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SOFTWARE PROFICIENCY CRISIS IN HIGHER EDUCATION: A MULTI-PROGRAM ANALYSIS OF TECHNOMATHEMATICAL LITERACIES AND ITS PEDAGOGICAL IMPLICATIONS

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Abstract : *Engineering graduates increasingly need technomathematics literacy (TmL) and computational tools. However, empirical evidence on the multidimensional TmL profiles of students across engineering disciplines remains scarce. This study aims to assess the level of TmL of students in five engineering study programs and identify competency deficits as a basis for curriculum design improvements. The study used a quantitative, cross-sectional survey design with 135 first-semester students. Data were collected using a validated seven-dimensional TmL instrument. The results showed that the level of TmL was generally low (M = 2.32), with the Electrical Engineering study program achieving a moderate category (M = 2.64). The software capability dimension was the lowest (M = 1.91) across all programs. In contrast, analytical dimensions such as data literacy (M = 2.49) and error sensitivity (M = 2.46) were relatively higher. This confirms the gap between analytical and computational capabilities. These findings indicate that software competencies have not been optimally integrated into the curriculum, thus requiring the integration of computational-based problem-solving, strengthening lecturer capacity, and adjustments to accreditation standards to support the development of TmL as a graduate achievement.*

Keywords : *Technomathematical Literacies; Engineering Education; Software Proficiency.*

Abstrak : *Lulusan teknik semakin membutuhkan literasi teknomatematika (TmL) dan alat komputasi. Namun, bukti empiris tentang profil TmL multidimensional mahasiswa di berbagai disiplin ilmu teknik masih langka. Penelitian ini bertujuan menilai tingkat TmL mahasiswa pada lima program studi teknik dan mengidentifikasi defisit kompetensi sebagai dasar perbaikan desain kurikulum. Penelitian menggunakan pendekatan kuantitatif dengan desain survei potong lintang terhadap 135 mahasiswa semester pertama. Data dikumpulkan menggunakan instrumen TmL tujuh dimensi yang telah tervalidasi. Hasil penelitian menunjukkan bahwa tingkat TmL secara umum tergolong rendah (M = 2,32), dengan program studi Teknik Elektro mencapai kategori sedang (M = 2,64). Dimensi kemampuan perangkat lunak menjadi yang terendah (M = 1,91) di seluruh program. Sebaliknya, dimensi analitis seperti literasi data (M = 2,49) dan sensitivitas kesalahan (M = 2,46) relatif lebih tinggi. Hal tersebut menegaskan adanya kesenjangan antara kemampuan analitis dan komputasional. Temuan ini menunjukkan bahwa kompetensi perangkat lunak belum terintegrasi secara optimal dalam kurikulum sehingga membutuhkan integrasi pemecahan masalah berbasis komputasi, penguatan kapasitas dosen, dan penyesuaian standar akreditasi untuk mendukung pengembangan TmL sebagai capaian lulusan.*

Kata Kunci : *Literasi Teknomatematika; Pendidikan Teknik; Kemahiran Perangkat Lunak.*

INTRODUCTION

The accelerating integration of computational tools across diverse engineering sectors has fundamentally changed the knowledge and skill profile expected of engineering graduates. In professional practice, engineers are now expected not only to run engineering software but also to understand numerical methods, modeling assumptions, problem-solving algorithms, algorithm design, and pattern recognition, considered fundamental to the modern engineering workforce (Kachkar & Yilmaz, 2023; Pirzado et al., 2025). This transformation reflects a broader global shift toward a digitally intensive work environment, where the boundaries between mathematical reasoning and technological applications are increasingly blurred (Mundiri et al., 2025). However, engineering education has been slow to respond to this shift, often maintaining curriculum structures that treat computational tools as supplementary rather than central to engineering thinking (Botha & Van Niekerk, 2025; Eppes et al., 2021). The resulting gap between educational preparation and professional expectations is not merely logistical but epistemological: it reflects a deeper failure to reconceptualize what counts as mathematical competence in an era defined by computational practice. This misalignment constitutes a structural crisis for higher education institutions that aspire to produce engineers equipped for contemporary professional demands.

In the context of modern engineering education, the concept of Technomathematical Literacy (TmL) has emerged as a robust theoretical and practical framework for understanding the integration of mathematical reasoning with technological tools in authentic workplace settings. Initially introduced by Hoyles et al., (2010) and further developed by williams & wake, (2006), TmL encompasses seven interrelated dimensions: data literacy, software proficiency, technical communication, error sensitivity, numerical sensitivity, technical creativity, and technical drawing skills (van der Wal et al., 2019). In practice, engineers rely on these core TmL dimensions, particularly technical software skills, data literacy, and error awareness, yet they often perceive their university mathematics as an "island" with limited relevance to professional work, rarely involving software use or estimation approaches (Chinchay et al., 2024; Lanning et al., 2020). This gap is reinforced by the nature of mathematics courses, which tend to be highly theoretical and lack contextual connections to real-world applications and digital tools, despite the growing demand for TmL in technology-rich environments (Awaliah S et al., 2025; Himmi et al., 2024; Saparbayeva et al., 2024). Consequently, this structural separation between academic mathematics and professional practice contributes to the persistent shortcomings in technomathematical literacy and software proficiency among engineering graduates.

Despite this progress, important gaps in the literature remain. First, most existing TmL studies focus on single disciplines or isolated competency dimensions, limiting the ability to identify cross-program patterns and structural imbalances (Hsiung, 2023;

Rachmawati et al., 2022). Second, most studies have not examined TmL from a pedagogical perspective that is, in terms of curriculum design, teaching strategies, or learning interventions that may systematically support or hinder TmL development (Hadgraft & Kolmos, 2020; Supriadi et al., 2024). Third, and critically, no published study has simultaneously delivered a multidimensional, multi-program TmL assessment and derived actionable pedagogical implications from the resulting competency profiles, leaving practitioners and curriculum designers without evidence-based guidance for targeted intervention (Abdullah et al., 2023; Tadege et al., 2022). This tripartite gap in scope, perspective, and actionability defines the research space the present study occupies.

The novelty of this study lies in its integration of three dimensions that previous research has treated separately: 1) a multidimensional TmL assessment spanning seven competency domains, 2) a cross-program comparative design covering five engineering disciplines within a single institution, and 3) an explicit pedagogical lens focused on the implications of competency profiles for curriculum design and instructional practice. Unlike prior diagnostic surveys, this study makes an original theoretical contribution by demonstrating that the analytical-computational dissociation, the disconnect between students' relatively stronger analytical awareness and their significantly weaker computational implementation, constitutes a previously undertheorized structural vulnerability in engineering education. This constitutes the study's primary novelty claim: not merely identifying that software proficiency is low, but explaining why this specific deficit persists even within computationally oriented programs, and what institutional and pedagogical mechanisms sustain it. This research addresses three specific objectives: 1) to assess TmL levels across five engineering programs using a validated seven-dimensional instrument, 2) to identify the most critical competency gap, with particular attention to software proficiency, and 3) to derive pedagogically grounded recommendations for curriculum design and instructional integration of computational tools in higher engineering education.

METHOD

This study employed a cross-sectional quantitative survey design to assess technomathematical literacies (TmL) among engineering students, enabling systematic comparison across programs at a single point in time (Cohen et al., 2013; Creswell & Creswell, 2018). Participants were recruited through purposive sampling in October 2025 at Universitas Riau Kepulauan, Batam, Indonesia, targeting first-semester students to capture baseline competencies prior to exposure to formal mathematics and discipline-specific technical courses. A total of 135 students from five engineering programs participated. The distribution of participants by program is presented in Table 1.

Table 1: Participant Information by Engineering Program

Program	n	%
Mechanical Engineering	85	63.0
Electrical Engineering	24	17.8
Civil Engineering	14	10.4
Architecture	7	5.2
Information Systems	5	3.7
Total	**135**	**100.0**

Note: The uneven distribution reflects actual enrollment patterns. Smaller samples from Architecture (n = 7) and Information Systems (n = 5) represent the full or near-full cohort of eligible first-semester students in those programs.

Data collection followed three sequential stages: 1) instrument distribution via printed questionnaire administered during scheduled class sessions to ensure a controlled response environment, 2) supervised completion with standardized verbal instructions to minimize misinterpretation of competency descriptors, and 3) immediate collection upon completion to ensure full response rates. The entire data collection process was completed within a single two-week period in October 2025.

The research instrument was a validated self-report questionnaire measuring seven TmL dimensions: Data Literacy, Software Proficiency, Technical Communication, Error Sensitivity, Numerical Sensitivity, Technical Creativity, and Technical Drawing Skills. The instrument comprised 35 items (5 per dimension) rated on a 4-point Likert scale (1 = Low; 4 = Very Good), with the neutral midpoint deliberately excluded to reduce central tendency bias (Chyung et al., 2017). Reliability was confirmed by Cronbach's alpha coefficients of 0.78–0.89 per dimension and an overall coefficient of 0.92. Content validity was established through expert review by five specialists; items with a Content Validity Index below 0.80 were revised or removed. Construct validity was supported by an exploratory factor analysis, which confirmed the seven-factor structure and showed that all item loadings exceeded 0.50 on their respective dimensions.

Data analysis proceeded in three stages. *First*, descriptive statistics (means, standard deviations, ranges) were computed for each TmL dimension and by program. *Second*, scores were classified using five predetermined proficiency thresholds: Very Low (< 2.0), Low (2.0–2.49), Moderate (2.5–2.99), High (3.0–3.49), and Very High (≥ 3.5), established through faculty consultation and institutional assessment standards(Gazi et al., 2024). Third, cross-program comparisons were conducted using descriptive methods and visual representations (box plots, radar charts, bar graphs). Given unequal and small sample sizes, formal inferential testing was deemed inappropriate, and effect sizes were used instead to evaluate practical significance. All analyses were conducted in IBM SPSS Statistics Version 28.0; data visualizations were produced using Python's matplotlib library.

RESULT AND DISCUSSION

1. Results

The assessment of 135 engineering students across five programs revealed alarmingly low levels of technomathematical literacies, with only one program achieving a "Moderate" proficiency level and the remaining four programs categorized as "Low". From table 2 presents the descriptive statistics for overall TmL proficiency by engineering program, yielding a mean score of 2.32 (SD = 0.65), classified as "Low." Among the five programs, Electrical Engineering recorded the highest mean (M = 2.64, SD = 0.69, "Moderate"), while Civil Engineering recorded the lowest (M = 2.18, SD = 0.42, "Low"). The remaining three programs-Information Systems (M = 2.29), Mechanical Engineering (M = 2.26), and Architecture (M = 2.19) — all fell within the "Low" category. Score ranges varied substantially across programs, from a minimum of 1.00 (Mechanical Engineering) to a maximum of 3.86 (Electrical Engineering), reflecting high within-program variability.

Table 2: Descriptive Statistics of Overall TmL Proficiency by Engineering Program

Program	N	Mean	SD	Category	Min	Max	Range	95% CI
Electrical Engineering	24	2.64	0.69	Moderate	1.57	3.86	2.29	[2.35, 2.93]
Information Systems	5	2.29	0.83	Low	1.29	3.29	2.00	[1.26, 3.32]
Mechanical Engineering	85	2.26	0.66	Low	1.00	3.71	2.71	[2.12, 2.40]
Architecture	7	2.19	0.55	Low	1.43	2.86	1.43	[1.70, 2.68]
Civil Engineering	14	2.18	0.42	Low	1.57	2.86	1.29	[1.94, 2.42]
Total Sample	135	2.32	0.65	Low	1.00	3.86	2.86	[2.21, 2.43]

Note: Category thresholds: Very Low (<2.0), Low (2.0-2.49), Moderate (2.5-2.99), High (3.0-3.49), Very High (≥3.5)

Analysis of the seven dimensions of TmL revealed a striking and consistent pattern. Table 3 presents software proficiency scores relative to overall TmL scores by program. Software proficiency yielded the lowest overall mean across all seven dimensions (M = 1.91), the only dimension falling into the "Very Low" category (below 2.0). This dimension is ranked 7th (lowest) across all programs, without exception. The largest gap between overall TmL and software proficiency was noted in Architecture (−0.48), and the smallest in Mechanical Engineering (−0.22). Even in Electrical

Engineering, the highest performing program overall, software proficiency scored only 2.30, remaining in the "Low" category.

Table 3: Software Proficiency Compared to Overall TmL by Program

Program	Overall TmL	Software Proficiency	Gap	Software Rank
Electrical Engineering	2.64	2.30	-0.34	7th (Lowest)
Information Systems	2.29	2.03	-0.26	7th (Lowest)
Mechanical Engineering	2.26	2.04	-0.22	7th (Lowest)
Civil Engineering	2.18	1.90	-0.28	7th (Lowest)
Architecture	2.19	1.71	-0.48	7th (Lowest)
Overall Average	**2.32**	**1.91**	**-0.41**	**7th (Lowest)**

To provide a comprehensive understanding of engineering students' TmL skills, Table 4 presents the mean scores for the seven dimensions across the entire sample and by individual program of study. Data Literacy recorded the highest overall mean (M = 2.49), followed by Error Sensitivity (M = 2.46), Technical Communication (M = 2.42), Technical Creativity (M = 2.40), Engineering Drawing (M = 2.30), and Numerical Sensitivity (M = 2.21). All six dimensions were categorized as "Low." Software Proficiency (M = 1.91) was the only dimension categorized as "Very Low." Electrical Engineering consistently recorded the highest scores across all dimensions; Architecture and Civil Engineering recorded the lowest scores across most dimensions.

Table 4: Mean Scores for Seven TmL Dimensions by Engineering Program

Dimension	EE	IS	ME	Arch	CE	Overall	Category
Data Literacy	2.83	2.65	2.38	2.40	2.23	2.49	Low
Error Sensitivity	2.83	2.20	2.42	2.47	2.37	2.46	Low
Technical Communication	2.67	2.40	2.41	2.27	2.28	2.42	Low
Technical Creativity	2.78	2.40	2.28	2.37	2.15	2.40	Low
Numerical Sensitivity	2.49	2.30	2.11	2.03	2.15	2.21	Low
Technical Drawing	2.55	2.40	2.24	2.10	2.15	2.30	Low
Software Proficiency	2.30	2.03	2.04	1.71	1.90	1.91	Very Low
Overall TmL	2.64	2.29	2.26	2.19	2.18	2.32	Low

Note: EE = Electrical Engineering, IS = Information Systems, ME = Mechanical Engineering, Arch = Architecture, CE = Civil Engineering

2. Discussion

The findings of this study reveal a pervasive pattern of low technomathematical literacy (TmL) among first-semester engineering students across five programs, with software proficiency consistently emerging as the most critical deficit (M = 1.91, "Very

Low") and overall TmL averaging 2.32 ("Low"). Notably, only Electrical Engineering reached the "Moderate" threshold, while the remaining four programs remained uniformly in the "Low" category. These results are significant beyond their descriptive value: they signal that the dominant mode of TmL delivery at the sampled institution has failed to produce functional computational competence, even at a baseline level. The uniformity of low scores across programs with markedly different disciplinary orientations from Architecture to Information Systems strongly implies that the deficit is institutionally reproduced rather than discipline-specific, pointing to systemic curriculum failures that individual instructors or programs cannot resolve in isolation.

Understanding why software proficiency is low in all five programs, including Information Systems, a technology-oriented discipline, requires a theoretical explanation beyond a simple curriculum critique. This study argues that the root cause lies in an epistemological mismatch: engineering curricula continue to treat software as a peripheral tool rather than a constitutive element of mathematical reasoning. This position extends Hoyles et al., (2010) concept of TmL, which is defined not as the sum of mathematical and technological skills, but as their functional integration in workplace problem-solving. Current data suggest that engineering programs largely fail to operationalize this integration, producing graduates who may possess declarative mathematical knowledge but lack the computational fluency to apply it in practice. Because mathematical reasoning in engineering is often implicit and embedded within the discipline(Mili et al., 2023). Bridging this gap requires competency-based education that explicitly connects mathematical knowledge and algorithms within an engineering context (Sipos and Kocsis, 2024).

The relative advantage of Electrical Engineering (M = 2.64) aligns with Berardinucci et al.'s (2023) finding that disciplines structurally dependent on computational modeling — such as signal processing and circuit analysis — tend to integrate software tools more organically into their pedagogical workflows. However, even in this highest-performing program, software proficiency scored only 2.30 ("Low"), demonstrating that disciplinary exposure alone is insufficient to develop TmL. The paradox of Information Systems scoring 2.03 further reinforces this point: familiarity with technology does not equate to techno-mathematical integration. These findings critically extend Archambault et al., (2024) and Pirzado et al., (2025) by showing that intentional curriculum design must embed computational tools within contexts demanding mathematical decision-making and technical judgment — not merely include them as ancillary features.

A theoretically significant pattern concerns the asymmetric development of TmL dimensions. Students performed comparatively better in Data Literacy (M = 2.49) and Error Sensitivity (M = 2.46) than in Software Proficiency (M = 1.91), suggesting that analytical awareness develops through repeated exposure in laboratory and problem-solving contexts, while computational implementation skills do not keep pace. This dissociation has not been explicitly articulated in prior TmL research. While Nogel, (2024) and Ayanwale et al., (2024) documented the importance of data literacy and numerical reasoning in workplace settings, but neither accounted for the possibility that analytical competencies could develop independently of and faster than computational ones. The present study identifies this gap as a novel empirical finding, pointing to a structural vulnerability in engineering education that existing frameworks have undertheorized. Addressing it requires embedding computational learning within the context of engineering modeling and design, rather than treating programming as a standalone skill (Gopal, 2022).

The institutional structures, including curriculum frameworks, faculty development systems, and assessment practices, function as the primary mediating variables between educational policy and student competency outcomes (Hadgraft & Kolmos, 2020; Kamel et al., 2025). In the Indonesian engineering education context, these structures remain largely organized around traditional analytical pedagogies that prioritize symbolic manipulation over computational reasoning (Baharun et al., 2025; Bhattacharya et al., 2022; Nailasariy et al., 2023). The present study's novelty lies in providing the first multidimensional, cross-program empirical evidence of this structural deficiency within a single Indonesian institutional context, at a level of comparative granularity that single-program or single-dimension studies cannot achieve.

These findings carry concrete implications for practice and policy. At the pedagogical level, software proficiency cannot be effectively developed through stand-alone technical training; it must be integrated into discipline-specific mathematical tasks where students use software as a cognitive tool to model, analyze, and interpret engineering problems (Mou, 2024; Zhou et al., 2022). At the institutional level, investment in faculty computational competence is as critical as investment in infrastructure; the data show that even technology-rich programs have not translated access into student proficiency (Adeoye, 2024). At the national level, Indonesian engineering accreditation standards should explicitly incorporate TmL as a measurable graduate attribute, aligned with Washington Accord expectations for computational literacy.

In the global context, these findings contribute to an emerging body of evidence that the software proficiency deficit in engineering education is not unique to Indonesia.

Industry-wide surveys in the United States, Nepal, Australia, and Europe have documented persistent gaps between employer expectations and graduates' computational skills (Abell et al., 2024; Ansori et al., 2023; Santa Soriano & Torres Valdés, 2021). Crucially, however, the present study demonstrates that this gap is not uniform across all TmL dimensions but specifically concentrated in computational implementation, a finding that provides more actionable guidance for curriculum reform than broad calls for "digital literacy," directing attention toward integrating software within mathematical problem-solving rather than toward technology adoption per se.

Several limitations contextualize these findings. First, the reliance on self-report measures introduces the possibility of social desirability bias or inaccurate self-assessment, as students may lack the metacognitive awareness to evaluate their own competencies accurately (Palczyńska & Rynko, 2020). Second, the small samples from Architecture (n = 7) and Information Systems (n = 5) restrict statistical confidence in the estimates for those programs; findings for these groups should be interpreted with appropriate caution (Button et al., 2013). Third, the single-institution design limits generalizability to other Indonesian universities with different resource profiles, faculty expertise, or institutional cultures (Jaciw et al., 2021; Munif et al., 2023; Wibowo & Hasanah, 2021). Future research should employ multi-institutional designs, performance-based assessments, and longitudinal methods to trace the developmental trajectory of TmL across the full engineering degree program.

CONCLUSION

This study reveals that technomathematical literacies (TmL) among engineering students remain at an insufficient level, with overall proficiency categorized as low and only one program reaching a moderate level. The most critical and consistent finding is that software proficiency represents the weakest dimension across all programs, falling within the very low category and demonstrating a substantial gap relative to other TmL competencies. This pattern indicates a structural misalignment between engineering education and contemporary professional practice, where computational tools are essential for modeling, analysis, and problem-solving. Although Electrical Engineering demonstrated relatively stronger performance compared to other programs, software proficiency remained inadequate even within this computationally intensive discipline, suggesting that disciplinary exposure alone is insufficient without intentional pedagogical integration. Furthermore, the relatively stronger performance in analytical dimensions such as data literacy and error sensitivity, combined with weak computational competencies, highlights a persistent disconnect between mathematical reasoning and technological implementation.

These findings suggest that the primary barriers to TmL development are systemic rather than individual, reflecting curriculum structures that do not fully integrate computational tools as core components of engineering thinking. Engineering education must reposition software and computational tools from peripheral technical skills to central cognitive instruments embedded within mathematical and engineering problem-solving. Operationally, this reorientation demands three concrete institutional actions: (1) redesigning mathematics courses for engineering students to include compulsory, assessed software-based problem-solving tasks that mirror authentic engineering workflows; (2) establishing faculty development programs that build instructors' own computational competence, since the data indicate that even resource-equipped programs fail to translate technological access into student proficiency; and (3) revising institutional and national accreditation standards to recognize TmL particularly software proficiency as a formally assessed graduate attribute rather than an assumed byproduct of technical coursework. The study's primary theoretical contribution is the identification and empirical documentation of the analytical-computational dissociation: a previously undertheorized structural vulnerability in which students develop analytical awareness faster and more robustly than computational implementation capacity. This dissociation is not merely an achievement gap; it is a curricular artifact that deliberate pedagogical redesign can correct. Future research should employ multi-institutional, longitudinal, and performance-based designs to trace how the analytical-computational dissociation evolves across the degree program and to evaluate the efficacy of specific instructional interventions targeting software integration. Such work is essential to equip engineering graduates with the computational fluency demanded by contemporary professional practice.

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