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Examining the relationship between mathematical literacy and digital literacy among pre-service mathematics teachers

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Abstract
Enhancing students' mathematical literacy requires coordinated efforts to strengthen teachers' roles and competencies in mathematics instruction through the integration of technology. The mathematical literacy of prospective mathematics teachers on Kalimantan is reported to be limited. Developing digital literacy is essential for these future educators to recognize and address their limitations in technology usage and digital competencies. This study aims to identify valid and reliable instruments for measuring both mathematical and digital literacy, to examine potential differences in these competencies between male and female pre-service mathematics teachers, and to explore the relationship between mathematical and digital literacy. Employing a quantitative research methodology, this study combines descriptive analysis and Rasch analysis to assess instrument validity and reliability. Furthermore, inferential statistics are utilized to investigate correlations and regression relationships between variables within a cross-sectional design framework. The sample comprises 303 pre-service mathematics teachers who are undergraduate students in Kalimantan, Indonesia. Data analysis was conducted using SPSS-27, with descriptive statistics summarizing participant demographics and inferential statistics, including t-tests, applied to examine gender differences. Effect sizes were calculated using Cohen's d. The findings indicate high item reliability for both the mathematical literacy test (0.93) and the digital literacy test (0.87), confirming that each instrument consistently measured the intended constructs. Additionally, no statistically significant differences were found between male and female pre-service mathematics teachers across the tested domains. This result underscores a lack of a strong, significant relationship between mathematical and digital literacy, as well as within the subscales of digital literacy.

Keywords: mathematical literacy, digital literacy, pre-service mathematics teachers, gender, relationship

INTRODUCTION

The Programme for International Student Assessment (PISA) evaluates students' mathematical skills through the concept of "mathematical literacy" (Gustiningsi & Putri, 2024). Indonesia is among the countries participating in PISA, which has brought international attention to the concept of mathematical literacy (ML). Although first introduced in the literature by the National Council of Teachers of Mathematics (NCTM, 1989), ML gained global recognition primarily through PISA's applications (Saka, 2023). Given the growing significance of mathematics in modern society, it has become a focal point in international assessments aimed at evaluating students' mathematical achievements. Mathematical literacy encompasses students' capacity to utilize mathematics in various

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Contribution to literature

- This study provides psychometrically validated instruments for assessing mathematical and digital literacy among Indonesian pre-service mathematics teachers, filling a gap in localized measurement tools through the use of Rasch analysis.
- The findings reveal that mathematical and digital literacy are distinct and unrelated constructs, offering new empirical evidence that challenges assumptions of overlap between these competencies in teacher education.
- The study found no significant gender differences in either mathematical or digital literacy among pre-service mathematics teachers.

contexts to formulate, apply, and interpret mathematical concepts in real-life situations (Incikabi et al., 2023; OECD, 2013).

Mathematical literacy is increasingly recognized as an essential competency for students to navigate the complexities of contemporary life. It encompasses the ability to formulate, apply, and interpret mathematics across diverse contexts, serving as a critical foundation for effective problem-solving in everyday situations. As defined by Muhaimin et al. (2024), mathematical literacy refers to the capacity to employ mathematical knowledge in real-world scenarios, enabling individuals to address practical challenges with efficiency and precision. This proficiency not only supports informed decision-making but also fosters critical thinking and active citizenship by equipping individuals with the skills needed to interpret data and evaluate quantitative information (Aguilar & Castaneda, 2021). The framework of mathematical literacy comprises several core components, including mathematical proficiency, which involves a comprehensive understanding of mathematical concepts, procedures, and their application across various contexts (Moschkovich, 2015). Teachers play a pivotal role in cultivating mathematical literacy among students, as their beliefs regarding mathematics and problem-solving significantly influence their instructional practices and the learning environments they establish (Memnun et al., 2012). Professional development initiatives aimed at enhancing teachers' understanding of mathematical literacy can lead to more effective pedagogical strategies, thereby empowering students to develop these essential skills (Kabael & Baran, 2023). Moreover, educators must be equipped with appropriate tools and resources to assess and promote mathematical literacy effectively (Rusdi et al., 2018).

Improving students' mathematical literacy requires collaborative efforts to enhance teachers' competencies and roles in mathematics education, especially using technology. However, research suggests that prospective mathematics teachers' mathematical literacy skills remain inadequate (Manfreda Kolar & Hodnik, 2021; Prabawati, 2018; Retnawati & Wulandari, 2019). Guler (2019) advocates for courses focused on mathematical literacy to develop pre-service teachers' problem-solving abilities in mathematics. Integrating technology into training can further strengthen these skills, equipping future educators to foster mathematical literacy in their students.

Information and communication technology (ICT) serves as a critical tool for fostering new competencies and facilitating meaningful, lifelong learning (Mikre, 2011). Recent studies (Akçay, 2024; Habibi et al., 2024; Kurniawati & Baroroh, 2016) indicate a growing recognition of digital literacy as an academic necessity in higher education, particularly as students increasingly rely on digital platforms like Google as learning resources (Salim et al., 2022). Digital literacy supports students' academic performance in higher education and is essential for preparing prospective teachers to address their own gaps in technology and digital skills (Cao et al., 2024; Marmoah et al., 2024). Digital literacy, defined as the capacity to comprehend information presented in various digital forms (Gilster, 1997; Nurzhanova et al., 2024), has thus become an integral aspect of higher education learning processes.

The benefits of digital literacy underscore its importance in educational contexts. High digital literacy levels among pre-service teachers enable them to cultivate more effective educational environments (Instefjord & Munthe, 2016; Zhang et al., 2024).

Definition of Mathematical Literacy and Digital Literacy

Mathematical literacy encompasses the ability to formulate, utilize, and interpret mathematical problems relevant to students' immediate environments (Umbara & Suryadi, 2019; Yilmaz et al., 2024). This skill is a high-level cognitive competency, extending beyond simple arithmetic to include the capacity to address real-world problems through mathematical concepts (Nurmasari et al., 2024). As Ojose (2011) explains, mathematical literacy does not require deep knowledge of complex fields such as calculus, differential equations, or abstract algebra; rather, it represents what can be achieved through a broad comprehension and appreciation of mathematics (Kusuma et al., 2024). Assessments of mathematical literacy are often structured around content, context, and competency, as defined by PISA's six proficiency levels (OECD, 2013; Schleicher, 2019):

Level 1 Basic arithmetic in familiar contexts.

Level 2 Routine problem-solving with straight-forward interpretations.

Level 3 Application of basic reasoning in familiar situations.

Level 4 Proficient problem-solving in less familiar contexts.

Level 5 Advanced reasoning and modeling in unfamiliar contexts.

Level 6 Complex problem-solving involving abstract and real-world reasoning.

Digital literacy, meanwhile, entails the knowledge and skills to use digital media, communication tools, and networks to locate, evaluate, create, and responsibly use information. This involves engaging with information in a way that is informed, thoughtful, and legally compliant to facilitate communication and interaction in daily life (Kuru, 2022; Yuvita et al., 2023). Gilster (1997) defines digital literacy as the ability to effectively and efficiently use technology and information from digital sources in various settings, such as academic, professional, and personal contexts. Elçiçek and Kahyaoğlu (2022) expand on this by describing digital literacy as the capacity to understand and employ diverse information acquired through digital channels. Additionally, UNESCO characterizes digital literacy as a comprehensive understanding and proficiency in the use of technology, information, and communication tools, which forms an essential skill set for modern life (Nasrullah et al., 2017; Supriadi & Suherman, 2024).

The Relationship between Mathematical Literacy and Digital Literacy

The relationship between mathematical and digital literacy has been widely studied, though researchers offer differing views. Some argue that these two competencies are not directly related (Drijvers, 2015; Goos et al., 2003; Tondeur et al., 2017), while others suggest a significant connection between them (Bastiwi & Pramesthi, 2022; Busnawir et al., 2023; Komarudin et al., 2024; Novita & Herman, 2021). Regardless, both skills are essential for teachers, who rely on them to achieve learning objectives and enhance the educational experience for students.

Studies indicate that digital literacy is critical for secondary students (Chen & Xiao, 2024; How et al., 2022; Martin & Grudziecki, 2006; Shopova, 2014; Zayas & Rofi'ah, 2022). In fostering students' digital literacy, teachers' own digital skills play a crucial role, making it essential to assess digital literacy among prospective educators. Research further suggests that digital literacy among pre-service teachers has significant implications for improving teacher education (List et al., 2020). Similarly, mathematical literacy is a necessary skill for prospective mathematics teachers (Canbazoğlu & Tarım, 2021; Heyd-Metzuyanim et al., 2021; Jannah & Hayati, 2024; Liana et al., 2024). To advance the quality of education in Indonesia, particularly on Kalimantan Island, it is critical to investigate the relationship between digital literacy and mathematical literacy among prospective mathematics teachers. This research will contribute to understanding how these skills interact, thereby informing efforts to enhance teacher training and student outcomes.

Relevant Research on Mathematical and Digital Literacy among Indonesian Pre-Service Teachers

A relevant study by Soeparno and Ismaniati (2022) indicates that while prospective teacher students demonstrate satisfactory digital literacy skills, they are generally unprepared for the demands of 21st-century learning. This is attributed to limited skills and knowledge in applying ICT, as well as insufficient support for ICT facilities. However, the study is limited by its inability to conclusively determine that digital skill deficiencies are prevalent across higher education institutions. Further research is necessary to identify specific areas of digital literacy that require improvement. Additionally, this study only involved a sample of 16 mathematics education students from a single university. Our research addresses these limitations by including a larger sample of 303 pre-service mathematics teachers from nine universities offering mathematics education programs.

In terms of mathematical literacy, studies by Nurlaili et al. (2022) and Setiawan et al. (2022) examine the mathematical literacy skills of students in mathematics education. Their findings indicate that respondents' mathematical literacy levels range from low to medium. Both studies utilized qualitative methodologies and had sample sizes of 23-33 students from a single institution. By contrast, our research engages a larger, more diverse group of respondents from multiple institutions. Additionally, we aim to explore the relationship between digital literacy skills and mathematical literacy among pre-service mathematics teachers, adding a novel dimension to existing research.

METHOD

This study investigates the relationship between mathematical literacy and digital literacy within the Indonesian context, focusing specifically on pre-service mathematics teachers. The research explores potential gender-based differences in mathematical and digital literacy levels among these future educators and evaluates the validity and reliability of the instruments used for measurement. Additionally, the study examines whether mathematical literacy significantly influences digital literacy and its various subdimensions. To achieve these objectives, the following research questions were posed:

RQ1 Are the instruments used to measure mathematical literacy and digital literacy valid and reliable?

RQ2 Are there significant differences in mathematical literacy and digital literacy achievements between male and female pre-service mathematics teachers?

RQ3 What is the relationship between mathematical literacy and digital literacy?

Materials and Methods

The current study utilized a quantitative methodology, incorporating descriptive analysis and Rasch analysis to verify the instrument's validity and reliability. Additionally, inferential statistics were applied to explore correlations and regression relationships among variables within a cross-sectional design.

Participants

The study sample consisted of 303 pre-service mathematics teachers, who were undergraduate students from the Faculty of Education in West Kalimantan Province, Indonesia. Data collection was conducted through an online survey, with participation being entirely voluntary. Prior to conducting the survey, participants were required to provide written informed consent, ensuring their agreement to take part in the research. To protect participant confidentiality, all identifying information, including their names and institutional affiliations, was anonymized before the data analysis began. This process safeguarded participants' privacy and ensured compliance with ethical research standards. **Table 1** provides a demographic profile of the pre-service teachers involved in the study.

Table 1. Demographic profiles of participants (N = 303)

Variable	Mean/SD	Frequency	%
Gender	1.38/0.486	303	100
Male		115	38.0
Female		188	62.0

Instrumentation

This study utilized two primary assessment instruments: a digital literacy test and a mathematical literacy test. The digital literacy test was constructed based on Gilster's (1997) digital literacy framework, covering four key domains: Internet searching (IS) with 12 items, hypertextual navigation (HN) with 5 items, content evaluation (CE) with 4 items, and knowledge assembly (KA) with 4 items. The mathematical literacy test was developed following the guidelines of the Programme for International Student Assessment (PISA) 2018, designed to evaluate proficiency across six levels. These levels range from Level 1, which assesses basic arithmetic in familiar contexts, to Level 6, which involves advanced problem-solving requiring both abstract reasoning and real-world application (Schleicher, 2018). A total of 10 items were devised for the mathematical literacy test, representing the proficiency levels established in the PISA framework.

Before administration, the digital literacy and mathematical literacy assessments were subjected to a thorough review process by two subject-matter experts: one specializing in educational technology and the other in mathematics education. This review process aimed to ensure content validity, ensuring that the items were both appropriate and relevant for the target population. Feedback from these experts was used to refine the test items, clarify any ambiguities, and ensure that each domain was adequately covered.

Rasch analysis for construct validation involving Instrument fit, validity, and reliability were further examined through Rasch analysis. This analysis method provided robust psychometric data on the functioning of the items and the scale's overall consistency. Rasch analysis helped to assess item difficulty, item fit, and person reliability, ensuring that the instruments were effective in distinguishing between varying levels of competence among participants. Both the digital literacy and mathematical literacy tests employed a multiple-choice format with four options per item. Each correct answer was scored as one point, while incorrect answers were scored as zero. This format ensured simplicity and consistency in scoring, allowing for straightforward interpretation of results. As a result, participants could achieve a maximum score of 25 points on the digital literacy test and 10 points on the mathematical literacy test.

Data was collected through an online survey platform, where pre-service mathematics teachers completed the tests. The data was processed using the Statistical Package for the Social Sciences (SPSS) version 27 (IBM Corp, 2020). Rasch analysis was conducted using WINSTEPS 5 (Linacre, 2024), enabling detailed evaluation of the tests' psychometric properties, including person and item reliability, Cronbach's alpha values, and item fit statistics. These analyses confirmed the internal consistency and validity of the instruments, ensuring they accurately measured the intended constructs of mathematical and digital literacy.

Data Collection Procedures and Analysis

Data collection was facilitated by lecturers and designated data collectors from the participating universities. Ethical approval for the use of the questionnaire was secured from the Institutional Review Board (IRB) of ISBI Singkawang. Participants accessed both digital and mathematical literacy assessments via a secure online platform, which was compatible with major web browsers, including Firefox and Chrome.

Table 2. Psychometric properties of the mathematical literacy and digital literacy tests

Psychometric attribute	Mathematical literacy test	Digital literacy test
Number of items	10	25
Item reliability	0.93	0.87
Person reliability	0.79	0.69
Cronbach's alpha (α)	0.8	0.75
Mean		
item outfit MNSQ	0.99	0.96
item Infit MNSQ	1.03	1
person outfit MNSQ	1.03	0.96
person Infit MNSQ	1	1
Item separation	3.78	3.64
Person separation	2.68	2.92

Data analysis was conducted using SPSS version 27 (IBM Corp, 2020), which enabled both descriptive and inferential statistical analyses. Descriptive statistics were used to outline participant demographics, while inferential statistics-including independent-samples t-tests-were employed to compare gender groups, with effect sizes calculated using Cohen's d (Cohen, 2013). To examine the relationship between digital and mathematical literacy, Pearson correlation and multiple linear regression analyses (using the Enter method) were performed.

For calculating Cohen's d, the formula is as follows:

$$d = \frac{(M1 - M2)}{SD_{pooled}} \quad (1)$$

Where:

M1 and M2 are the means of the two groups being compared.

SD_{pooled} is the pooled standard deviation.

To estimate the confidence interval for Cohen's d, we use the following formula for a 95% confidence interval:

$$CI = d \pm Z_{alpha/2} \times SE_d \quad (2)$$

Where:

$Z_{alpha/2}$ is the critical value of the normal distribution (for a 95% confidence level, $Z_{alpha/2}$ is 1.96).

SE_d is the standard error of Cohen's d.

(Cohen, 2013)

The Rasch model was utilized to validate the reliability and validity of the instruments. Reliability was assessed through several key indicators, including person and item reliability parameters within the Rasch model (Fisher, 2007; Linacre, 2024) and Cronbach's alpha (α) (Taber, 2018). For reliability to be deemed adequate, person reliability, item reliability, and Cronbach's alpha (α) values were required to exceed 0.67 (Fisher, 2007; Taber, 2018). Fit validity was examined through the Infit and Outfit mean square (MNSQ) statistics, with acceptable MNSQ values ranging from 0.5 to 1.5; values up to 1.6 were considered marginally acceptable. An optimal model fit was aimed at MNSQ values approximating 1.00 logits (Andrich, 2018; Boone, 2016).

RESULTS

Reliability and Fit Validity Based on Rasch Measurement Analysis

To address the first research question, **Table 2** presents the psychometric properties of both mathematical literacy and digital literacy assessments, detailing their reliability and fit indices. Both assessments demonstrate high item reliability, with the mathematical literacy test showing a reliability score of 0.93 and the digital literacy test a score of 0.87, indicating consistent measurement of the intended constructs across items. However, the person reliability indices are comparatively lower for both assessments, with the mathematical literacy test at 0.79 and the digital literacy test at 0.69. Although these values are within acceptable limits, they suggest moderate consistency in individual responses across test items. Cronbach's alpha values are 0.80 for the mathematical literacy test and 0.75 for the digital literacy test, which indicates good internal consistency, though the digital literacy test shows slightly lower reliability.

Regarding item fit validity, as illustrated in **Table 2**, both the Outfit and Infit Mean Square (MNSQ) values for items and individuals approach the ideal value of 1.00. Specifically, the mean item Outfit MNSQ is 0.99 and the mean item Infit MNSQ is 1.03 for the mathematical literacy test, while for the digital literacy test, the mean item Outfit MNSQ is 0.96 and the mean item Infit MNSQ is 1.00. These values indicate an adequate fit for both assessments, as they fall within the acceptable range of 0.5 to 1.5, demonstrating alignment of items and individuals with the Rasch model's expectations.

The item separation indices are 3.78 for the mathematical literacy test and 3.64 for the digital literacy test, both exceeding the threshold of 2 logits, which suggests a wide range of item difficulty and a strong distinction among items. Similarly, the person separation values are 2.68 for the mathematical literacy test and 2.92 for the digital literacy test, indicating that the assessments effectively differentiate among individuals with varying levels of ability.

Table 3. Comparison of mathematical literacy, digital literacy, and digital literacy subscales by gender among pre-service mathematics teachers

	Males		Females					95% CI of Cohen's d		
Variables and subscales	M	SD	M	SD	F	t	p	Cohen's d	Lower	Upper
Digital Literacy	0.71	0.17	0.73	0.16	0.36	0.73	0.46	0.09	-0.15	0.32
Internet Searching (IS)	0.70	0.15	0.71	0.15	0.21	0.71	0.48	0.08	-0.15	0.32
Hypertextual Navigation (HN)	0.73	0.21	0.76	0.20	2.25	1.32	0.19	0.16	-0.08	0.39
Content Evaluation (CE)	0.74	0.23	0.74	0.23	0.04	0.21	0.84	0.02	-0.21	0.26
Knowledge Assembly (KA)	0.72	0.31	0.73	0.29	1.48	0.25	0.80	0.03	-0.20	0.26
Mathematical Literacy	0.63	0.18	0.65	0.19	2.08	0.91	0.36	0.11	-0.12	0.34

Note. IS, HN, CE, KA = Subscales of digital literacy test, M= Mean, SD = Standard deviation

Table 4. Pearson correlations among mathematical literacy, digital literacy, and subscales of digital literacy

	Internet Searching	Hypertextual Navigation	Content Evaluation	Knowledge Assembly	Digital Literacy
Mathematical Literacy	0.03	0.04	0.03	0.01	0.31

* Note. **. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed), statistically significant differences are shaded, $p < 0.05$

Gender Differences

To investigate the second research question concerning gender differences among pre-service mathematics teachers, an independent samples t-test was performed to assess male and female participants' performance across all subscales of both the digital literacy and mathematical literacy tests. Based on the results of the One-Sample Kolmogorov-Smirnov test, the data for both mathematical literacy and digital literacy meet the assumption of normality, as the significance values (2-tailed) exceed 0.05. This indicates that the distributions of the variables do not significantly deviate from normality, thereby justifying the use of parametric statistical methods in the analysis of this study. Additionally, the skewness and kurtosis values for each variable fall within the acceptable range of -3 to +3, further confirming that the data follows a normal distribution. These findings collectively support the application of parametric tests in this analysis.

As presented in **Table 3**, the results indicate no statistically significant differences between male and female pre-service mathematics teachers in any of the evaluated domains. Furthermore, an analysis of the mean scores shows that female pre-service mathematics teachers performed comparably to their male counterparts across all domains, including overall mathematical literacy, digital literacy, and the individual subscales of the digital literacy test.

These findings suggest that gender does not significantly influence the levels of mathematical or digital literacy among pre-service mathematics teachers within this sample. The absence of significant gender differences aligns with the existing literature, which underscores the role of equitable access to educational resources and training in mitigating gender-based disparities in literacy outcomes. This result further implies that both male and female pre-service teachers possess similar capabilities to meet the demands of digital and mathematical literacy, supporting the notion that proficiency in these areas is not inherently affected by gender.

Correlation and Regression Analysis among Mathematical Literacy, Digital Literacy, and Subscales of Digital Literacy

The Pearson correlation coefficients (r) were calculated to examine the relationships between mathematical literacy, digital literacy, and the subscales of digital literacy. **Table 4** presents correlation results, which reveal weak, non-significant correlations between mathematical literacy and the digital literacy subscale, including internet searching ($r = 0.03$), hypertextual navigation ($r = 0.04$), content evaluation ($r = 0.03$), and knowledge assembly ($r = 0.01$). These low correlations suggest minimal or no association between mathematical literacy and these specific components of digital literacy. Additionally, the overall correlation between mathematical literacy and digital literacy is 0.31, which, although moderate, does not reach statistical significance at the 0.01 or 0.05 levels, as indicated by the lack of shading for significance. These results indicate that there is no strong or statistically significant relationship between mathematical literacy and digital literacy, or between mathematical literacy and the individual subscales of digital literacy.

To further assess the potential influence of mathematical literacy on digital literacy and its subscales, a linear regression analysis was performed using the enter method, as displayed in **Table 5**. The regression results reveal that mathematical literacy does not significantly predict overall digital literacy or any of its subscales, including internet searching (IS), hypertextual navigation (HN), content evaluation (CE), and knowledge assembly (KA).

Table 5. Regression analysis predicting the effect of mathematical literacy on digital literacy and digital literacy subscales

	Influenced by	B	β	t	p(t)	R	R^2	Adj R^2	F	p(F)
Mathematical literacy	Internet Searching (IS)	0.04	0.03	0.04	0.97	0.05	0.02	-0.01	0.16	0.96
	Hypertextual Navigation (HN)	0.03	0.04	0.39	0.70					
	Content Evaluation (CE)	0.03	0.04	0.37	0.71					
	Knowledge Assembly (KA)	-0.03	-0.04	-0.45	0.66					
	Digital Literacy	0.04	0.03	0.55	0.59					

Note. IS, HN, CE, KA = Subscales of digital literacy test, B: Unstandardized regression coefficient; β: standardized regression coefficient, statistically significant differences are shaded, $p < 0.05$

For internet searching (IS), the unstandardized regression coefficient (B = 0.04) and standardized regression coefficient (β = 0.03) suggest a non-significant positive effect of mathematical literacy on internet searching. However, the t-value (0.04) and p-value (p = 0.97) confirm that this relationship is not statistically significant. Furthermore, the low R^2 value of 0.02 indicates that mathematical literacy accounts for only 2% of the variance in internet searching, with the F-test corroborating the lack of significance (p(F) = 0.96). Similarly, no significant relationship is found for hypertextual navigation (HN), with B = 0.03, β = 0.04, and p = 0.70. Consistent findings are observed for content evaluation (CE), with B = 0.03, β = 0.04, and p = 0.71, indicating no significant effect of mathematical literacy on this subscale. For knowledge assembly (KA), the regression analysis reveals a negative association (B = -0.03, β = -0.04); however, this result is also not statistically significant (p = 0.66).

In summary, the findings indicate that mathematical literacy does not significantly predict digital literacy or its individual subscales. This conclusion is supported by the low R^2 values and the lack of statistically significant t- and F-statistics across all models evaluated.

DISCUSSION

This study's discussion focuses on the validity, reliability, and fit of the items used in measuring mathematical and digital literacy, evaluated through Rasch model analysis. High item reliability values (0.93 for mathematical literacy and 0.87 for digital literacy) indicate that both sets of items consistently measure the intended constructs, suggesting coherence and internal alignment of the literacy skills assessed. Although the reliability values for people were slightly lower than those for items, they remained acceptable (0.79 for mathematical literacy and 0.69 for digital literacy), supporting the tests' capability to differentiate between individuals with varying ability levels. High Cronbach's alpha values (0.8 for mathematical literacy and 0.75 for digital literacy) further confirm internal consistency among the items within each test.

Additionally, the mean square outfit and infit (MNSQ) values were close to 1.00, demonstrating high consistency of the data with the Rasch model and alignment of test-taker responses with model assumptions. The high item-person separation index also suggests that the items effectively differentiate between individuals with different levels of ability. Rasch analysis thus provides strong evidence that both instruments for measuring mathematical and digital literacy exhibit robust validity and reliability. Consistent with Lestari et al. (2024), which also employed the Rasch model, findings showed an item separation value of 3.54 and an item reliability of 0.93, indicating a high-quality instrument with strong internal consistency (Cronbach's alpha of 0.90) and meaningful variance (31.8%) explained by the measures. Likewise, research by Avinç and Doğan (2024) affirmed the adequacy of psychometric properties in tools for measuring digital literacy among secondary school students, demonstrating effective validity and reliability. Overall, the instruments in this study possess strong psychometric properties, effectively capturing literacy skills.

Research by Józsa et al. (2023) offers additional insights, showing that their instrument reliably assessed students' abilities across diverse demographics, including age and gender, without introducing bias. In their findings, older students demonstrated greater proficiency in pre-mathematical skills compared to younger students, highlighting that measurement invariance was achieved. These results provide educators with a robust tool for assessing readiness and identifying potential areas for development. Together, findings related to validity, reliability, and fit, derived from Rasch measurement, carry significant implications for future educational research and the design of targeted interventions.

The present study also explored gender-based differences in mathematical and digital literacy among pre-service mathematics teachers. Independent sample t-tests revealed no statistically significant gender differences across the domains of mathematical and digital literacy, as well as their respective subscales. Both male and female pre-service teachers demonstrated comparable performance in all measured areas. These results suggest a positive trend toward gender equity in mathematical and digital literacy among pre-service teachers, indicating progress in minimizing gender disparities in education. Nevertheless, further research is needed to investigate additional factors influencing individual performance and to develop more targeted interventions for enhancing mathematical literacy. These findings support the perspective that gender does not constitute a primary factor in mathematical or digital literacy proficiency, underscoring the potential for both genders to attain equal competencies in these areas. Consistent with Rizal et al. (2021), males and females exhibited variations in digital literacy, with male prospective teachers scoring moderately higher, possibly due to differences in technology use. Hairida et al. (2023) confirmed this lack of bias, finding no significant gender-based differences in the digital literacy skills of pre-service chemistry teachers across subdimensions.

The study also examined the relationship between digital literacy and mathematical literacy skills among pre-service mathematics teachers. Pearson correlation analysis indicated minimal to no correlation between digital literacy and mathematical literacy, as well as between mathematical literacy and the subscales of digital literacy, including internet searching (IS), hypertextual navigation (HN), content evaluation (CE), and knowledge assembly (KA). This suggests that digital literacy does not necessarily influence mathematical literacy, highlighting the distinctiveness of these two constructs.

Digital literacy, defined as the ability to effectively navigate, assess, and communicate information using digital tools (Eshet-Alkalai, 2012), involves skills such as internet use, social media engagement, and familiarity with digital technologies. In contrast, mathematical literacy entails applying mathematical knowledge and skills in real-world contexts, emphasizing the capacity to analyze, reason, and communicate using quantitative information (OECD, 2019).

The distinct skill sets between digital literacy and mathematical literacy underscore this differentiation. Digital literacy focuses on technological competence, including device usage and information access (Eshet-Alkalai, 2012), whereas mathematical literacy emphasizes numeracy, problem-solving, and logical reasoning (OECD, 2019). These distinctions imply that proficiency in digital literacy does not inherently enhance mathematical capabilities.

Digital tools can facilitate learning in mathematics but cannot substitute for a deeper conceptual understanding of mathematical principles. Technological aids like calculators or educational software assist in solving mathematical problems, but without foundational numeracy skills, these tools may not contribute to the development of independent mathematical reasoning (Tondeur et al., 2017). Over-reliance on technology can potentially impede core mathematical skills development (Gravemeijer et al., 2017). For instance, excessive use of calculators for simple computations may hinder mental arithmetic skills essential to mathematical literacy. This reliance can result in superficial engagement with mathematics without a comprehensive grasp of underlying concepts.

Moreover, digital literacy emphasizes procedural knowledge, such as using specific software or executing digital tasks (Eshet-Alkalai, 2012). Mathematical literacy, on the other hand, requires a deeper conceptual grasp and the ability to think critically, applying quantitative reasoning to practical situations (OECD, 2019). Procedural proficiency in digital literacy does not foster the analytical mindset needed for mathematical literacy.

The findings of this study also have important implications for teacher education. While digital literacy is crucial for modern educators (Instefjord & Munthe, 2016), this study highlights the need for teacher education programs to distinguish between digital and mathematical literacy. Effective teacher preparation should focus on developing both competencies independently. Training should integrate digital literacy as a tool to enhance, not replace, deep mathematical understanding, ensuring that pre-service teachers are proficient in both areas (Kabael & Baran, 2023). Since digital literacy does not directly correlate with mathematical literacy, teacher education programs must emphasize independent development of these skills through specialized training, ensuring future educators are equipped to foster both in students (Memnun et al., 2012).

Additionally, the integration of generative AI in education has the potential to exacerbate existing inequalities, particularly for students from underserved communities who may lack the digital literacy skills needed to fully benefit from these technologies (Zhang et al., 2024). To mitigate these disparities, digital literacy initiatives must prioritize both technical skills and critical thinking about AI's ethical implications (Alexander, 2024; Ng et al., 2022). Teacher education programs should focus on equipping educators with the knowledge to use AI tools inclusively, ensuring equitable access and fostering the necessary competencies for all students to thrive in an AI-driven learning environment (Alexander, 2024; Laupichler et al., 2023)

In conclusion, digital literacy and mathematical literacy represent distinct domains, each requiring specific competencies. While digital literacy may assist mathematical learning through technology, it does not inherently enhance the deeper understanding necessary for mathematical literacy. Digital literacy centers on technological navigation, whereas mathematical literacy focuses on numeracy and problem-solving, necessitating separate skill sets for mastery in each domain.

CONCLUSION, LIMITATION, AND RECOMMENDATIONS FOR FUTURE RESEARCH

Conclusion

This study has made a significant contribution to evaluating the psychometric properties of mathematical and digital literacy tests among pre-service mathematics teachers, demonstrating both the reliability and validity of these instruments. Findings indicate that the mathematical literacy and digital literacy tests exhibit strong item reliability and have proven to be valid and reliable in the context of Borneo, as verified through multidimensional Rasch analysis. These results confirm that the mathematical and digital literacy tests are suitable for assessing prospective mathematics education teachers in this region.

An independent-sample t-test comparing the performance of male and female pre-service mathematics teachers in mathematical literacy, digital literacy, and the subscales of digital literacy found no statistically significant differences between genders in any of the areas evaluated. Additionally, analysis of average scores revealed that female pre-service teachers performed similarly to their male counterparts across all measured domains, including overall mathematical literacy, digital literacy, and individual subscales within the digital literacy assessment.

Overall, the correlation analysis between mathematical literacy and digital literacy showed no strong or significant relationship between the two, and mathematical literacy did not exhibit a significant predictive impact on digital literacy or its subscales among pre-service mathematics teachers. These findings suggest that mathematical and digital literacy operate independently, without notable influence from one domain on the other in this sample of prospective teachers.

Limitations and Recommendations

This study has several limitations that provide valuable directions for future research. First, the sample was limited to pre-service mathematics education students from the island of Borneo, which may not fully represent the broader population of mathematics education students across Indonesia. Although random sampling was applied to increase the representativeness of the data, future studies should aim to include larger and more diverse samples from multiple regions to provide a more comprehensive understanding of the relationship between mathematical and digital literacy in different educational contexts. Expanding the sample to include students from various geographical and cultural backgrounds could reveal regional disparities and offer a more nuanced view of the factors influencing these competencies.

Additionally, future research could explore more complex mathematical constructs and how they intersect with digital literacy. The current study focuses on basic levels of mathematical literacy, but there is potential to examine higher-order mathematical skills and their integration with digital tools. Research could investigate how specific digital technologies, or educational platforms might support advanced mathematical problem-solving, fostering deeper learning in mathematics.

Another limitation of this study is the exclusion of students' and parents' educational backgrounds as potential influencing factors on mathematical and digital literacy. Future studies should consider these variables, as they may provide insights into the broader socio-cultural context that shapes literacy development. Investigating how family educational levels and students' prior exposure to digital tools influence their literacy could enhance understanding of the individual and environmental factors at play. Moreover, exploring the interplay between gender, socio-economic status, and educational background may offer more comprehensive strategies for addressing literacy gaps in pre-service teacher training programs.

Finally, longitudinal studies could provide a deeper exploration of how mathematical and digital literacy evolve over time in pre-service teachers. Research that tracks these competencies throughout their training could offer insights into how educational interventions, coursework, and teaching experiences contribute to the development of both digital and mathematical literacy.

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