experimental group demonstrated high levels of acceptance across all three TAM dimensions Perceived Usefulness, Perceived Ease of Use, and

Attitude/Intention to Use indicating a strong positive response toward technology-enhanced mathematics instruction.

Table 8. Technology Acceptance Model (TAM) scores

Dimension	Mean ± SD	Interpretation
Perceived Usefulness	4.25 ± 0.45	High
Perceived Ease of Use	4.10 ± 0.50	High
Attitude/Intention	4.20 ± 0.48	High
Total TAM	33.8 ± 3.2 / 40	Positive acceptance

The high Perceived Usefulness score suggests that students believed the digital tools played a meaningful role in improving their mathematical understanding. This perception aligns with the substantial gains observed in numeracy performance, reinforcing the conclusion that students viewed the technology not simply as supplemental, but as an effective learning aid that contributed directly to their academic progress. Similarly, the high rating for Perceived Ease of Use reflects students' comfort and familiarity with the digital platforms. Features such as intuitive interfaces, clear instructions, and responsive feedback mechanisms likely reduced cognitive load, allowing students to focus more on conceptual exploration and problem solving rather than navigating technical complexities. This ease of use is especially important in elementary education, where younger learners benefit from accessible, user-friendly digital environments.

The positive Attitude/Intention to Use score indicates that students developed a favorable disposition toward continuing to use digital learning tools in future mathematics lessons. Such positive attitudes are critical for sustaining engagement beyond the scope of the intervention, and they align with previous research showing that learners who perceive technology as beneficial and easy to use are more likely to engage deeply and consistently with digital learning activities. Overall, the TAM findings demonstrate that elementary students not only adapted well to the digital platforms but also embraced them as valuable components of their learning experience. This high level of acceptance supports the scalability of the intervention and suggests that digital learning tools have strong potential to foster long-term engagement, reduce math-related anxiety, and develop digital literacy an increasingly essential skill in 21st-century education.

Observation of engagement

The classroom observation findings provide additional support for the effectiveness of digital technology in promoting students' behavioral engagement during mathematics learning. As presented in Table 9, students in the experimental group consistently demonstrated higher levels of engagement than those in the control group across almost all observed indicators. Improvements were particularly evident in students' attention to learning tasks, active participation, collaborative interactions, persistence in solving problems, learning initiative, and reflective behaviors, indicating that technology-enhanced instruction encouraged more active involvement throughout the instructional process.

A notable improvement was observed in students' ability to remain focused during learning activities. The interactive characteristics of the digital learning tools—including dynamic visualizations, immediate feedback, and game-like learning elements—appear to have helped students sustain their attention while minimizing distractions. Similarly, students in the experimental group participated more actively in classroom discussions, demonstrated greater willingness to ask questions, and engaged more confidently with mathematical tasks presented through digital platforms. These findings suggest that technology-enhanced environments create learning conditions that encourage students to become active participants rather than passive recipients of information.

Table 9. Engagement observation scores

Indicator	Experimental (M)	Control (M)
Focus on tasks	3.6	2.8
Participation	3.4	2.7
Collaboration	3.5	2.9
Persistence	3.3	2.6
Use of digital tools	3.7	–
Rule compliance	3.4	3.2
Time management	3.5	3.0
Initiative	3.2	2.6
Note-taking	3.4	2.9
Reflection	3.3	2.7
Total (mean)	34.3 / 40	26.4 / 40

Collaborative learning behaviors also improved considerably within the experimental group. Many technology-supported activities required students to work together to interpret visual representations, discuss mathematical ideas, and solve contextual problems, thereby promoting communication and shared knowledge construction. Such learning experiences are consistent with constructivist perspectives, which emphasize collaboration as an essential process for developing conceptual understanding and deeper mathematical reasoning.

Students exposed to digital learning also demonstrated greater persistence when confronted with challenging mathematical tasks. Continuous feedback and instructional scaffolding embedded within the digital platforms likely reduced frustration and encouraged students to continue working through difficulties instead of abandoning the task. In addition, higher scores on indicators such as initiative, note-taking, and reflective learning suggest that digital environments supported the development of self-regulated learning behaviors by encouraging students to monitor, evaluate, and improve their own learning processes.

Although both groups displayed relatively similar levels of compliance with classroom rules, the experimental group obtained higher scores on all remaining engagement indicators. The overall engagement score (34.3/40) was substantially higher than that of the control group (26.4/40), indicating a considerably stronger level of behavioral involvement during mathematics instruction. These observational findings are consistent with the results of the ARCS motivation questionnaire and the numeracy achievement test, suggesting that digital learning tools contribute not only to improved academic performance but also to greater classroom participation and positive learning behaviors. Furthermore, the implementation fidelity reached 94% throughout the intervention, indicating that the instructional procedures were delivered consistently as planned and strengthening the credibility of the observed outcomes.

The present study also demonstrates that integrating digital technology into mathematics instruction produces meaningful improvements in students' numeracy achievement. Compared with conventional instruction, the experimental group achieved higher posttest scores, larger normalized gains, and a very large effect size (Cohen's d = 1.99), indicating that the intervention had a substantial educational impact. These findings are in agreement with previous research showing that technology-supported learning environments facilitate conceptual understanding and procedural fluency by allowing students to manipulate mathematical representations, receive immediate feedback, and explore contextualized mathematical situations (Decker et al., 2023; Procópio et al., 2024). Such instructional affordances may help address persistent challenges in Indonesian mathematics classrooms, including procedural teaching, rote memorization, and limited student engagement (Purnomo et al., 2022).

Besides improving cognitive performance, the findings also highlight the importance of motivational factors in mathematics learning. Students who learned through digital technology reported significantly higher levels of attention, relevance, confidence, and satisfaction across all dimensions of the ARCS framework. These results indicate that technology-enhanced learning environments not only improve students' understanding of mathematical concepts but also create learning experiences that are more engaging, personally meaningful, and enjoyable. This finding supports Keller's ARCS motivational model, which argues that students are more likely to persist when learning activities are perceived as interesting, relevant, and attainable. Similar conclusions were reported by Hidayanthi et al. (2024), who found that STEAM-based digital learning simultaneously enhances numeracy performance and students' enthusiasm for learning.

Students' responses to the Technology Acceptance Model (TAM) questionnaire further reinforce the effectiveness of the intervention. High ratings for perceived usefulness, perceived ease of use, and intention to continue using digital technology indicate that students accepted the instructional innovation positively. According to Choi et al. (2022) and Koreňová et al. (2024), positive technology acceptance is an important prerequisite for sustained engagement because students are more willing to adopt digital learning tools when they perceive them as beneficial and easy to operate. The present findings also demonstrate that elementary school students, including those in relatively remote regions such as Tanah Tidung, are capable of adapting successfully to digital learning environments when adequate instructional support and technological resources are available.

The classroom observation data further complement these findings by showing that digital learning promoted higher levels of focus, participation, collaboration, persistence, and learning initiative. These behavioral improvements reflect the interactive characteristics of digital learning environments, which encourage students to engage actively with mathematical ideas instead of passively receiving information. Interactive problem-solving activities combined with immediate feedback appear to strengthen students' perseverance and foster a growth-oriented approach to learning, which is consistent with the findings reported by Busyairi and Kusuma (2024). These results are also compatible with active learning theories, which emphasize that meaningful learning develops through active participation, reflection, and collaborative interaction.

The consistently high implementation fidelity (94%) indicates that the intervention was delivered according to the planned instructional procedures, thereby increasing confidence that the observed improvements were attributable to the digital learning intervention rather than inconsistencies in implementation. From a broader perspective, the findings suggest that improvements in numeracy achievement are closely accompanied by increases in motivation, behavioral engagement, and positive perceptions of technology. As noted by Jiawen et al. (2024), Nasir et al. (2023), and Syauqi et al. (2024), evaluating educational innovations requires consideration of these interrelated cognitive, motivational, and behavioral dimensions in order to obtain a more comprehensive understanding of learning outcomes.

From a theoretical perspective, this study extends current knowledge on technology-enhanced mathematics education by demonstrating how cognitive achievement, learning motivation, behavioral engagement, and technology acceptance interact within a unified instructional framework. The findings also provide additional empirical support for applying the ARCS and Technology Acceptance Model (TAM) frameworks in elementary mathematics education. Practically, the results emphasize that successful digital learning depends not only on technology itself but also on teachers' digital competence (Koreňová et al., 2024; Suprawata & Riastini, 2022), equitable access to technological infrastructure (Suwarjo et al., 2022), and continuous parental support in reinforcing numeracy learning beyond the classroom (Rohmah et al., 2022). Collectively, these findings indicate that digital technology–integrated mathematics instruction offers multidimensional benefits by improving students' numeracy achievement, strengthening motivation and engagement, and encouraging positive acceptance of educational technology, thereby providing a promising strategy for addressing persistent challenges in elementary mathematics education, particularly in underserved rural settings.

CONCLUSION

This study demonstrates that integrating digital technology into elementary mathematics instruction effectively enhances students' numeracy achievement while simultaneously fostering positive learning experiences. Compared with conventional instruction, students who participated in the digital technology–integrated learning environment demonstrated superior numeracy performance, accompanied by higher levels of learning motivation, stronger behavioral engagement, and more positive perceptions of educational technology. These findings suggest that the educational benefits of digital learning extend beyond cognitive achievement by supporting the affective and behavioral dimensions that are essential for sustained mathematics learning. This study contributes to the growing literature on technology-enhanced mathematics education by providing empirical support for the complementary roles of the ARCS motivational framework and the Technology Acceptance Model (TAM) in explaining students' learning experiences within digital environments. The findings indicate that effective technology integration should not be evaluated solely through academic performance but also through students' motivation, engagement, and acceptance of digital learning tools.

The results highlight the importance of designing mathematics instruction that integrates interactive digital technologies with pedagogically meaningful learning activities. Successful implementation requires not only appropriate technological resources but also teachers' digital pedagogical competence and supportive learning environments that encourage active student participation. These findings are particularly relevant for elementary schools, including those located in rural areas, where digital learning has considerable potential to improve both learning quality and educational equity. Future research is recommended to examine the long-term effects of digital technology–integrated mathematics instruction across different grade levels and educational contexts. Further studies should also investigate additional learning outcomes, such as mathematical problem-solving, critical thinking, self-regulated learning, and digital literacy, to provide a more comprehensive understanding of how digital technologies contribute to students' mathematical development.

REFERENCES

Busyairi, A., & Kusuma, A. (2024). The effectiveness of campus teaching programs in improving students' literacy and numeration. *Jurnal Ilmiah Profesi Pendidikan, 9*(2), 1438–1442. https://doi.org/10.29303/jipp.v9i2.2287

Choi, E., Choi, Y., & Park, N. (2022). Blockchain-centered educational program embodies and advances 2030 sustainable development goals. *Sustainability, 14*(7). https://doi.org/10.3390/su14073761

Cohen, S. (2004). Social relationships and health. *American Psychologist, 59*(8), 676–684. https://doi.org/10.1037/0003-066X.59.8.676

Damopolii, I. (2025). Student Motivation in Biology Learning Using Augmented Reality and Comics. *Report of Biological Education*, *6*(2), 76–86. https://doi.org/10.37150/11vdyg02

Decker, L., Mason, C., Lee, J., Chan, J., Sales, A., Liu, A., & Tu, S. (2023). The impacts of three educational technologies on algebraic understanding in the context of COVID-19. *AERA Open, 9*. https://doi.org/10.1177/23328584231165919

Fauzan, A., Harisman, Y., Yerizon, Y., Suherman, S., Tasman, F., Nisa, S., & Syaputra, H. (2024). Realistic mathematics education (RME) to improve literacy and numeracy skills of elementary school students based on teachers' experience. *Infinity Journal, 13*(2), 301–316. https://doi.org/10.22460/infinity.v13i2.p301-316

Georgiou, Y., & Ioannou, A. (2021). Developing, enacting and evaluating a learning experience design for technology-enhanced embodied learning in math classrooms. *TechTrends, 65*(1), 38–50. https://doi.org/10.1007/s11528-020-00543-y

Handaryani, H., Gani, H. A., & Muin, A. (2026). The influence of local wisdom-based gamification on students' literacy and numeracy in mathematics learning. *Journal of Research in Instructional*, *6*(1), 308–322. https://doi.org/10.30862/jri.v6i1.40

Hidayah, Y., Suyitno, S., & Trihastuti, M. (2022). Promoting the values of Pancasila for elementary school through interactive learning media: Responding to challenges and responses of citizenship education in a pandemic COVID-19. *Proceedings of the International Conference on Social Science and Humanities* (ASSEHR). https://doi.org/10.2991/assehr.k.220108.087

Hidayanthi, R., Siregar, N., Siregar, D., & Siregar, H. (2024). Implementation of STEAM-based digital learning for students' numeracy literacy in elementary schools. *Research and Development in Education (RADEN), 4*(1), 653–661. https://doi.org/10.22219/raden.v4i1.32663

Jiawen, W., Oh, D., Hyde, D., & Pomerantz, E. (2024). Cognitive and motivational numeracy parenting practices: Implications for children's numeracy engagement during early elementary school. *Developmental Psychology, 60*(4), 680–692. https://doi.org/10.1037/dev0001706

Kalaitzidis, T. (2026). How generative AI fixes what higher education broke: Reframing the "colonization" of knowing and learning. *AI & Society, 41*(2), 895–913. https://doi.org/10.1007/s00146-025-02629-8

Kalifah, D. R. N., Nasrullah, A., Nasir, B. M., & Jojo, Z. M. M. (2025). Implementation of jigsaw learning to improve mathematics learning outcomes of grade IV elementary school. *Journal of Research in Instructional*, *5*(2), 91–104. https://doi.org/10.30862/jri.v5i2.692

Koreňová, L., Krpec, R., & Barot, T. (2024). Digital technologies in primary mathematics education: Insights from future teachers' portfolios. *European Conference on E-Learning, 23*(1), 197–208. https://doi.org/10.34190/ecel.23.1.2929

Laurens, T., Batlolona, F. A., Batlolona, J. R., & Leasa, M. (2018). How does realistic mathematics education (RME) improve students' mathematics cognitive achievement? *Eurasia Journal of Mathematics, Science and Technology Education, 14*(2), 569–578. https://doi.org/10.12973/ejmste/76959

Nasir, N. I. R. F., Arifin, S., & Damopolii, I. (2023). The analysis of primary school student's motivation toward science learning. *Journal of Research in Instructional*, *3*(2), 258–270. https://doi.org/10.30862/jri.v3i2.281

Ochogboju, A. O., & Díez-Palomar, J. (2025). Modeling concrete and virtual manipulatives for mathematics teacher training: A case study in ICT-enhanced pedagogies. *Information, 16*(8). https://doi.org/10.3390/info16080698

Othman, M. A., & Mazlan, C. A. N. (2026). Enhancing critical thinking through the moral theories debate model (MTDM): A pedagogical framework for moral reasoning. *International Journal of Ethics Education*, 1–23. https://doi.org/10.1007/s40889-025-00233-4

Procópio, M., Cézar, R., Fernandes-Procopio, L., & Yáñez-Araque, B. (2024). Neuroscience-based information and communication technologies development in elementary school mathematics through games: A case study evaluation. *Education Sciences, 14*(3). https://doi.org/10.3390/educsci14030213

Purnomo, H., Sa'dijah, C., Hidayanto, E., Sisworo, S., Permadi, H., & Anwar, L. (2022). Development of instrument numeracy skills test of minimum competency assessment (MCA) in Indonesia. *International Journal of Instruction, 15*(3), 635–648. https://doi.org/10.29333/iji.2022.15335a

Randy, M. Y., Sukoriyanto, S., Rahayuningsih, S., Dewi, R. S. I., & Kusumaningrum, S. R. (2024). Development of a numeracy literacy-based mathematics test assessment on integers in primary schools. *AKSIOMA: Jurnal Program Studi Pendidikan Matematika, 13*(4), 1202–1214. https://doi.org/10.24127/ajpm.v13i4.9797

Rohmah, A., Sutama, S., Hidayati, Y., Fauziati, E., & Rahmawati, L. (2022). Planning for cultivating numeracy literacy in mathematics learning for the minimum competency assessment (AKM) in elementary schools. *Mimbar Sekolah Dasar, 9*(3), 503–516. https://doi.org/10.53400/mimbar-sd.v9i3.51774

Runniarsiti, R., Arismunandar, A., & Febriati, F. (2025). Development of web-based learning multimedia to improve students understanding of mathematical concepts in elementary schools. *Journal of Research in Instructional*, *5*(2), 698–713. https://doi.org/10.30862/jri.v5i2.820

Siregar, N. N., Firmansyah, F., Natasya, D., & Damopolii, I. (2025). Efektivitas Project Based Learning Berbantuan Wordwall untuk Meningkatkan Prestasi Belajar Ditinjau dari Rasa Ingin Tahu. *Cokroaminoto Journal of Primary Education*, *8*(1), 32–41. https://doi.org/10.30605/cjpe.812025.5338

Suprawata, I., & Riastini, P. (2022). Gender and educational level: Analysis of elementary school teachers' numeracy skills. *Jurnal Ilmiah Sekolah Dasar, 6*(2), 236–243. https://doi.org/10.23887/jisd.v6i2.42501

Suwarjo, S., Haryanto, H., Wuryandani, W., Mahfuzah, A., Hidayah, R., & Erviana, V. (2022). Digital literacy analysis of elementary school teachers on distance learning instructional processes in Yogyakarta. *Al-Ishlah: Jurnal Pendidikan, 14*(2), 1145–1156. https://doi.org/10.35445/alishlah.v14i2.1233

Syauqi, S. K., Winarno, N., Samsudin, A., Damopolii, I., & Firdaus, R. A. (2024). From online to in-person: Students' motivation and self-regulation in science teaching activities during and after the Covid-19 pandemic. *INSECTA: Integrative Science Education and Teaching Activity Journal*, *5*(1), 87–107. https://doi.org/https://doi.org/10.21154/insecta.v5i1.8689

Widyaningrum, A., Lutfiyana, R., Faradillah, A., & Miatun, A. (2024). Survey of Rasch model analysis of mathematical literacy abilities of senior high school students. *Pattimura Proceeding Conference of Science and Technology, 5*(1), 57–66. https://doi.org/10.30598/ppcst.knmxxiiv5i1p57-66