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IDENTIFICATION OF STUDENTS' TECHNO-MATHEMATICAL LITERACIES (TML) ABILITIES: PRELIMINARY RESEARCH

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Abstrak
Perkembangan teknologi digital telah mengubah cara manusia berinteraksi dengan informasi matematika, menjadikan Techno-Mathematical Literacies (TmL) semakin krusial di era digital. Penelitian bertujuan untuk mengidentifikasi dan menganalisis kemampuan TML mahasiswa sebagai langkah awal dalam memahami profil kemampuan TML di tingkat pendidikan tinggi. Penelitian menggunakan pendekatan mixed method dengan desain explanatory sequential. 31 mahasiswa program studi Teknik Sipil Universitas Riau Kepulauan yang dipilih sebagai subjek penelitian menggunakan teknik purposive sampling. Pengumpulan data menggunakan tes kemampuan TML dengan empat dimensi. Nilai validitas konten 0.85 menggunakan formula Aiken's V, dilanjuti wawancara semi-terstruktur 6 mahasiswa. Hasil penelitian menunjukkan rata-rata kemampuan TML mahasiswa berada pada kategori rendah (35,53%). Analisis komponen TML mengungkapkan bahwa mahasiswa paling baik dalam representasi matematis digital (42,78%), literasi matematis digital (37,08%), validasi matematis digital (34,79%), dan kemampuan menggunakan software matematis terendah (24,58%). Analisis tematik mengidentifikasi empat faktor utama yang mempengaruhi pengembangan TML: proses integrasi teknologi, hambatan teknis dan adaptasi, pengembangan kemampuan problem-solving, serta persepsi dan sikap terhadap TML. Temuan ini mengimplikasikan perlunya intervensi pembelajaran yang lebih intensif dan terstruktur untuk meningkatkan kemampuan TML mahasiswa, terutama dalam aspek penguasaan software matematis. Strategi yang disarankan meliputi pendekatan berbasis proyek, dan penggunaan berbagai media digital inovatif.

Keywords: Integrasi Teknologi; Pembelajaran Matematika; Pendidikan Tinggi; Studi Pendahuluan; Techno-Mathematical Literacies

Abstract
The development of digital technology has changed the way humans interact with mathematical information, making Techno-Mathematical Literacies (TML) increasingly crucial in the digital era. The research aims to identify and analyze the TML abilities of students as an initial step in understanding the TML ability profile at the higher education level. The research uses a mixed-method approach with an explanatory sequential design. 31 students from the Civil Engineering program at the University of Riau Islands, selected as research subjects, were chosen using the purposive sampling technique. Data

collection used the TML ability test with four dimensions. The content validity score was 0.85 using Aiken's V formula, followed by semi-structured interviews with 6 students. The research results show that the average TML ability of the students is in the low category (35.53%). The analysis of TML components reveals that students perform best in digital mathematical representation (42.78%), digital mathematical literacy (37.08%), digital mathematical validation (34.79%), and have the lowest ability in using mathematical software (24.58%). Thematic analysis identified four main factors influencing the development of TML: the process of technology integration, technical and adaptation barriers, the development of problem-solving skills, and perceptions and attitudes towards TML. These findings imply the need for more intensive and structured learning interventions to enhance students' TML skills, particularly in the aspect of mastering mathematical software. The recommended strategies include a project-based approach and the use of various innovative digital media.

Keywords: Higher Education; Mathematics Learning; Premilinary Research; Techno-Mathematical Literacies; Technology Integration

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INTRODUCTION

Digital technology has revolutionized mathematical problem-solving, necessitating the integration of mathematical understanding with technological skills, a competency known as Techno-Mathematical Literacies (TmL) (C Hoyles et al., 2010). TmL is a combination of mathematical understanding, situational knowledge, and technological skills necessary to solve mathematical problems in a digital context. (Noss & Hoyles, 2010) add that TmL not only includes the ability to use technology to solve mathematical problems but also the ability to interpret and communicate the results of mathematical analysis using digital media.

TmL is a complex construct that involves dynamic interactions between mathematical, contextual, and technological understanding. (Kent et al., 2007) outline four fundamental components of TmL, which include the ability to model mathematically in a digital context, interpret digital representations, systemic understanding, and evaluate and problem-solving using digital tools. (Celia Hoyles & Noss, 2003) deepen this understanding by asserting that TmL is not merely a simple combination of mathematical literacy and technology but rather a new form of literacy that encompasses the ability to identify mathematical elements in technology-mediated problems, select and use appropriate digital tools for mathematical analysis, interpret results in the context of the original problem, and communicate findings through various modes of digital representation. This theoretical framework emphasizes that TmL is a complex integration that requires a deep understanding of the interactions between mathematics, technology, and its application context in problem-solving. This integration aligns closely with evolving industry demands, where technological and mathematical competencies are increasingly intertwined.

Research conducted by (C Hoyles et al., 2013) shows that success in higher education and the workforce increasingly depends on the ability to integrate mathematical understanding with digital technology. Graduates in the digital era face significant challenges in education, skill requirements, and job market uncertainty (Nguyen, 2018). Universities must avoid the adoption of consumer-oriented technologies that lack pedagogical features, integrate pedagogical innovations (Cunha 2020), and prepare students for skill flexibility (Aulia, 2020). Additionally, graduates must possess adaptable skills and the ability to adjust to various types of jobs (Alenezi et al 2023).

Despite the increasing emphasis on TmL in higher education, there exists a significant gap between students' current competencies and industry expectations. The gap between the current capabilities of graduates and industry demands encompasses three main aspects: 1). Technical skills: students are less proficient in using essential software (Radermacher & Walia, 2013), less capable in digital processing (Rahmat et al 2021) and lack direct project experience to overcome work barriers (Dube, 2023); 2). Personal skills: students are lacking in effective communication (Ramadi et al 2016) and adaptability (Jackson et al., 2020); 3). Professional quality: graduates lack professional ethics (Radermacher & Walia, 2013) and have low self-confidence (Pujol-Jover et al 2022).

Based on this gap, this preliminary research aims to identify and analyze students' TmL abilities as an initial step in understanding the profile of TmL abilities at the higher education level. This aligns with the recommendation (Gravemeijer et al., 2017) which emphasizes the importance of a deep understanding of TmL abilities as the foundation for developing effective educational programs. The research questions in this study are: (1) What is the profile of students' TmL abilities in the context of mathematics learning? (2) What are the factors that influence the development of students' TmL abilities? The results of this preliminary study are expected to provide an empirical foundation for the development of more effective learning strategies to enhance students' TmL skills.

METHODOLOGY

This research uses a mixed-method approach with an explanatory sequential design, where quantitative data is collected and analyzed first, followed by the collection and analysis of qualitative data to deepen the understanding of the phenomenon being studied (Creswell & Creswell, 2018). This design was chosen as it allows for comprehensive profiling of students' TmL capabilities through multiple perspectives: the quantitative phase enables broad measurement and identification of TmL competency patterns across the student population, while the subsequent qualitative phase provides deeper insights into how students integrate mathematical thinking with technological tools and reveals the contextual factors influencing their TmL development in higher education. The sequential nature of this design ensures that qualitative investigations can be strategically focused on explaining and elaborating the initial quantitative findings, thereby providing a more nuanced understanding of students' TmL profiles and competency development pathways. The research subjects consisted of 31 students from the Civil Engineering study program at the University of Riau Islands, this program was selected as civil engineering students regularly engage with complex mathematical modeling and digital tools in their coursework, particularly in structural analysis, construction planning, and design tasks. These students represent an ideal context for studying TmL capabilities as their field demands the integration of mathematical concepts with technological applications for solving real-world engineering problems. They are selected using purposive sampling techniques with consideration for the representation of academic ability levels (high, medium, low) based on the students' Grade Point Average (GPA).

Data were collected using a TmL ability test specifically developed for this study, based on four dimensions: Digital Mathematical Literacy, Mathematical Software Competency, Digital Mathematical Validation, and Digital Mathematical Representation. These indicators were validated by three experts in mathematics education, achieving a content validity score of 0.85 using Aiken's V formula as shown in Table 1.

Table 1. Indicators and Student TmL Questions

Indicator		Questions
Digital Mathematical Literacy	(a), (b)	The distribution of stress on a steel beam due to lateral load is expressed in the function $\sigma(y) = 200y - 5y^3$, where y is the vertical distance from the neutral axis in cm and σ in MPa. a. Analyze the behavior of the stress function by determining the critical points. b. Illustrate the stress distribution and mark its important characteristics. c. Determine the intervals where the stress function is concave up and down. d. Interpret the implications of the analysis results on beam design.
Mathematical Software Competency	(a), (b)	
Digital Mathematical Validation	(a), (c), (d)	
Digital Mathematical Representation	(b), (d)	

Semi-structured interviews were conducted with 6 students strategically selected to represent different TmL proficiency levels (2 from high, middle, and low ability levels) based on their performance in the TmL assessment test. This purposive sampling strategy aimed to capture diverse perspectives and experiences across the spectrum of TmL capabilities. The interviews were designed to provide deeper insights into students' TmL development processes and to elaborate on the quantitative findings by exploring individual learning trajectories and contextual factors. The interview protocol followed a structured progression: 1) The Opening

Section began with introduction and explanation of the interview's purpose and confirmation of consent to record. 2) The Core Section explored students' lived experiences through questions about their experiences using technology in mathematics learning, specific challenges in developing TmL skills, strategies for overcoming difficulties, and supporting and hindering factors. 3) The Closing Section included clarifying important points, providing opportunities for additional questions from participants, and confirming interview interpretations through member checking to ensure accuracy and validity of the qualitative data

Data analysis was carried out in stages using a sequential mixed analysis approach (Lund, 2012). Quantitative data from the TML test and questionnaires were analyzed using descriptive statistics to obtain an overview of students' TML skill profiles. The percentage of TML ability was calculated using the formula

$$P = \left(\frac{f}{N}\right) \times 100\%$$

Where: P = Percentage; f = Frequency being sought; N = Total number of data (Sugiyono, 2020)

For result interpretation, TmL ability categories are used based on the criteria in Table 2

Table 2. TmL ability categories

Descriptions	Interval
Very High	81%-100%
High	61% - 80 %
Medium	41% - 60%
Low	21% - 40%
Very Low	0.0% - 20%

Meanwhile, qualitative data from interviews were analyzed using thematic analysis techniques developed by (Braun & Clarke, 2006) to identify patterns and themes that emerged related to factors influencing the development of TML skills. The stages carried out include data familiarization, initial coding, theme search, theme review, theme definition, and reporting. To enhance the credibility of the research results, source triangulation was conducted by comparing data from TmL tests, interviews, and documentation, as well as verifying interpretations with participants.

RESULT AND DISCUSSION

Student TmL Ability

Based on the results of the TmL test given to 31 students, the categories of TmL achievement among students are as shown in Table 3.

Table 3. Categories of TmL achievement among students

Categories	Number of students
Very High	0
High	0
Medium	9
Low	19
Very Low	3

With an average TmL ability of students in the low category at 35.53%. This low performance indicates a substantial gap between current capabilities and the level of TmL competency required in the engineering workplace, where technological tools and mathematical modeling are increasingly integral to professional practice. If examined further for each category, it can be seen in image 1.

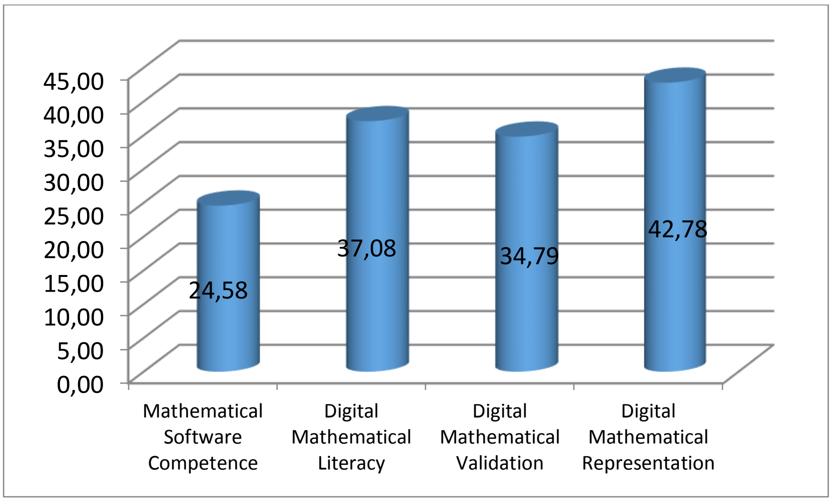
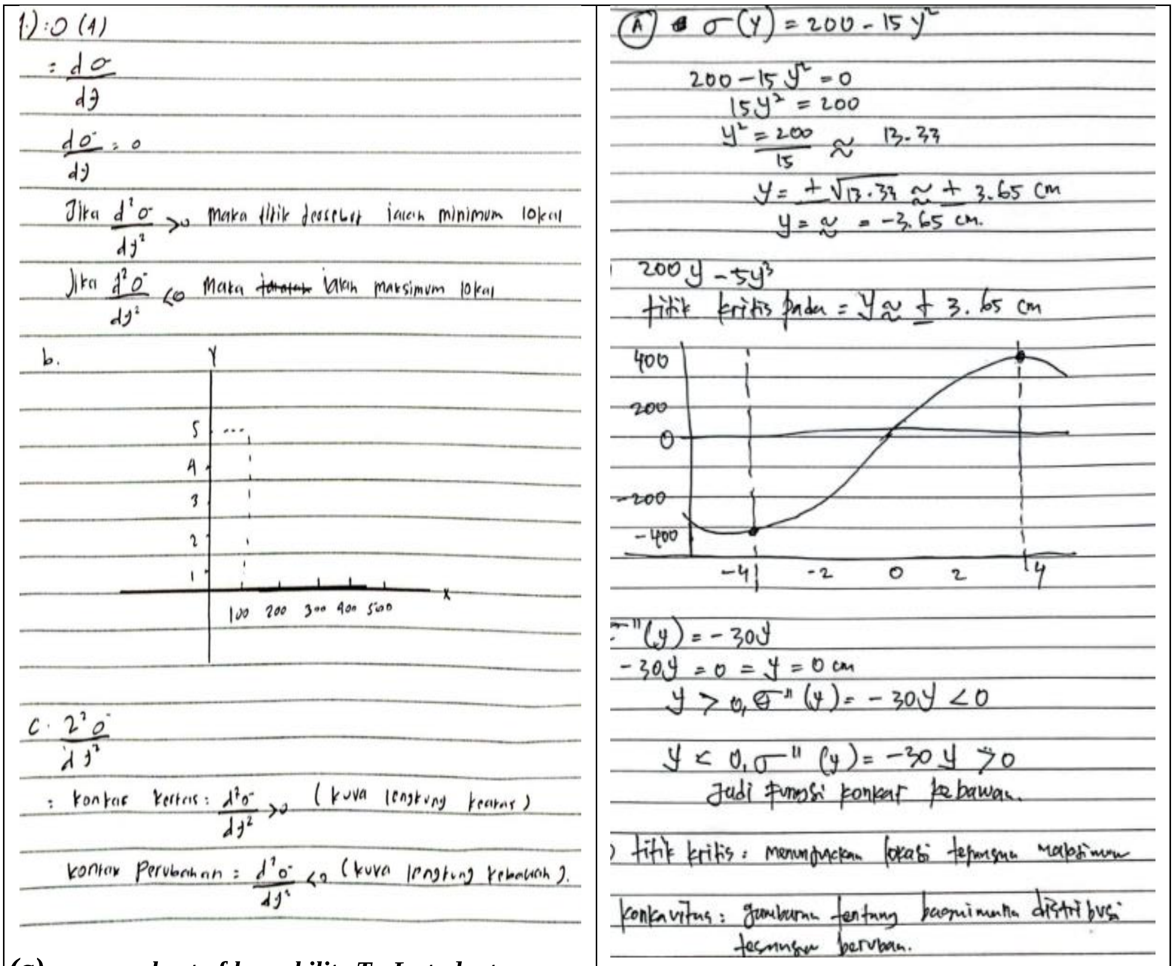


Figure 1. Presentation of Student TmL Achievement

Then, to see one form of the students' TmL answers, it is presented in Figure 2.



(a) answer sheet of low-ability TmL students **(b) answer sheet of medium-ability TmL students**

Figure 2. students' TmL answers

Figure 2a is the answer sheet of a student with low ability, shows that students performed incomplete calculations, did not conduct validation, did not use GeoGebra as a visual aid, the graphs were unclear, there were no characteristic markings, and concavity was not identified. And Figure 2b shows the TmL students' ability where in the process of calculating critical points, it is accurate with minor errors, they have manually drawn and marked the critical points, the intervals of concavity are identified with some errors, they have used basic analysis but have not yet used applications as visual aids and data validation tools.

Digital Mathematical Representation

The ability to represent mathematical concepts digitally emerged as the strongest TmL component, though still moderately low at 42.78% (middle category). While quantitative analysis of answer sheets revealed that students with moderate ability could perform basic manual representations such as drawing and marking critical points, they had not yet fully leveraged digital applications for visualization. The interview data helped illuminate this transitional stage in students' digital representation skills. As Participant 3 explained:

> *'Initially, I was used to learning mathematics traditionally with paper and pencil. But now, the use of software like GeoGebra helps me visualize abstract concepts better.'*

This reflection aligns with the quantitative findings, suggesting that while students are beginning to recognize and utilize digital tools for mathematical representation, they are still in the process of transitioning from traditional to technology-enhanced methods. This transitional state explains both the relatively higher performance in representation compared to other TmL components and why the overall score remains in the middle category

Digital Mathematical Literacy

Analysis of mathematical digital literacy revealed a concerning gap between awareness and implementation, with students scoring only 37.08% (low category). While quantitative analysis of answer sheets showed incomplete calculations and limited use of digital tools, the qualitative data helped explain this discrepancy. Interview responses indicated that students recognize the potential of digital tools but struggle with their practical application. This pattern was exemplified by Participant 2, who acknowledged:

> *"Using spreadsheets for mathematical data analysis helps me better understand the relationships between concepts, especially in statistics."*

This contrast between students' positive perceptions and their low performance scores (37.08%) suggests that while students understand the value of digital mathematical literacy, they have not yet developed the practical skills necessary for effective implementation. This finding points to a specific area where targeted interventions could help bridge the gap between theoretical understanding and practical application of digital tools in mathematical contexts.

Digital Mathematical Validation

Mathematical digital validation ability received a score of 34.79% (low category). Analysis of answer sheets shows that students often ignore the validation process when using digital tools, thus indicating the existence of systematic gaps in verification practices. Qualitative data from interviews helps explain these low quantitative scores by revealing two main factors. First, technical barriers greatly hinder students' ability to carry out digital validation, as stated by Participant 5:

> *"Limitations of internet access and adequate devices sometimes hinder the learning process, especially if using mathematics software that requires high specifications."*

However, interviews also revealed that when technical barriers were overcome, students realized the value of digital tools in mathematics learning. As Participant 6 noted:

> *"Mathematics software allows me to focus on understanding concepts and problem-solving strategies, not just on mechanical calculations."*

The contrast between technical challenges and perceived benefits helps explain why students may skip validation steps despite understanding their importance, thereby contributing to the low performance observed in quantitative assessments.

Mathematical Software Competency

Competence in mathematical software emerged as the most critical area for improvement, with students scoring only 24.58% - the lowest among all TmL components. The quantitative analysis of answer sheets revealed a widespread absence of GeoGebra usage for visualization, indicating significant barriers in software utilization. The follow-up interviews provided crucial insights into this low performance while also revealing students' coping strategies and recognition of technology's potential. For instance, Participant 1's statement,

> *"I try to learn collaboratively with friends to overcome my limitations in using the application"*

demonstrates awareness of their limitations and proactive efforts to address them. This sentiment was complemented by Participant 3's observation that

> *“Using technology helps me explore various approaches to solving mathematical problems. I can try different strategies more efficiently.”*

The contrast between the extremely low quantitative scores (24.58%) and these interview responses suggests that while students recognize the value of mathematical software and are developing strategies to learn it, there remains a substantial gap between their aspirations and current capabilities in practical software implementation."

Factors Affecting TmL

Several key factors were identified that influence the development of students' TmL abilities. First, learning transition factors play an important role where quantitative data shows the existence of significant ability gaps. This is reinforced by the results of interviews which reveal that students are experiencing an adaptation process from traditional learning to digital-based learning. Despite the challenges of this transition, students recognized the positive role of technology in enhancing their understanding of concepts. As stated by Participant 3:

> *"Initially, I was used to learning mathematics traditionally with paper and pencil. But now, the use of software like GeoGebra helps me visualize abstract concepts better."*

The second factor relates to technical barriers that significantly influence the development of TmL capabilities. The low score on mathematical software competency (24.58%) is strongly correlated with access barriers and infrastructure limitations experienced by students. This is reflected in Participant 5's statement:

> *"The limitations of internet access and adequate devices sometimes hinder the learning process, especially when using mathematics software that requires high specifications."*

However, interesting findings from the interviews revealed that students developed collaborative strategies as adaptive solutions to overcome these limitations. As stated by Participant 1: *"I try to learn collaboratively with friends to overcome my limitations in using the application."*

This collaborative strategy shows student resilience in facing technical challenges.

In the context of developing problem solving abilities, analysis of student answer sheets shows variations in the solution strategies used. Interviews revealed that technology integration provided opportunities for students to explore various problem-solving approaches more efficiently. Participant 3 emphasized:

> *"Using technology helps me explore various approaches to solving mathematical problems. I can try different strategies more efficiently."*

Participant 6 added an interesting perspective:

> *"Mathematics software allows me to focus on understanding concepts and problem-solving strategies, not just on mechanical calculations."*

The final factor is related to students' perceptions and attitudes towards TmL. Interestingly, although the quantitative data shows relatively low proficiency, there is a high awareness among students about the importance of TmL for their future careers in the digital era. This is reflected in Participant 3's statement:

> *"The ability to integrate technology with mathematics is very important for a career in the digital era. It's not just about mathematics or technology alone, but how to effectively combine both."*

However, some students also expressed concerns, as expressed by Participant 4:

> *"Sometimes I worry about becoming too dependent on technology and losing basic mathematical skills. There needs to be a balance between using technology and understanding fundamental concepts."*

This shows the need for a learning approach that can help students achieve a balance between the use of technology and mastery of fundamental concepts.

Based on research findings that show students' low TmL ability, especially in the mathematical software competency aspect (24.58%), effective learning strategies are needed to improve this ability. (Wijaya et al., 2021) suggests a project-based approach, while (Panaoura, 2012) recommends computerized mathematical modeling, and (Noto et al 2018) emphasize the importance of valid learning material design. Findings regarding technical barriers expressed by students ("*The limitations of internet access and adequate devices sometimes hinder the learning process*") in line with research by (Saifiyah et al 2017) who identified student motivation, (Rismi, 2021) who discussed difficulties in understanding prerequisite material, and (Lestari, 2021) who highlighted the importance of self-regulation skills as the main challenge that needs to be overcome.

Collaborative strategies developed by students, as revealed in the statement *"I try to learn collaboratively with friends to overcome my limitations in using the* *application,"* supports (Ran et al 2021) recommendation regarding the importance of creating a collaborative environment. To increase mathematical digital literacy which is still in the low category (37.08%), (Marsitin 2023) suggest using various innovative digital media and methods such as the Wolfram Alpha Android application, Geogebra, and Matlab. This is relevant to students' recognition that using software helps them visualize abstract concepts better.

Identified TmL capability gaps can be addressed through a variety of approaches recommended in the literature, including the use of adaptive learning systems (Toktarova, 2022), personalized instruction (Walkington, 2013), integration of adaptive feedback (Rodionov et al., 2020), and digital support for students the disadvantaged (Roschelle et al., 2016). The importance of the lecturer's role in supporting the development of TmL capabilities, as implied in the interview findings, is reinforced by research by (Weltman et al., 2018) who emphasize the importance of training and active use by teachers. These approaches have been shown to improve engagement (Wong & Wong, 2021), understanding (Shé 2023), and student mathematics learning outcomes (Viberg et al 2020).

CONCLUSION

This research successfully answered two main research questions regarding the profile of students' TmL abilities and the factors influencing their development. Regarding the first research question, the analysis results show that students' TmL abilities are generally still in the low category (35.53%). Dimensional analysis reveals significant variation in TmL components: Digital Mathematical Representation is the strongest component (42.78%), while Mathematical Software Competency emerges as the main weakness (24.58%). Digital Mathematical Literacy (37.08%) and Digital Mathematical Validation (34.79%) also show unsatisfactory results. These findings indicate a substantial gap between current capabilities and the competency demands in the engineering workforce.

In answering the second research question, the study identified four main factors influencing the development of TmL: the transition of learning from traditional methods to digital, technical barriers such as infrastructure limitations, variations in problem-solving abilities, and students' perceptions and attitudes towards technology integration. Qualitative data from interviews reinforce these quantitative findings, revealing how students develop adaptive strategies such as collaborative learning to overcome existing limitations.

Based on these findings, several concrete recommendations can be provided to educational institutions. (1) The development of adequate technological infrastructure, including internet access and devices that support mathematical software. (2) The implementation of a project-based learning approach that integrates digital technology. (3) The development of structured training programs to enhance mathematical software competence. (4) The integration of various innovative digital media such as Wolfram Alpha, GeoGebra, and Matlab into the regular curriculum. For future research, several recommendations are proposed based on the limitations of this study. (1) Experimental research to test the effectiveness of various learning interventions in improving specific TmL components. (2) Comparative studies between institutions with different infrastructure conditions to understand the influence of contextual factors. (3) Development and validation of more comprehensive TmL assessment instruments.

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