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Enhancing secondary students' mathematical literacy through Android-based modules integrating deep learning and intrapersonal intelligence

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Abstract

Indonesian students' low performance in international mathematics literacy assessments highlights the need for instructional approaches that foster higher-order thinking and learner autonomy. Conventional, procedure-oriented instruction has shown limitations, whereas Android-based learning modules implemented within the context of mobile-assisted learning provide opportunities to integrate deep learning pedagogy with students' intrapersonal intelligence. Intrapersonal intelligence, particularly self-regulation, metacognitive reflection, and goal setting, plays an important role in supporting students' engagement and mathematics literacy development. This study aimed to compare secondary students' mathematics literacy outcomes between Android-based deep learning instruction and conventional teaching, while examining the structural contribution of intrapersonal intelligence dimensions to mathematics literacy. A quasi-experimental design was employed involving 68 secondary school students, divided into an experimental group (n = 34) and a control group (n = 34). Instruments included a mathematics literacy test and an intrapersonal intelligence questionnaire. Data were analyzed using independent samples t-tests, effect size estimation, Pearson correlation, and structural equation modeling. The results indicated that students in the experimental group demonstrated significantly higher post-test mathematics literacy scores than those in the control group ($t = 7.25$, $p<0.001$), with a large effect size (Cohen's $d = 1.25$). Significant positive associations were found between intrapersonal intelligence dimensions and mathematics literacy ($r = 0.41$-0.63, $p < 0.01$), with goal setting and planning ($\beta = 0.28$) and metacognitive reflection ($\beta = 0.24$) showing the strongest standardized contributions. These findings suggest that integrating deep learning pedagogy with intrapersonal intelligence through Android-based modules is associated with higher mathematics literacy outcomes and provides practical insights for designing technology-enhanced mathematics instruction in secondary education.

Keywords: deep learning, intrapersonal intelligence, android-based learning, learning module, mathematics literacy

INTRODUCTION

The rapid development of information and communication technology in the 21st century has profoundly transformed various aspects of human life, including education. Digital transformation, characterized by the widespread use of mobile devices, particularly Android-based smartphones has created opportunities for more flexible, interactive, and personalized learning experiences that align with the characteristics of digital native learners (Lestari et al., 2025; OECD, 2023). In many educational contexts, especially in developing countries such as Indonesia, Android devices dominate students' access to digital technology due to their affordability, widespread availability, and compatibility with low- to mid-range hardware. Consequently, Android-based learning modules represent a scalable and ecologically valid form

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Contribution to the literature

- This study provides empirical evidence on the effectiveness of Android-based deep learning modules in improving mathematical literacy among secondary students.
- It demonstrates how intrapersonal intelligence components—particularly self-regulation, goal setting, and metacognitive reflection—significantly influence students' mathematics learning outcomes.
- It offers a practical instructional model that integrates technology, deep learning principles, and intrapersonal factors to foster learner autonomy and higher-order thinking.

of mobile-assisted learning that aligns closely with students' everyday digital practices and has become an increasingly essential component of contemporary teaching and learning strategies.

Despite these technological advances, Indonesian students' mathematics literacy remains a persistent challenge. Results from the program for international student assessment (PISA) consistently indicate that Indonesian students perform below the international average in mathematics literacy. Within the PISA framework, mathematics literacy is defined not simply as procedural competence but as the ability to formulate, apply, and interpret mathematics in a variety of real world contexts (Holenstein et al., 2021; Omiralievna, 2024; Sikko, 2023). This competency requires students to reason mathematically, think critically, and creatively apply mathematical knowledge to everyday problems. The recurring low performance suggests a mismatch between conventional classroom practices and the competencies demanded in the 21st century (Bolstad, 2020; Stylos et al., 2023).

One instructional approach that has gained increasing attention in addressing this challenge is deep learning. In contrast to surface learning, which emphasizes memorization and routine procedures, deep learning encourages students to connect new knowledge with prior understanding, construct meaningful conceptual relationships, and apply mathematical ideas across different contexts. Prior studies have demonstrated that deep learning-oriented instruction supports higher-order thinking skills such as reasoning, problem solving, and conceptual understanding in mathematics (Alayubi et al., 2024; Sappaile et al., 2024; Toikka et al., 2024). However, the effectiveness of deep learning does not depend solely on instructional design; it is also influenced by students' internal capacities to regulate, reflect on, and sustain their learning processes.

In this regard, intrapersonal intelligence represents a critical learner-related factor. It refers to individuals' capacity to understand themselves, recognize their strengths and limitations, regulate emotions, and manage motivation during learning. In mathematics education, students with stronger intrapersonal intelligence are better able to monitor their thinking, persist through cognitive challenges, and adapt learning strategies when encountering difficulties (Gasong & Toding, 2020; Lyndgaard & Kanfer, 2024; Wahab Abdi & Desfandi, 2020). Empirical evidence indicates that dimensions of intrapersonal intelligence such as self-regulation, goal setting, self-monitoring, and metacognitive reflection are positively associated with academic achievement, including mathematics performance (Amini et al., 2020; Birgisdottir et al., 2020). From a theoretical standpoint, deep learning and intrapersonal intelligence are not independent constructs but mutually reinforcing components in the development of mathematics literacy. Deep learning emphasizes meaningful knowledge construction, conceptual integration, and transfer across contexts, whereas intrapersonal intelligence provides the self-regulatory capacity that enables learners to sustain motivation, monitor understanding, engage in metacognitive reflection, and plan goal-directed learning activities. When integrated within an Android-based learning environment, these two dimensions operate synergistically, supporting students' ability to formulate, employ, and interpret mathematics in real-world contexts.

From a theoretical perspective, integrating deep learning with intrapersonal intelligence offers a complementary framework for improving mathematics literacy. While deep learning emphasizes meaningful knowledge construction and conceptual understanding, intrapersonal intelligence functions as the self-regulatory mechanism that enables students to engage deeply, reflect on their learning, and sustain effort over time (Jin & Cutumisu, 2024). Android-based learning modules provide a practical medium for implementing this integration. Such modules can present interactive content through text, visuals, animations, and problem-based activities, while also embedding reflective features such as learning journals, self-check quizzes with automated feedback, and goal-setting prompts. These features support both deep cognitive engagement and students' intrapersonal development within a mobile-assisted learning environment. Previous studies have reported that Android-based applications can enhance student engagement, learning motivation, and independence (Lishchynska et al., 2023; Supriadi et al., 2024).

Nevertheless, existing research reveals several limitations. Many studies on mobile learning in mathematics primarily focus on technical aspects, usability, or motivational outcomes, with less attention

Table 1. Research design

Group	Pre-test	Treatment	Post-test
Experimental	O_1	Android-based learning module integrating deep learning & intrapersonal intelligence	O_2
Control	O_3	Conventional mathematics instruction	O_4

Note. O_1 and O_3 = Pre-test results & O_2 and O_4 = Post-test results

to mathematics literacy as a complex cognitive competency. Similarly, research on deep learning often emphasizes general academic achievement or critical thinking, while studies on intrapersonal intelligence are frequently situated within educational psychology without direct integration into mathematics instruction. As a result, empirical investigations examining how deep learning pedagogy and intrapersonal intelligence jointly contribute to mathematics literacy particularly within Android-based learning modules at the secondary school level remain limited (Ozkale & Ozdemir Erdogan, 2020).

Unlike previous studies that examine mobile learning, deep learning pedagogy, or intrapersonal intelligence as separate variables, this study integrates deep learning principles and intrapersonal intelligence within a single Android-based learning module and empirically examines both learning outcome differences and structural relationships with mathematics literacy among secondary school students in Indonesia. Accordingly, this study compares students' mathematics literacy outcomes between Android-based deep learning instruction and conventional teaching, while also analyzing the structural contributions of intrapersonal intelligence dimensions namely self-awareness, self-regulation, metacognitive reflection, and goal setting and planning to mathematics literacy.

METHODS

Research Design

This study employed a quantitative approach using a quasi-experimental design with a pre-test post-test control group structure. Two intact groups were designated as an experimental group and a control group. The experimental group received instruction using an Android-based learning module designed to integrate deep learning pedagogy and intrapersonal intelligence, while the control group received conventional mathematics instruction.

The pre-/post-test control group design was selected to examine differences in students' mathematics literacy outcomes before and after the instructional intervention, as well as to compare these outcomes with those of a group that did not experience the Android-based learning module. Because the study was conducted in a natural classroom setting where random assignment of individual students was not feasible, a quasi-experimental design was considered appropriate for addressing the research objectives while maintaining ecological validity.

It is important to note that this design allows for the examination of group differences and associations between instructional approaches and learning outcomes, rather than causal inference. Accordingly, the findings are interpreted as indicating differences and relationships rather than definitive causal effects (**Table 1**).

Research Site and Participants

The study was conducted at a private digital oriented senior high school located in Gowa Regency, South Sulawesi, Indonesia. This school was selected purposively because it supports the integration of digital technology particularly the use of Android-based devices—in classroom instruction, making it a suitable context for implementing mobile-assisted learning aligned with the objectives of this study.

The participants were grade 10 students enrolled in the 2025/2026 academic year. A cluster random sampling technique was employed, in which two intact classes were randomly selected from the available grade 10 classes. One class was assigned as the experimental group (n = 34), and the other as the control group (n = 34), resulting in a total of 68 participants. Class placement was determined by the school prior to the study and was not based on academic ability, achievement tracking, or streaming. To ensure comparability between the experimental and control groups, baseline equivalence was examined using pre-test mathematics literacy scores, as well as normality and homogeneity of variance tests. The results indicated that the two groups had comparable initial mathematics literacy levels before the intervention.

The demographic characteristics of the participants showed a relatively balanced gender distribution, with 36 male students (52.9%) and 32 female students (47.1%). Participants' ages ranged from 15 to 16 years, with a mean (M) age of 15.4 years, which is typical for grade 10 students in the Indonesian secondary education system. Ethical considerations were strictly observed throughout the study. Approval was obtained from the school administration prior to data collection. All participants and their parents were informed about the research objectives, procedures, and data usage, and written informed consent was obtained. Participation in the study was voluntary, and confidentiality of students' data was ensured in accordance with ethical research standards.

Table 2. Mathematics literacy test instrument

Mathematical literacy aspect	Indicator
Formulating	-Identifying variables in contextual situations (e.g., population growth based on exponents). -Formulating mathematical models from real-life situations (e.g., savings with compound interest or installments).
Employing	-Using the properties of exponents to solve contextual problems. -Calculating the *n*-th term of an arithmetic sequence in real contexts (e.g., stadium seating, classroom arrangement). -Applying the formula for the sum of the first *n* terms of a geometric series in financial contexts (e.g., installments, investments).
Interpreting and evaluating	-Interpreting the results of exponential calculations in the context of growth or decline. -Evaluating solutions of arithmetic sequences in real contexts (e.g., seat distribution not matching the calculation). -Drawing conclusions from the results of geometric series calculations in financial contexts (whether the solution is realistic). -Evaluating mathematical models created by students to solve real-life problems.

Table 3. Intrapersonal intelligence questionnaire instrument

Dimension	Indicator
Self-awareness	Recognizing personal strengths, weaknesses, & emotions while learning through digital media
Self-regulation	Managing emotions, setting targets, and organizing study time when using digital media
Self-motivation	Maintaining self-motivation to complete learning tasks independently through digital media
Metacognitive reflection	Reflecting on thinking processes & learning strategies using reflective features in digital media
Goal-setting and planning	Establishing personal learning goals and designing study plans within digital media

Research Instruments

Three types of instruments were employed in this study to collect quantitative and supporting observational data: a mathematics literacy test, an intrapersonal intelligence questionnaire, and a learning implementation observation sheet. Each instrument was selected and developed to align with the research objectives and variables examined in this study.

Mathematics literacy test

The mathematics literacy test was developed based on the PISA framework, which conceptualizes mathematics literacy as the ability to formulate, employ, and interpret mathematics in real-world contexts. Accordingly, the test focused on three core processes:

(1) formulating mathematical situations,

(2) employing mathematical concepts, facts, procedures, and reasoning, and

(3) interpreting and evaluating mathematical outcomes.

The test items consisted of a combination of multiple-choice reasoning questions and short essay items designed to assess students' conceptual understanding, mathematical reasoning, and ability to apply mathematics to contextual problems. Content validity was established through expert judgment by two mathematics education specialists to ensure alignment with PISA indicators and the grade 10 curriculum. The internal consistency reliability of the test was examined using Cronbach's alpha, yielding a coefficient of 0.82, which indicates high reliability (**Table 2**).

Intrapersonal intelligence questionnaire

The intrapersonal intelligence questionnaire was developed based on the theory of multiple intelligences, self-regulated learning theory, and an extended dimension of goal setting and planning. The instrument was designed to measure students' ability to understand themselves, regulate learning behaviors, and reflect on their cognitive processes in a digital learning environment.

The questionnaire employed a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Construct validity was assessed using confirmatory factor analysis, which demonstrated acceptable model fit indices (comparative fit index [CFI] = 0.93; root mean square error of approximation [RMSEA] = 0.04), indicating that the questionnaire adequately represented the intended construct dimensions. The internal consistency reliability was high, with a Cronbach's alpha coefficient of 0.89. The questionnaire measured five dimensions of intrapersonal intelligence: self-awareness, self-regulation, self-motivation, metacognitive reflection, and goal-setting and planning (**Table 3**).

Learning implementation observation sheet

The learning implementation observation sheet was used to monitor instructional fidelity and ensure that the planned learning activities were implemented

Table 4. Learning implementation observation sheet

Observed aspect	Indicator
Student activeness	Students actively ask questions and provide answers
Student participation	Students participate in group discussions
Use of Android module	Students use the module according to instructions
Teacher–student interaction	Teachers provide guidance and constructive feedback

consistently in both the experimental and control classrooms. This instrument was not used to measure learning outcomes but served as a supporting tool to verify the quality and consistency of instructional implementation. Observations were conducted by two independent observers using a four-point scale ranging from 1 (not implemented) to 4 (fully implemented). The observed aspects included student activeness, participation in discussions, use of the Android-based learning module, and teacher–student interactions. Inter-rater reliability was examined using Cohen's Kappa, yielding a coefficient of 0.79, which indicates good agreement between observers (**Table 4**).

Development of Android-Based Learning Module

The Android-based learning module was developed using the ADDIE instructional design model, which consists of the stages of analysis, design, development, implementation, and evaluation. The use of this model was intended to ensure a systematic and iterative development process aligned with instructional objectives and learner characteristics. During the analysis stage, curriculum requirements, students' prior knowledge, and learning challenges related to mathematics literacy were identified through curriculum review and teacher consultation. The design stage focused on mapping mathematics literacy indicators from the PISA framework to grade 10 mathematics content, particularly exponents, sequences, and series, while embedding deep learning principles such as contextualization, conceptual exploration, and reflective thinking to support students' mathematics literacy development.

In the development stage, learning materials were created in the form of interactive digital content accessible via Android devices, including contextual problems, guided conceptual tasks, multimedia explanations, and formative assessment items. Deep learning pedagogy was operationalized through problem-based activities that required students to connect mathematical concepts with real-life situations, explain their reasoning, and evaluate alternative solution strategies. The integration of intrapersonal intelligence was implemented through features designed to support self-regulated learning, including self-reflection prompts, digital learning journals, automated feedback, and goal-setting activities. These features were intended to encourage students to monitor their understanding, reflect on their learning processes, and plan subsequent learning actions within the digital learning environment.

Prior to implementation in the main study, the module underwent expert validation by two mathematics education specialists to assess content accuracy, instructional design, and alignment with mathematics literacy objectives. Feedback from the experts was used to revise and refine the module. In addition, a limited pilot test was conducted with a small group of students to evaluate usability and clarity of instructions. The results of this pilot testing informed minor revisions to improve navigability and user experience. The module development process focused on instructional suitability and usability rather than on claims of effectiveness, which were examined empirically through the quasi-experimental study.

Procedures

The research procedures were organized into three sequential phases: the pre-test phase, the treatment phase, and the post-test phase. Each phase was systematically designed to ensure the accuracy, reliability, and consistency of the data collected, in accordance with the quasi-experimental research design.

Pre-test phase

Prior to the instructional intervention, both the experimental and control groups completed a mathematics literacy pre-test that had been validated by subject-matter experts. The pre-test assessed students' initial mathematics literacy levels based on key indicators, including their ability to formulate contextual mathematical problems, apply concepts of exponents, sequences, and series in real-life situations, and demonstrate mathematical reasoning in problem-solving. The pre-test data were analyzed using normality and homogeneity of variance tests to examine baseline equivalence between the two groups. The results indicated that the experimental and control groups had comparable initial mathematics literacy levels. Establishing baseline equivalence was essential to support meaningful comparison of post-test outcomes and to minimize the influence of pre-existing differences. In addition, the intrapersonal intelligence questionnaire was administered to the experimental group to capture students' initial profiles across the dimensions of self-awareness, self-regulation, self-motivation, metacognitive reflection, and goal-setting and planning. These data provided a baseline for

examining associations between intrapersonal intelligence and mathematics literacy within the experimental condition.

Treatment phase

The treatment phase was conducted over six instructional sessions, each lasting 90 minutes and implemented twice a week. Both the experimental and control groups were taught by the same mathematics teacher to ensure instructional consistency and to minimize potential teacher-related confounding effects. In the experimental group, instruction was facilitated using the Android-based learning module designed to integrate deep learning pedagogy and intrapersonal intelligence. Learning activities were organized in a student-centered manner, emphasizing contextual problem-based tasks, conceptual exploration, reflective questioning, and goal-setting activities. The teacher's role was to guide students' engagement with the module, encourage metacognitive reflection, and support self-regulated learning processes embedded in the digital environment.

In contrast, the control group received conventional mathematics instruction characterized by teacher-led explanations, textbook-based exercises, and limited use of digital media. Although the instructional approaches differed, both groups studied the same mathematical topics exponents, sequences, and series within equivalent instructional time and with aligned learning objectives and assessment criteria. To monitor instructional fidelity, students' engagement, participation, and use of learning resources were observed using a structured learning implementation observation sheet. These observations served to verify the consistency of the instructional procedures and to ensure that the planned intervention was implemented as intended, rather than to evaluate learning outcomes.

Post-test phase

Upon completion of the treatment, both the experimental and control groups completed a mathematics literacy post-test equivalent in content, difficulty, and indicators to the pre-test. The post-test was used to examine changes in students' mathematics literacy following the instructional period and to compare outcomes between the two groups. Additionally, the experimental group completed the intrapersonal intelligence questionnaire administered at the pre-test stage. Comparisons between pre- and post-test questionnaire responses provided insights into changes in students' intrapersonal intelligence dimensions, particularly self-regulation, metacognitive reflection, self-motivation, and goal-setting and planning, in relation to their engagement with the Android-based learning module.

Data Analysis

Quantitative data obtained from the mathematics literacy pre- and post-test, as well as the intrapersonal intelligence questionnaire, were analyzed using SPSS version 26 and AMOS version 24. SPSS was employed for descriptive and inferential statistical analyses, while AMOS was used to examine the structural relationships between intrapersonal intelligence dimensions and mathematics literacy. The data analysis was conducted in several sequential steps. First, descriptive statistics including means (Ms), standard deviations (SDs), minimum and maximum scores were calculated to provide an overview of students' mathematics literacy performance and intrapersonal intelligence profiles. Prior to inferential analysis, assumptions of normality and homogeneity of variance were examined using the Kolmogorov-Smirnov test and Levene's test, respectively. The results indicated that the data met the assumptions required for parametric statistical testing.

Second, independent samples t-tests were conducted to examine whether students who participated in Android-based deep learning instruction demonstrated statistically different mathematics literacy post-test outcomes compared to those who received conventional instruction. Effect size was calculated using Cohen's d to estimate the magnitude of the observed differences, thereby providing additional information beyond statistical significance.

Third, Pearson correlation analysis was performed to examine the strength and direction of associations between dimensions of intrapersonal intelligence (self-awareness, self-regulation, self-motivation, metacognitive reflection, and goal-setting and planning) and mathematics literacy scores within the experimental group. This analysis was conducted to explore relationships between intrapersonal intelligence and mathematics literacy without implying causal effects.

Finally, structural equation modeling (SEM) was conducted using AMOS version 24 to analyze the structural contributions of intrapersonal intelligence dimensions to mathematics literacy. SEM was selected to examine the relationships among multiple latent variables simultaneously and to assess the relative contributions of each intrapersonal intelligence dimension. Model fit was evaluated using multiple goodness-of-fit indices, including the CFI, RMSEA, and Chi-square statistics, in accordance with established criteria.

All statistical analyses were conducted using a significance level of $p < 0.05$. The results of these analyses were interpreted cautiously, with an emphasis on differences and associations rather than causal inference, in line with the quasi-experimental design of the study (**Figure 1**).

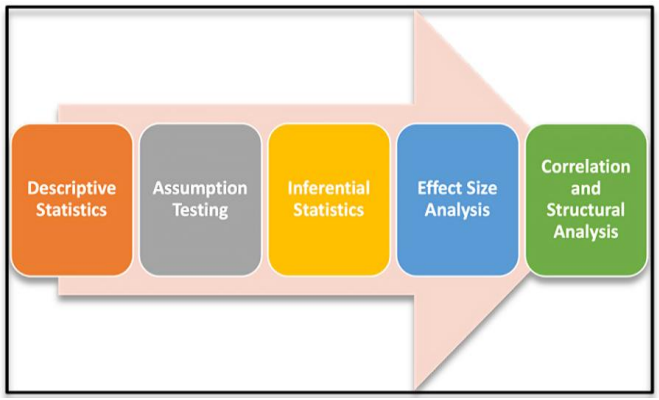

Figure 1. Stages of data analysis illustrating (Source: Authors' own elaboration)

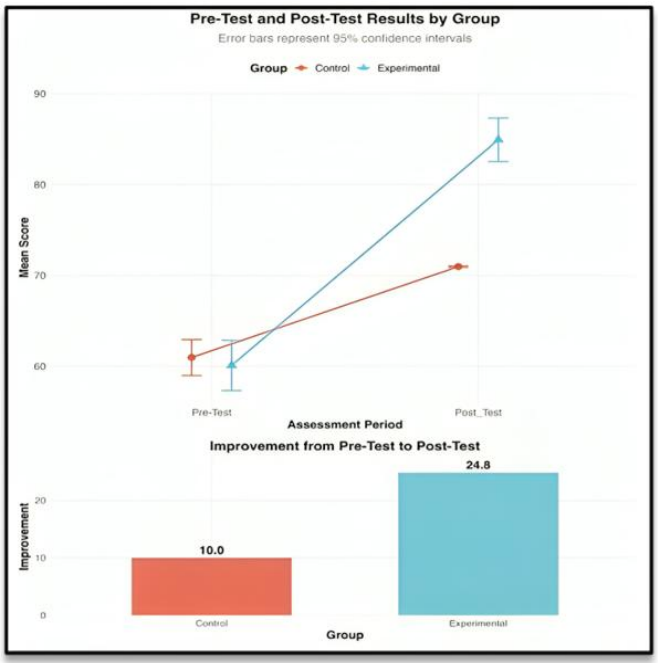

Figure 2. Descriptive statistics of mathematical literacy (pre- and post-test) (Source: Authors' own elaboration)

RESULTS

Descriptive Statistics

Descriptive statistical analysis was conducted to summarize students' mathematics literacy scores in the experimental and control groups before and after the intervention, as well as to describe the intrapersonal intelligence profiles of students in the experimental group. This analysis was intended to provide an overview of score distributions and central tendencies prior to inferential testing.

Figure 2 presents the mean pre- and post-test mathematics literacy scores for both groups. In the experimental group, the mean score increased from 60.06 (SD = 8.16) in the pre-test to 84.56 (SD = 7.08) in the post-test. In the control group, the mean score increased from 60.97 (SD = 5.53) to 70.97 (SD = 5.65). These values indicate that both groups demonstrated higher mean scores in the post-test compared to the pre-test, with a larger mean difference observed in the experimental group.

In terms of score dispersion, the post-test scores in the experimental group ranged from 70 to 95, whereas the post-test scores in the control group ranged from 60 to 80. The experimental group also showed a wider distribution of scores. These descriptive differences reflect variations in score distribution between the two groups; however, no conclusions regarding statistical significance or instructional effectiveness were drawn at this stage. Inferential analyses were conducted in subsequent sections to examine these differences more rigorously.

Figure 3 illustrates the mean scores of intrapersonal intelligence dimensions measured in the experimental group after the intervention. The results indicate generally comparable mean levels across self-awareness, self-regulation, self-motivation, metacognitive reflection, and goal setting and planning, with only slight variations among dimensions. These descriptive

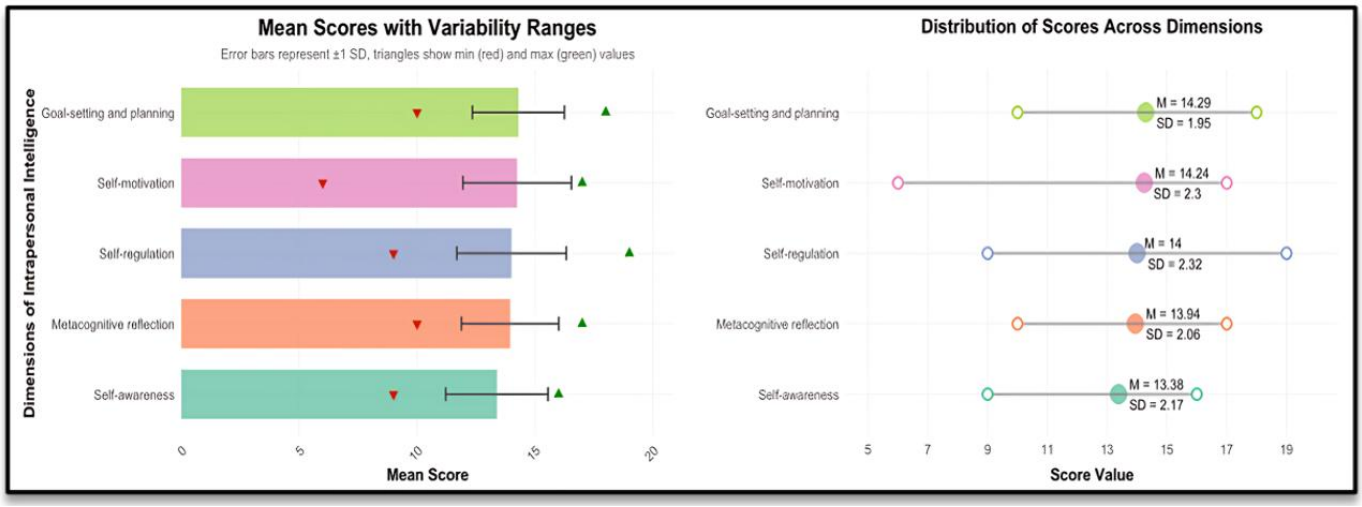

Figure 3. Descriptive statistics of intrapersonal intelligence (experimental group only) (Source: Authors' own elaboration)

Table 5. Normality test results (Kolmogorov-Smirnov)

Group	Test	K-S statistic	Sig. (p)
Experimental	Pre-test	0.094	0.200
	Post-test	0.089	0.200
Control	Pre-test	0.102	0.200
	Post-test	0.086	0.200

results are presented to provide an overview of students' intrapersonal profiles and do not imply hierarchical differences among dimensions. The findings serve as a descriptive basis for subsequent correlation and structural analyses examining relationships between intrapersonal intelligence and mathematics literacy.

Assumption Testing

Prior to conducting inferential statistical analyses, assumption testing was performed to examine whether the data met the requirements for parametric statistical procedures. Specifically, tests of normality and homogeneity of variances were conducted for the mathematics literacy scores of both the experimental and control groups.

Normality test

The normality of the mathematics literacy pre- and post-test scores was examined using the Kolmogorov–Smirnov test for both the experimental and control groups. As presented in **Table 5**, the significance values for all test conditions were greater than 0.05 ($p > 0.05$), indicating no statistically significant deviation from a normal distribution.

These results indicate that the distributions of mathematics literacy scores in both the experimental and control groups were approximately normal at the pre- and post-test stages. Therefore, the normality assumption required for subsequent parametric analyses was considered to be met.

Homogeneity test

Following the normality assessment, the homogeneity of variances between the experimental and control groups was examined using Levene's Test. The results, shown in **Table 6**, indicate that the significance values for both the pre- and post-test scores were greater than 0.05 ($p > 0.05$), suggesting no statistically significant differences in variances between groups.

These findings indicate that the assumption of homogeneity of variances was satisfied for mathematics literacy scores at both measurement points. Accordingly, parametric statistical procedures that assume equal variances, such as the independent samples t-test, were deemed appropriate for subsequent group comparisons, in accordance with the assumptions underlying parametric statistical testing.

Table 6. Homogeneity of variance test results (Levene's test)

Variable	F (Levene's)	Sig. (p)
Mathematics literacy pre-test	1.042	0.314
Mathematics literacy post-test	0.872	0.356

Inferential Statistics

Inferential statistical analyses were conducted to examine differences in mathematics literacy outcomes between students who participated in Android-based deep learning instruction and those who received conventional instruction. The analyses were performed after confirming that the assumptions of normality and homogeneity of variance were satisfied.

Independent samples t-test

An independent samples t-test was used to compare the mathematics literacy scores of the experimental and control groups at both the pre- and post-test stages. The results of the analysis are presented in **Table 7**.

The t-test results indicated no statistically significant difference between the experimental and control groups on the pre-test scores ($t = -0.52$, $p = 0.604$), suggesting that both groups had comparable mathematics literacy levels prior to the intervention. In contrast, a statistically significant difference was observed in the post-test scores ($t = 7.25$, $p < 0.001$), with the experimental group obtaining a higher mean score than the control group. These results indicate a difference in post-test mathematics literacy outcomes between the two groups following the instructional period.

Analysis of covariance

To further examine whether the observed post-test differences between groups persisted after accounting for initial mathematics literacy levels, analysis of covariance (ANCOVA) was conducted using the pre-test scores as a covariate. The ANCOVA results are presented in **Table 8**. The ANCOVA results showed that the group factor remained statistically significant after controlling for pre-test scores ($F = 25.41$, $p < 0.001$, partial

Table 7. Independent samples t-test results of mathematics literacy scores

Variable	Group	N	M	SD	t	df	Sig. (p)
Pre-test	Experimental	34	60.06	8.16	-0.52	66	0.604
	Control	34	60.97	5.53			
Post-test	Experimental	34	84.56	7.08	7.25	66	0.000
	Control	34	70.97	5.65			

Note. $p < 0.001$ indicates a statistically significant difference

Table 8. ANCOVA results of post-test scores controlling for pre-test

Source	Sum of squares	df	Mean squares	F	Sig. (p)	Partial η^2
Pre-test (covariate)	210.34	1	210.34	2.14	0.149	0.03
Treatment (group)	2,470.82	1	2,470.82	25.41	0.000	0.28
Error	6,451.27	65	99.25			

Note. $p < 0.001$ indicates a statistically significant difference

Table 9. Effect size (Cohen's d)

Group	Mean pre-test	Mean post-test	SD pooled	Cohen's d
Experimental	60.06	84.56	9.80	1.25
Control	60.97	70.97	10.20	0.48

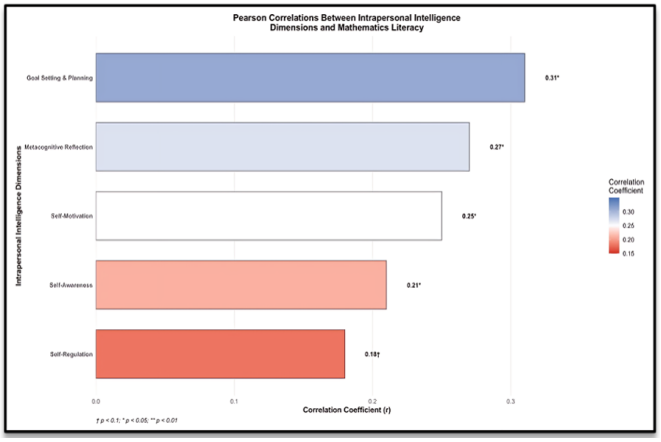

Figure 4. Pearson correlations between dimensions of intrapersonal intelligence and mathematics literacy (Source: Authors' own elaboration)

$\eta^2 = 0.28$). This finding indicates that differences in post-test mathematics literacy scores between the experimental and control groups were observed even when initial performance levels were considered. The partial eta-squared value suggests that a substantial proportion of variance in post-test scores was associated with group membership.

Effect Size Analysis

In addition to statistical significance testing, effect size analysis was conducted to estimate the magnitude of differences in students' mathematics literacy scores observed within each group. Effect size was calculated using Cohen's d, following Cohen's (1988) guidelines, where values of 0.20, 0.50, and 0.80 indicate small, medium, and large effects, respectively.

Table 9 presents the effect size results for the experimental and control groups based on the comparison of pre- and post-test mathematics literacy scores.

The results indicate that the experimental group demonstrated a large effect size ($d = 1.25$), reflecting a substantial magnitude of difference between pre- and post-test mathematics literacy scores. In contrast, the control group exhibited a moderate effect size ($d = 0.48$), indicating a smaller magnitude of change over the same period.

These effect size estimates complement the inferential statistical findings by providing information about the magnitude of observed score differences. Interpretation of these results is presented in the Discussion section, with careful consideration of the quasi-experimental design and without implying causal relationships.

Correlation and Structural Analysis

To examine the relationships between intrapersonal intelligence and mathematics literacy, Pearson product–moment correlation analysis was conducted to analyze the associations between the five dimensions of intrapersonal intelligence—self-awareness, self-regulation, self-motivation, metacognitive reflection, and goal setting and planning—and students' mathematics literacy scores in the experimental group.

Figure 4 presents the Pearson correlation coefficients between the intrapersonal intelligence dimensions and mathematics literacy. The results indicate varying degrees of positive association across the dimensions. Self-awareness showed a weak but statistically significant positive correlation with mathematics literacy ($r = 0.21$, $p < 0.05$), indicating a small association between students' awareness of their learning characteristics and mathematics literacy scores. Self-regulation demonstrated a weak positive but non-significant correlation ($r = 0.18$, $p > 0.05$).

Self-motivation and metacognitive reflection exhibited moderate and statistically significant positive correlations with mathematics literacy ($r = 0.25$, $p < 0.05$ and $r = 0.27$, $p < 0.05$, respectively). The goal setting and planning dimension showed the strongest positive correlation among the five dimensions ($r = 0.31$, $p < 0.05$). These results indicate that higher levels of goal setting and planning, self-motivation, and metacognitive reflection were associated with higher mathematics literacy scores.

To further examine the relative structural relationships among the intrapersonal intelligence dimensions and mathematics literacy, path analysis was conducted using SEM. The results of the path analysis are presented in **Table 10** and illustrated in **Figure 5**.

The path analysis results indicate that goal setting and planning ($\beta = 0.28$, $p = 0.006$), metacognitive

Table 10. Path analysis results: Structural relationships between intrapersonal intelligence dimensions and mathematics literacy

Dimension of intrapersonal intelligence	β (standardized)	t-value	Sig. (p)
Self-awareness	0.19	2.05	0.044
Self-regulation	0.14	1.62	0.109
Self-motivation	0.22	2.32	0.025
Metacognitive reflection	0.24	2.47	0.018
Goal setting & planning	0.28	2.89	0.006

Note. $p < 0.05$ & $p < 0.01$ indicate statistical significance at different levels

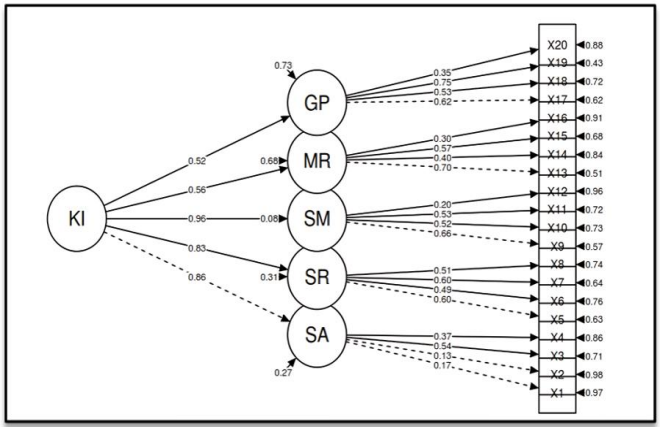

Figure 5. Path analysis: Structural relationships between intrapersonal intelligence dimensions and mathematics literacy (Source: Authors' own elaboration)

reflection (β = 0.24, p = 0.018), and self-motivation (β = 0.22, p = 0.025) showed statistically significant positive structural relationships with mathematics literacy. Self-awareness demonstrated a smaller but statistically significant relationship (β = 0.19, p = 0.044), whereas self-regulation exhibited a positive but non-significant relationship (β = 0.14, p = 0.109).

Overall, the correlation and structural analyses indicate that several dimensions of intrapersonal intelligence are positively associated with mathematics literacy, with varying magnitudes of relationship. These findings describe the patterns of association among variables and provide a basis for further interpretation, which is presented in the Discussion section, without implying causal relationships.

DISCUSSION

This study investigated differences in mathematics literacy outcomes between secondary school students who learned through an Android-based learning module integrating deep learning principles and intrapersonal intelligence and those who received conventional instruction. In addition, it examined the relationships between multiple dimensions of intrapersonal intelligence and mathematics literacy within a mobile-assisted learning context. The discussion interprets these findings by situating them within established theoretical perspectives and relevant empirical research, while explicitly acknowledging the non-causal nature of the findings due to the quasi-experimental design.

Overall, the results indicated that students in the experimental group achieved higher mathematics literacy scores at the post-test stage compared to students in the control group. The large effect size observed further reflects a substantial magnitude of difference in mathematics literacy development between the two groups. These findings are consistent with previous research suggesting that technology-supported learning environments designed to promote deep cognitive engagement are associated with improved mathematical understanding and reasoning (Holenstein et al., 2021; Mukuka et al., 2023; Nurjanah et al., 2020; Zachariades et al., 2025). However, consistent with the study design, these results are interpreted as differences and associations rather than direct causal effects.

Mathematics Literacy from a Theoretical Perspective

Mathematics literacy, as conceptualized by (Inganah et al., 2023; OECD, 2023), extends beyond procedural competence to encompass the ability to formulate, employ, and interpret mathematics in a wide range of real-life contexts. This definition emphasizes reasoning, conceptual understanding, and the flexible application of mathematical knowledge. Consequently, mathematics literacy is closely aligned with deep learning theory, which prioritizes meaning-making, conceptual integration, and the transfer of knowledge to novel and authentic situations.

This conception aligns closely with deep learning theory, which emphasizes meaning-making, conceptual integration, and the transfer of knowledge to novel and authentic situations. Deep learning contrasts with surface learning approaches that prioritize memorization and routine execution of procedures. In contrast to surface learning, deep learning emphasizes meaningful engagement with content, conceptual integration, and reflective understanding of underlying principles, rather than fragmented and context-bound knowledge acquisition. In mathematics education, this distinction is particularly salient because literacy-oriented tasks require learners not only to perform calculations but also to explain reasoning, justify solutions, and interpret results in relation to contextual constraints (Bolstad, 2020; Holenstein et al., 2021).

Within this theoretical framework, the Android-based learning module implemented in the present study can be understood as an instructional environment designed to support deep learning processes. The module incorporated contextual problem scenarios, guided conceptual exploration, and reflective prompts that encouraged students to engage with mathematical ideas beyond procedural execution. These design features are consistent with previous studies reporting that deep-learning-oriented instructional approaches are associated with stronger conceptual understanding and problem solving performance in mathematics (Stern & Hertel, 2022; Toikka et al., 2024; Vessonen et al., 2025). In this sense, technology functions not as an instructional determinant but as a pedagogical medium through which deep learning principles may be operationalized.

Furthermore, the digital learning environment provided affordances such as flexible access, visualization, and immediate feedback, which have been shown to support cognitive processing and conceptual understanding. From the perspective of multimedia learning theory, the integration of symbolic representations, visual elements, and interactive features may facilitate the construction of coherent mental models by reducing extraneous cognitive load and supporting meaningful information processing. Such affordances are particularly relevant for mathematics literacy, which requires learners to integrate symbolic, visual, and contextual representations when interpreting and solving real-world problems.

In addition, Android-based technology enabled a more personalized and learner-centered experience. Students were able to access content at varying levels of difficulty, monitor their learning progress through activity logs, and extend their understanding through embedded resources. Such personalization aligns with constructivist perspectives on learning, which emphasize learners' active role in constructing knowledge based on prior understanding and individual learning trajectories. Within the context of mathematics literacy, personalization may support deeper engagement by allowing learners to revisit concepts, reflect on misunderstandings, and connect mathematical ideas to familiar contexts.

The present discussion also aligns with prior research indicating that mobile-assisted learning environments are associated with enhanced cognitive engagement and intrinsic motivation when instructional design emphasizes meaningful interaction rather than mere content delivery (Jin & Cutumisu, 2024; Sappaile, 2024), These studies suggest that the educational value of mobile technology lies not in its novelty but in its potential to support pedagogical strategies that foster deep engagement and higher-order thinking. Consequently, Android-based learning modules may be viewed as pedagogical tools that are capable of supporting deep-learning-oriented environments when aligned with clear instructional goals.

From a theoretical perspective, the development of mathematics literacy relies heavily on instructional approaches that encourage learners to think deeply, reflectively, and in connection with authentic experiences. The integration of deep learning principles within an Android-based learning module therefore represents a theoretically grounded approach for creating learning conditions that are conducive to mathematics literacy development, without implying deterministic or causal effects.

Intrapersonal Intelligence in Mathematics Literacy

Intrapersonal intelligence refers to an individual's capacity for self-understanding, including awareness of personal strengths and weaknesses, emotional states, and motivational orientations. In educational contexts, intrapersonal intelligence provides an important foundation for self-regulated learning, as it enables learners to monitor their progress, set learning goals, regulate emotions, and adapt strategies in response to challenges. This construct is particularly relevant to mathematics literacy, which requires sustained effort, strategic thinking, and emotional regulation when solving complex and non-routine problems (Arteaga-Checa et al., 2023; Gasong & Toding, 2020).

The findings of this study indicate that several dimensions of intrapersonal intelligence namely self-awareness, self-regulation, self-motivation, metacognitive reflection, and goal setting and planning are positively associated with mathematics literacy. These results suggest that students' engagement with literacy-oriented mathematical tasks is related not only to cognitive competence but also to intrapersonal capacities that support learning processes. Such an interpretation aligns with contemporary views of learning that emphasize the interplay between cognitive and self-regulatory factors in academic achievement.

Among the examined dimensions, self-regulation has been widely recognized in the literature as a central component of effective learning. Self-regulation involves managing learning behaviors, allocating time and effort, and adjusting strategies in response to feedback and task demands. Previous studies have shown that self-regulated learners tend to demonstrate greater persistence and adaptability in mathematics learning (He et al., 2023; Okwuduba et al., 2021). In the present study, although self-regulation exhibited a positive association with mathematics literacy, its structural relationship was not statistically significant, suggesting that its role may be indirect or mediated through other intrapersonal dimensions, such as goal setting or metacognitive reflection.

Self-awareness represents another important dimension, as it enables students to recognize internal

factors that influence learning, including anxiety, confidence, and perceived competence. Through self-awareness, learners may become better positioned to identify personal learning challenges and adopt strategies to address them. Prior research has indicated that emotional awareness contributes to more effective management of academic anxiety, which is particularly relevant in mathematics learning contexts often characterized by high levels of stress and avoidance Trusz (2020) In this study, self-awareness demonstrated a positive but relatively modest association with mathematics literacy, suggesting that awareness alone may be insufficient without accompanying regulatory and reflective processes.

Self-motivation also emerged as a meaningful intrapersonal dimension associated with mathematics literacy. Mathematics is frequently perceived by students as abstract and demanding, requiring sustained effort and resilience. Intrinsic motivation supports learners' willingness to persist despite difficulty and to engage more deeply with learning tasks. This finding is consistent with self-determination theory, which posits that intrinsic motivation develops when learners experience autonomy, competence, and relatedness in learning environments (Durkaya et al., 2011), Within the context of mathematics literacy, motivated students may be more inclined to engage with challenging problems that require interpretation, reasoning, and contextual application.

Metacognitive reflection plays a critical role in supporting mathematics literacy by enabling learners to evaluate the effectiveness of their strategies, identify conceptual misunderstandings, and refine problem-solving approaches. Flavell's work on metacognition emphasizes reflection as a core component of metacognitive awareness, which is essential for deep learning and conceptual understanding. Empirical studies have shown that students who engage in metacognitive reflection are better able to transfer knowledge and apply mathematical concepts in novel contexts (Dabarera et al., 2014; Hoorfar & Taleb, 2015). The association between metacognitive reflection and mathematics literacy observed in this study reinforces the view that reflective processes are integral to literacy-oriented mathematical thinking.

Goal setting and planning emerged as the dimension most strongly associated with mathematics literacy. By establishing clear learning objectives and planning strategies to achieve them, students create a structured framework for navigating complex mathematical tasks. Goal setting provides direction and focus, while planning supports efficient allocation of cognitive and motivational resources. This interpretation aligns with perspectives within self-regulated learning that emphasize goal setting as a key mechanism supporting sustained academic performance. In literacy-oriented mathematics tasks, where problems often require multiple steps and strategic decision-making, goal setting and planning may be particularly important.

Taken together, these findings highlight the multifaceted role of intrapersonal intelligence in mathematics literacy development. Rather than functioning as isolated predictors, intrapersonal dimensions appear to interact in complex ways to support students' engagement with mathematical content. Within the context of Android-based deep learning instruction, intrapersonal intelligence may shape how students engage with digital resources, reflect on feedback, and regulate their learning processes. Accordingly, mathematics literacy can be understood not only as an outcome of students' interaction with content but also as a reflection of their interaction with themselves as autonomous and reflective learners.

Integrating Deep Learning and Intrapersonal Intelligence in Digital Learning

The integration of deep learning and intrapersonal intelligence within digital learning contexts offers a holistic framework for understanding mathematics literacy development. Deep learning emphasizes conceptual connections, meaningful understanding, and the application of knowledge in novel contexts (Teng, 2024). However, theoretical and empirical perspectives suggest that deep learning is unlikely to be fully realized without learners' intrapersonal capacities that support self-management, sustained engagement, and reflective regulation throughout the learning process.

In the present study, the Android-based learning module provided a flexible, interactive, and adaptive learning environment. Digital features such as interactive quizzes, automated feedback, and visual representations were designed to encourage cognitive engagement and support meaningful interaction with mathematical content. From a theoretical perspective, such features may create conditions that are conducive to deep learning by enabling learners to explore concepts, receive timely feedback, and revisit ideas as needed. Nevertheless, consistent with prior research, the educational value of technology cannot be attributed solely to the presence of digital features; rather, it is closely related to how learners regulate motivation, reflect on progress, and plan learning strategies while interacting with the technology.

This interpretation aligns with views that position technology as a pedagogical medium rather than an instructional determinant. In this sense, digital tools may enhance opportunities for deep learning, whereas intrapersonal intelligence functions as the internal mechanism through which learners engage productively with these opportunities. Students who are able to regulate motivation, monitor understanding, and plan learning activities are more likely to benefit from

interactive digital environments, while those lacking such capacities may engage only superficially with technological resources.

The findings of this study indicate that goal setting and planning showed the strongest structural association with mathematics literacy, followed by metacognitive reflection and self-motivation. These patterns are consistent with perspectives advanced (Alamro et al., 2025; Masum et al., 2022) who describe self-regulation as a multidimensional process involving the coordination of cognition, motivation, and behavior toward learning goals. In digital learning contexts, where learners are often required to manage pacing and direct their own learning activities, goal setting and planning may be particularly salient. Without clear goals and strategic planning, learners may struggle to maintain focus or engage meaningfully with digital tasks, potentially limiting the depth of conceptual understanding.

Metacognitive reflection also emerged as an important dimension in the present findings. Rather than functioning independently, reflection appears to support mathematics literacy by enabling learners to evaluate the effectiveness of their strategies, identify misconceptions, and adjust approaches accordingly. This interpretation is consistent with theoretical accounts of metacognition, which emphasize reflection as a mechanism for transforming experience into understanding. Within the framework of deep learning, metacognitive reflection helps ensure that knowledge is not merely accumulated or memorized but integrated into coherent conceptual structures that can be transferred to new contexts.

These interpretations are supported by prior studies indicating that mobile-assisted mathematics learning environments are associated with higher levels of cognitive engagement and intrinsic motivation when coupled with effective self-regulatory and reflective strategies (Burrows et al., 2024; Hartmann et al., 2024; Nguyen et al., 2025) Rather than suggesting that technology itself produces learning gains, these studies emphasize the interaction between instructional design and learner characteristics in shaping learning outcomes.

The integration of deep learning and intrapersonal intelligence can also be interpreted through the lens of self-determination theory, which posits that meaningful learning is supported when learners experience autonomy, competence, and relatedness (Stylos et al., 2023), The Android-based module provided opportunities for autonomy by allowing students to control their learning pace and access resources independently. However, the extent to which learners were able to benefit from this autonomy appeared to depend on their intrapersonal capacities, particularly their ability to set goals, sustain motivation, and engage in reflective learning. From this perspective, digital learning environments may create opportunities for deep learning, while intrapersonal intelligence shapes how effectively learners engage with and capitalize on these opportunities.

Implications and Limitations

The findings of this study offer several implications for mathematics education. First, they suggest that efforts to improve mathematics literacy may benefit from instructional designs that integrate deep learning principles with explicit support for students' intrapersonal development. Second, digital learning tools should be designed not only to present content interactively but also to encourage reflection, goal setting, and sustained motivation.

At the same time, several limitations should be acknowledged. The quasi-experimental design and the single-school context limit the generalizability of the findings and preclude strong causal inferences. Furthermore, the relationships identified through correlation and structural analyses should be interpreted as associations rather than causal pathways. Future research could employ longitudinal or experimental designs across diverse educational settings to further investigate how deep learning approaches and intrapersonal intelligence interact over time in supporting mathematics literacy development.

CONCLUSION

This study examined differences in mathematics literacy outcomes between secondary school students who participated in Android-based learning modules integrating deep learning principles and intrapersonal intelligence and those who received conventional instruction. In addition, the study explored the relationships between dimensions of intrapersonal intelligence and mathematics literacy within a digital learning context. The findings indicate that students in the experimental group achieved higher mathematics literacy post-test scores than those in the control group, with a substantial magnitude of difference as reflected by the effect size. These results suggest that learning environments designed to promote deep engagement with mathematical concepts and reflective learning processes are associated with higher mathematics literacy outcomes. However, these findings should be interpreted as differences and associations rather than direct causal effects, given the quasi-experimental design of the study. The correlation and structural analyses further revealed that several dimensions of intrapersonal intelligence particularly goal setting and planning, metacognitive reflection, and self-motivation were positively associated with mathematics literacy. These results highlight the importance of students' intrapersonal capacities in supporting engagement with literacy-oriented mathematical tasks. While self-

awareness also demonstrated a positive association, self-regulation did not show a statistically significant structural relationship in the model, suggesting that its role may be indirect or mediated by other intrapersonal dimensions.

Taken together, the findings underscore that the development of mathematics literacy is related not only to instructional approaches but also to learners' intrapersonal characteristics that support self-directed and reflective learning. The integration of deep learning pedagogy and intrapersonal intelligence within Android-based learning modules offers a promising framework for designing mathematics learning environments that align with the demands of 21st century education. Several limitations should be acknowledged. The study was conducted within a single school context using a quasi-experimental design, which limits the generalizability of the findings and precludes strong causal inferences. Future research is encouraged to employ longitudinal or experimental designs across diverse educational settings to further examine the dynamic interactions between instructional approaches, intrapersonal intelligence, and mathematics literacy development.

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AI statement: The authors states that generative AI tools were used solely to improve the clarity of the English language in the manuscript. AI was not used for content generation or data analysis.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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