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# Impact of Learning Management Systems and Digital Skills on TPACK Development Among Pre-service Mathematics Teachers

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**ABSTRACT:** The technological era has significantly impacted the quality of mathematics education. In reality, the frequency of technology usage in the classroom is minimal, and teachers continue to face challenges when utilizing learning management systems (LMS). Therefore, the purpose of this study is to identify the impact of LMS on the development of technological pedagogical content knowledge (TPACK) and digital skills of pre-service mathematics teachers. This mixed-methods study, employing an exploratory approach, involved 76 pre-service mathematics teachers (22 males, 54 females). Data was collected through questionnaires and interviews and subsequently compiled using Microsoft Excel and saved in CSV format. The data were then analyzed using Jamovi software version 2.4.8.0. Findings show that digital skills significantly influence TPACK development ($\beta = 0.63$, $p < 0.001$), more so than LMS usage ($\beta = 0.49$, $p < 0.001$), with a combined explanatory power of 65% ($R^2 = 0.65$). Higher digital skills improve pre-service teachers' ability to integrate technology into pedagogy and content. Additionally, final-year pre-service teachers show greater competencies. Male pre-service teachers generally exhibit higher digital skills than females ($p < 0.001$), influencing their capacity to effectively use digital tools in teaching. The strong correlation between digital skills and LMS usage (Spearman's $\varrho = 0.86$) underscores the need for structured digital competency development in teacher education. These findings emphasize the importance of fostering digital literacy and technology-integrated practicum experiences in mathematics instruction. Universities and school administrators should implement targeted training programs to enhance LMS utilization and help pre-service teachers develop strong TPACK competencies.

**Keywords:** TPACK, digital skills, learning management system, pre-service mathematics teachers, technology integration.

## I. INTRODUCTION

Recent technological advancements have driven the rapid growth of digitalization in education [1]. In Indonesia, the government continues to promote educational digitalization, especially in areas lacking access to adequate technological facilities and infrastructure. However, many educational institutions have yet to integrate technology into key sectors to enhance educational quality. Digitalization in education is often synonymous with technology as the primary driver, such as the implementation of learning management systems (LMS), which is increasing globally [2]. Initial surveys indicate that in West Nusa Tenggara, particularly in Bima City, Bima Regency, and Dompu Regency, the government has only realized 50% of the necessary technological facilities and infrastructure. This percentage reflects complaints from teachers and educational managers in these regions, highlighting disparities or backwardness compared to other provinces such as Bali and the Special Region of Yogyakarta. This situation affects many schools that are unable to conduct technology-enhanced learning [3-6].

The advancement of technology necessitates high-quality educators who possess knowledge and skills beyond what is traditionally taught in schools or educational institutions. Ultimately, these resources will produce graduates with 21st-century skills who can compete globally in various fields. Observations and interviews with high school mathematics teachers reveal that their knowledge of using technology in the classroom is still very limited. In fact, many teachers express frustration at the lack of professional development and support in integrating technology into their teaching practices. The inability of mathematics teachers to use technology in the learning process is very apparent. Despite having mastered the subject matter, teachers state that the application of technology in learning has not been well-implemented, with no technology usage occurring even within a single semester. This problem is similar to the findings of Bueno & Niess [7], who mentioned that many teachers have not yet studied content teaching with technology. Given this issue, researchers observe and describe the TPACK levels of pre-service teachers, indicating that they tend to accept and recognize TPACK [7].

Such problems have been widely discussed by researchers, including the identification of TPACK domain differences between primary and secondary school mathematics pre-service teachers [8], the development of a TPACK efficiency scale as a self-efficacy measurement tool for pre-service teachers [9], the impact of TPACK knowledge and subcomponent knowledge on high school mathematics pre-service teachers [10], and the investigation of TPACK in pre-service mathematics teachers [11]. However, there is a notable gap in research that specifically addresses the use of Learning Management Systems (LMS) in the development of TPACK and digital skills, particularly for pre-service mathematics teachers in regions with limited access to educational technology. Regarding the challenges faced by mathematics teachers in integrating technology into teaching at the primary and secondary school levels, research by Stein et [12] indicates that these challenges arise due to the lack of technical support from schools for integrating technology. Additionally, limited experience using digital technology for teaching and inadequate training on technology integration are also problematic [13]. Kopcha [14] notes that professional development for teachers in integrating technology into lessons should involve real practice, not just technical training or separate workshops, to enhance technology integration by teachers.

These issues impact students' achievement and learning completion in mathematics. High school mathematics content used in national and computer-based school exams in Indonesia is highly relevant for integration into technology or a learning management system (LMS), such as algebra, calculus, geometry and trigonometry, and statistics. LMS can be used for collecting student performance data [15] and strengthening the learning process through online classes [16], such as google apps for education [17], moodle [2, 18], and flipped problem-based learning using Google Classroom [19]. The use of LMS was very high in Indonesia during and after COVID-19 but has now started to decline. The Indonesian government's response to this situation is through ICT-based learning, developing online learning platforms and digital content through Rumah Belajar, facilitating internet network coverage, and collaborating to deliver learning materials on several television stations.

Based on the issues, theories, and relevant research results, a crucial point to investigate is the use of learning management systems for the development of TPACK and digital skills of current mathematics pre-service teachers. While previous research has predominantly focused on experienced teachers, both male and female, and varying educational levels and research locations, this study shifts the focus to pre-service mathematics teachers. Previous researchers have predominantly focused on experienced teachers, both male and female, and varying educational levels and research locations. Widodo [17] explored the use of an LMS in the form of Google Apps for Education. This study differs by analyzing the correlation between TPACK domains, LMS usage, and digital skills specifically in pre-service mathematics teachers. In contrast, this study focuses on analyzing the correlation between TPACK domains, LMS usage, and digital skills as an extension of TPACK, the relationship between digital skills and LMS usage, and the impact of LMS on digital skills in pre-service mathematics teachers who will dedicate themselves as professional teachers in the future. Mathematics pre-service teachers are the focus to ensure that the challenges faced by today's teachers, as found in preliminary studies and literature, do not continue. This is especially significant for universities producing future teachers and schools employing new teachers, particularly private universities.

## II. LITERATURE REVIEW

### *1. TECHNOLOGICAL PEDAGOGICAL CONTENT KNOWLEDGE*

In 1986, Shulman introduced the concept of pedagogical content knowledge (PCK), asserting that content and pedagogical knowledge are inseparable for promoting effective learning. The success of a teacher depends not only on mastering pedagogical content [20], but also on linking academic content understanding with effective teaching strategies, tailored to students' characteristics and needs [21, 22]. Alongside Shulman's concept, the evolution of teaching practices in the technological era includes the TPACK framework introduced by Mishra & Koehler in 2006 [23]. The TPACK framework as consisting of seven domains: content knowledge, pedagogical knowledge, technological knowledge, pedagogical content knowledge, technological content knowledge, technological pedagogical knowledge, and technological pedagogical content knowledge [23]. These domains are useful for developing learning opportunities for teachers' professional development in the technological era, such as learning with modeled, integrated, and developed technological tools [24].

The TPACK framework has been widely used in educational research to understand teachers' knowledge of using digital technology in classroom teaching [25], significantly impacting the field of mathematics education technology [26-28]. The impact on student achievement from TPACK includes fostering mathematical concept understanding, problem-solving, and enhancing students' thinking abilities [25, 28-31].

### *2. LEARNING MANAGEMENT SYSTEM IN MATHEMATICS EDUCATION*

A Learning management system (LMS) is a highly trendy digital platform in the technological era, especially during the COVID-19 pandemic. LMS supports digital access and management of educational activities. Saygılı & Çetin [32] explain that LMS is a web-based tool for learning, communication, and evaluation activities. LMS provides a space for learners to interact and access teaching materials without time and place limitations, potentially increasing the effectiveness of virtual learning, such as students uploading assignments and taking exams online [33]. Implementing LMS, such as the Edmodo platform, can make assignment management and assessment more efficient. LMS manages all aspects of the learning and teaching process, from administration to reporting [34]. On LMS, instructors can publish assignments, receive student submissions, and grade through a centralized web interface.

Recent studies from several countries indicate that using module-based LMS in mathematics education, particularly geometry, can improve student understanding and performance compared to conventional methods [2]. Widodo [17] emphasizes the need to consider theoretical, pedagogical, and technological aspects in developing LMS to support online learning in higher education. With features like learning paths that allow the organization of learning objects into a navigation map, LMS provides a clear and organized structure for students. The utilization of LMS positively impacts academic performance, enhancing numeracy skills and arithmetic fluency [35, 36].

### 3. DEVELOPING DIGITAL SKILLS THROUGH LMS

Developing digital skills through a learning management system is crucial in the digital era and post-COVID-19 pandemic [37]. LMS also plays a vital role in enhancing the digital skills of pre-service mathematics teachers. Digital skills are essential for 21st-century teachers, as pre-service teachers need to effectively use various technological tools. By engaging with LMS, pre-service teachers develop competencies in using digital tools for instructional purposes, including creating and managing digital content, using data analytics for student assessment, and fostering online collaboration among students. The use of various technologies and digital tools, such as communication, collaboration, scheduling, and content creation tools, is crucial in helping learners direct their own learning [38].

Digital skills encompass the ability to find, evaluate, develop, use, and share digital resources, as well as communicate and collaborate effectively using digital technology. Conversely, developing digital skills is also important for educators to adopt technology in teaching [39]. Assessing teachers' digital competence can be done by monitoring their interactions through LMS, which can help plan the enhancement of teachers' digital competence [40]. Using Moodle LMS in project-based learning has proven effective in developing students' soft skills [41]. Therefore, integrating LMS in higher education not only supports the development of digital and soft skills in students but also enhances the digital competence of lecturers [42-44].

## III. METHOD

### 1. RESEARCH DESIGN

This study employs a sequential explanatory design to generate more constructive concepts and recommendations based on quantitative and qualitative evidence [45]. This design consists of two phases: quantitative and qualitative, with the quantitative data collection and analysis process preceding the qualitative analysis [46]. Through this method, the researchers investigate TPACK, LMS usage, and digital skills. The research was conducted from January to June 2024 at five private universities on Sumbawa Island, West Nusa Tenggara Province, Eastern Indonesia. These universities are listed on Indonesia's higher education data platform with codes 081048, 081051, 083051, 083062, and 083091.

### 2. QUANTITATIVE PHASE

The sample consisted of 76 prospective mathematics teachers selected using simple random sampling. These pre-service teachers are in their 7th and 9th semesters and have completed teaching practice in high schools and junior high schools. Additionally, they have a minimum GPA of 3.00. These pre-service teachers are from private universities under the management of LLDikti Region 8 Denpasar – Bali, covering West Nusa Tenggara, Indonesia.

**Table 1.** Sample and demographics of prospective mathematics teachers.

| Variable | Category | Counts (N = 76) | % of Total |
|---|---|---|---|
| Gender | Male | 22 | 28.9 % |
| | Famale | 54 | 71.1 % |
| Age | 18 | 3 | 3.9 % |
| | 20 | 19 | 25.0 % |
| | 21 | 15 | 19.7 % |
| | 22 | 23 | 30.3 % |
| | 23 | 13 | 17.1 % |
| | 24 | 3 | 3.9 % |
| Semesters | 7 | 54 | 71.1 % |

| | | |
|---|---|---|
| 9 | 22 | 28.9 % |

The instruments used in this sstudy are questionnaires and interviews. These instruments include statements and questions about TPACK, LMS, and the digital skills of prospective mathematics teachers. The questionnaires were distributed directly at the universities' mathematics education programs and through Google Forms sent via email, WhatsApp contacts, and course WhatsApp groups. The questionnaire was validated and reviewed by three experts in mathematics education, educational technology, and educational practitioners with a minimum qualification of Associate Professor to identify and measure content validity. The expert agreement was measured using Aiken's index, as formulated by Retnawati [47].

$$\text{Formula: } V = \frac{\sum_{i=1}^{n} s_i}{R(c-1)} \quad (1)$$

$V$ : index of expert agreement on item validity $\sum_{i=1}^{n} s_i$ : the sum of scores given by each expert is subtracted by the lowest score within the utilized category. $R$ : number of experts, $c$ : number of categories that can be chosen by experts.

The interpretation of the V index calculation results can be categorized as follows: if the index is less than or equal to 0.4, the validity is low; if the index is between 0.4 - 0.8, the validity is moderate; and if the index is greater than 0.8, the validity is high [47]. The average Aiken's V obtained was 0.75, indicating moderate validity. Additionally, the study's instrument reliability was ensured by identifying the Cronbach's Alpha value. The criteria from DeVellis & Thorpe [48] were used to interpret the instrument's Cronbach's Alpha (Table 2).

**Table 2.** Interpretation criteria for Cronbach's alpha.

| Cronbach's Alpha | Reliability Interpretation |
|---|---|
| Less than 0.6 | Low |
| 0.60 - 0.69 | Moderate |
| 0.70 - 0.79 | Good |
| 0.80 - 0.89 | Very Good |
| 0.90 or higher | Excellent |

Based on Jamovi 2.4.8.0 output, the questionnaire showed a Cronbach's Alpha of 0.94, indicating a very high level of consistency for the TPACK, LMS, and digital skills instruments. All statistical analyses in this study were conducted using Jamovi software version 2.4.8.0 [49-51].

## 3. *QUALITATIVE PHASE*

Based on the results of the quantitative data analysis, several participants were selected for interviews using purposive sampling. From the total of 76 prospective mathematics teachers who participated in the quantitative phase, five were chosen for the interviews. The interviews were conducted in person, recorded, and subsequently transcribed. The interview data were manually analyzed using thematic analysis techniques. The analysis process began by identifying interview transcripts, with each respondent assigned a unique code represented by initials A.L., M.B., P.H., R.A., and M.I. Relevant themes were then identified from these codes based on the research questions. These themes were later interpreted into narratives that aligned with the quantitative data obtained. Although only five participants were selected, this purposive sampling approach aimed to gain in-depth insights from individuals who could provide rich and relevant information. By selecting a smaller group, the analysis could focus more closely on the participants' perspectives in greater detail.

To ensure the validity of the qualitative data, triangulation was applied by comparing the quantitative and qualitative results. Furthermore, the findings were cross-checked with participants via Google Meet, as well as with the research team and three experts in the field of mathematics education. This process aimed to confirm that the interpretations of the qualitative data truly reflected the participants' perspectives and were consistent with the quantitative data previously obtained. To enhance the quality of the qualitative data, the researchers have published extensively in the field, with a focus on qualitative studies related to mathematics teaching. Additionally, involving experts to verify the findings further strengthened the reliability and credibility of the analysis. By applying triangulation, the researchers sought to minimize bias and ensure that the study's findings encompassed multiple supporting perspectives, ensuring the relevance between both quantitative and qualitative data used in this research.

### *4. ETHICAL CONSIDERATIONS*

The researchers prioritized the comfort of respondents, building good communication and relationships to gain trust for obtaining reliable and academically accountable data. This study maintained respondent anonymity and confidentiality using pseudonyms [52], especially in the qualitative phase. Respondents voluntarily gave their consent to explore conditions in schools through questionnaires and interviews without any pressure from the research team or other parties, providing written consent in a signed statement. However, there are some limitations to notes. First, potential respondent bias may affect the results, as participants who are more familiar with technology or have a positive view of the research topic may be more inclined to participate or provide favorable responses. Second, the interview data is subjective and may not fully reflect the objective reality of the situations studied. Lastly, although the measurement tools were validated, limitations in capturing the complexities of digital skills could impact the scope of the findings, so interpretations should be made with caution.

## IV. RESULTS

This study aims to identify the responses of pre-service teachers to the TPACK domains, the use of LMS, and digital skills based on TPACK, the relationship between digital skills and LMS usage, and the influence of LMS on digital skills among pre-service mathematics teachers using a sequential explanatory mixed methods design.

**Table 3.** Descriptive and comparative analysis of TPACK, digital skills, and LMS.

| | N | Mean | SE | SD | p | Effect Size |
|---|---|---|---|---|---|---|
| Technological knowledge (TK) | 76 | 3.79 | 0.05 | 0.50 | 0.002 | 0.44 |
| Pedagogical knowledge (PK) | 76 | 3.80 | 0.04 | 0.43 | 0.005 | 0.40 |
| Content knowledge (CK) | 76 | 3.79 | 0.07 | 0.62 | 0.558 | 0.08 |
| Technological pedagogical knowledge (TPK) | 76 | 3.88 | 0.05 | 0.50 | 0.054 | 0.27 |
| Technological content knowledge (TCK) | 76 | 3.82 | 0.06 | 0.60 | 0.008 | 0.38 |
| Pedagogical content knowledge (PCK) | 76 | 3.78 | 0.05 | 0.49 | 0.009 | 0.37 |
| Technological pedagogical content knowledge (TPCK) | 76 | 3.71 | 0.07 | 0.62 | 0.021 | 0.33 |
| Digital skills (DS) | 76 | 3.89 | 0.05 | 0.44 | 0.001 | 0.46 |
| Learning management system (LMS) | 76 | 3.78 | 0.05 | 0.50 | 0.004 | 0.41 |

Note: Independent samples T-Test use Mann-Whitney U, H $\mu 7 \neq \mu 9$

Based on Table 3, it can be concluded that pre-service mathematics teachers generally have positive assessments of various TPACK domains, digital skills, and learning management systems. Digital skills received the highest average rating of 3.89, while technological pedagogical content knowledge received the lowest average rating of 3.71, indicating that most TPACK data accurately represent the TPACK domains of pre-service teachers.

Moreover, Table 3 shows significant differences between 7th and 9th-semester pre-service teachers in TPACK, digital skills, and LMS usage. An analysis of the LMS features used by both groups reveals that specific tools may contribute more significantly to the development of certain domains of TPACK. Mann-Whitney U test results indicate that 9th-semester pre-service teachers significantly outperform 7th-semester teachers in various aspects. Specifically, 9th-semester students excel in technological knowledge ($p = 0.002$, ES = 0.44), pedagogical knowledge ($p = 0.005$, ES = 0.40), technological content knowledge ($p = 0.008$, ES = 0.38), pedagogical content knowledge ($p = 0.009$, ES = 0.37), combined technological pedagogical content knowledge ($p = 0.021$, ES = 0.33), digital skills ($p = 0.001$, ES = 0.46), and LMS usage ($p = 0.004$, ES = 0.41). The differences in LMS usage and TPACK development between 7th and 9th-semester students also point to the importance of experiential learning and the progressive mastery of LMS tools. As students advance in their academic journey, they likely gain more practical experience and develop a deeper understanding of how to effectively integrate technology in teaching, thus improving their PCK and TCK. Conversely, 7th-semester students do not show significant differences in content knowledge ($p = 0.558$, ES = 0.08) and technological pedagogical knowledge ($p = 0.054$, ES = 0.27), indicating no significant difference between 7th and 9th semesters in these aspects. This aligns with interview results from 9th-semester pre-service teachers A.L. and P.H., who stated:

During my teaching practice, I often used applications and software in math classes, such as Microsoft Excel, Geogebra, PPT, LCD, Mathway, E-books, and educational videos. These tools were used extensively during my three-month teaching practice period. I mainly learned independently and through self-study simulations.

**Table 4.** Correlation of TPACK domains among pre-service mathematics teachers.

| | | TK | PK | CK | TPK | TCK | PCK | TPCK |
|---|---|---|---|---|---|---|---|---|
| TK | Pearson's r | — | | | | | | |
| PK | Pearson's r | 0.71 | — | | | | | |
| CK | Pearson's r | 0.46 | 0.48 | — | | | | |
| TPK | Pearson's r | 0.50 | 0.66 | 0.52 | — | | | |
| TCK | Pearson's r | 0.70 | 0.80 | 0.45 | 0.89 | — | | |
| PCK | Pearson's r | 0.38 | 0.62 | 0.43 | 0.82 | 0.71 | — | |
| TPCK | Pearson's r | 0.68 | 0.83 | 0.54 | 0.84 | 0.89 | 0.73 | — |

The correlation matrix analysis in Table 4 shows significant positive relationships among all aspects of technological pedagogical content knowledge (TPACK). Technological knowledge (TK) positively correlates with pedagogical knowledge (PK) ($r = 0.71$), indicating that an increase in technological knowledge corresponds to an increase in pedagogical knowledge. Additionally, TK positively correlates with content knowledge (CK) ($r = 0.46$) and technological pedagogical knowledge (TPK) ($r = 0.50$), though these relationships are not as strong as with pedagogical knowledge. Pedagogical knowledge (PK) shows a strong positive correlation with other variables, especially technological content knowledge (TCK) ($r = 0.80$) and technological pedagogical content knowledge (TPCK) ($r = 0.83$), indicating that pedagogical knowledge is highly related to combined pedagogical and technological knowledge.

Interviews with pre-service teachers M.B. and R.A. revealed:

Most of my technological knowledge comes from hands-on practice, but I also read books, journals, and watch YouTube videos as a foundation before applying my technology knowledge, especially aligning technological models with math content in the classroom.

On the other hand, content knowledge significantly positively correlates with technological pedagogical knowledge (TPK) ($r = 0.52$) and technological content knowledge (TCK) ($r = 0.45$), highlighting the contribution of content knowledge to this combined understanding. Technological pedagogical knowledge (TPK) has a very strong correlation with technological content knowledge (TCK) ($r = 0.89$) and technological pedagogical content knowledge (TPCK) ($r = 0.84$), indicating that pedagogical and technological content knowledge are interconnected with combined knowledge. Technological content knowledge (TCK) also shows a very strong correlation with TPCK (r = 0.89), suggesting that technological content knowledge is closely related to combined knowledge. Pedagogical content knowledge (PCK) significantly positively correlates with all variables, with the strongest relationship to TPCK (r = 0.73).

**Table 5.** Impact of LMS usage and digital skills on TPACK development among pre-service mathematics teachers

| | **Model Fit Measures** | | | |
|---|---|---|---|---|
| **Model** | **R** | **$R^2$** | | |
| 1 | 0.81 | 0.65 | | |
| | **Omnibus ANOVA Test** | | | |
| | **Sum of Squares** | **Mean Square** | **F** | **p** |
| Learning Management System | 1.62 | 1.62 | 11.9 | < .001 |
| Digital Skills | 2.03 | 2.03 | 14.9 | < .001 |
| Residuals | 9.98 | 0.13 | | |
| | **Model Coefficients** | | | |
| **Predictor** | **Estimate** | **SE** | **t** | **p** |
| Intercept | -0.63 | 0.37 | -1.67 | 0.098 |
| Learning Management System | 0.49 | 0.14 | 3.44 | < .001 |
| Digital Skills | 0.63 | 0.16 | 3.86 | < .001 |
| | **Assumption Checks** | | | |
| **Durbin–Watson Test for Autocorrelation** | **Autocorrelation** | **DW Statistic** | **p** | |
| | -0.07 | 2.13 | 0.54 | |
| **Collinearity Statistics** | **VIF** | **Tolerance** | | |
| Learning Management System | 2.91 | 0.34 | | |
| Digital Skills | 2.91 | 0.34 | | |

The regression analysis results in Table 5 identify the impact of LMS and digital skills on TPACK development among pre-service mathematics teachers. The regression model shows an R-value of 0.81 and an $R^2$ value of 0.65, indicating that 65% of the variability in TPACK development can be explained by LMS and digital skills. In the omnibus ANOVA test, both LMS ($F = 11.9$, $p < 0.001$) and digital skills ($F = 14.9$, $p < 0.001$) significantly influence TPACK development. The model coefficients indicate that LMS has a positive estimate of 0.49 ($p < 0.001$), and digital skills have a positive estimate of 0.63 ($p < 0.001$). This clarifies that each increase in LMS and digital skills indicators is associated with a significant increase in TPACK development. Assumption checks show a Durbin-Watson value of 2.13 ($p = 0.54$), indicating no autocorrelation, and a variance inflation factor (VIF) value of 2.91, indicating no multicollinearity issues.

Interview results with pre-service teacher M.I. stated:

The use of LMS at schools is challenging for students due to limited facilities and internet access. The school where I practiced had an internet quota of only 30 Mbps, with many other needs for school administration and other purposes. This limited internet access became a barrier for me in using technology.

**Table 6.** Relationship between digital skills and LMS usage among pre-service mathematics teachers.

| | | **Digital Skills** | **Learning Management System** |
|---|---|---|---|
| Digital Skills | Spearman's rho | — | |
| Learning Management System | Spearman's rho | 0.86 | — |

The Spearman correlation results between digital skills and LMS usage among pre-service mathematics teachers in Table 6 show a very significant positive correlation between the two variables, with a Spearman's rho value of 0.86. This high correlation indicates that an increase in digital skills is strongly associated with continuous LMS usage. This suggests that better digital skills among pre-service mathematics teachers contribute significantly to LMS utilization in the learning process.

**Table 7.** Impact of LMS on digital skills among pre-service mathematics teachers.

| | **Model Fit Measures** | | | |
|---|---|---|---|---|
| **Model** | **R** | **$R^2$** | | |
| 1 | 0.90 | 0.81 | | |
| | **Omnibus ANOVA Test** | | | |
| | **Sum of Squares** | **Mean Square** | **F** | **p** |
| Learning Management System | 1.62 | 1.62 | 11.9 | < .001 |
| Digital Skills | 2.03 | 2.03 | 14.9 | < .001 |
| Residuals | 9.98 | 0.13 | | |
| | **Model Coefficients** | | | |
| **Predictor** | **Estimate** | **SE** | **t** | **p** |
| Intercept | 1.00 | 0.23 | 4.20 | < .001 |
| Learning Management System | 0.78 | 0.05 | 14.31 | < .001 |
| Gender | | | | |
| Female - Male | -0.27 | 0.07 | -3.81 | < .001 |
| Age | | | | |
| 20 – 18 | -0.01 | 0.14 | -0.07 | 0.93 |
| 21 – 18 | 0.41 | 0.13 | 3.17 | 0.00 |
| 22 – 18 | 0.15 | 0.14 | 1.11 | 0.27 |
| 23 – 18 | 0.04 | 0.14 | 0.31 | 0.75 |
| 24 – 18 | -0.14 | 0.19 | -0.72 | 0.47 |
| Semesters | | | | |
| 9 – 7 | -0.07 | 0.07 | -0.98 | 0.32 |
| | **Assumption Checks** | | | |
| **Durbin–Watson Test for Autocorrelation** | **Autocorrelation** | **DW Statistic** | **p** | |
| | -0.188 | 2.34 | 0.11 | |
| **Collinearity Statistics** | **VIF** | **Tolerance** | | |
| Learning Management System | 1.19 | 0.84 | | |
| Gender | 1.39 | 0.71 | | |
| Age | 1.15 | 0.86 | | |
| Semesters | 1.40 | 0.71 | | |

Table 7 explains the linear regression analysis results evaluating the impact of LMS on digital skills among pre-service mathematics teachers. The regression model shows an R-value of 0.90 and an $R^2$ value of 0.81, indicating that 81% of the variability in digital skills can be explained by LMS usage. The omnibus ANOVA test shows that both LMS ($F = 11.9$, $p < 0.001$) and digital skills ($F = 14.9$, $p < 0.001$) significantly influence digital skills. The model coefficients indicate that LMS has a positive estimate of 0.78 ($p < 0.001$).

Additionally, the analysis results show that gender significantly affects digital skills, with a coefficient estimate of -0.27 ($p < 0.001$). This negative coefficient indicates a significant difference in digital skills between males and females, with males tending to have higher digital skills than females. Age and semester did not show a significant impact on digital skills. Assumption checks with a Durbin-Watson value of 2.34 ($p = 0.11$) indicate no significant autocorrelation in residuals, and the VIF values for all predictors are within the range indicating no multicollinearity issues. These findings suggest that LMS usage significantly impacts the improvement of digital skills among pre-service mathematics teachers, with differences based on gender.

## V. DISCUSSION

The research findings indicate that pre-service mathematics teachers generally have positive assessments of various TPACK domains, digital skills, and LMS usage. The knowledge required to teach mathematics can be integrated with the technological pedagogical content knowledge (TPACK) framework as a foundation for understanding technology-integrated mathematics instruction [53]. Specifically, among the seven subdomains, pre-service teachers scored highest in PK, TPK, and TCK. PK refers to knowledge about teaching methods and processes as well as practices for mathematics instruction [31]. TPK pertains to knowledge about how to utilize various technologies with different pedagogical approaches. It is crucial for teachers to recognize and apply technology and choose pedagogical approaches that match specific technologies, and vice versa [53]. Meanwhile, TCK refers to understanding how technology can be used to deliver and represent content effectively and has seen improvement in recent years [54].

Beyond these three subdomains, digital skills were rated higher than TPACK subdomains. Digital skills are essential for effectively actualizing TPACK, impacting the quality of classroom instruction. Various studies have revealed that the digital skills required by pre-service mathematics teachers include proficiency in using educational technology [55, 56], developing digital content [57, 58], utilizing online learning platforms [59, 60], and data literacy [61, 62]. These digital skills not only enhance teaching quality but also support more interactive and student-centered learning environments, improving the overall effectiveness of classroom instruction. These skills not only enhance teaching quality but also motivate students and facilitate more constructive learning.

However, there are significant differences in the assessments between 7th and 9th-semester pre-service teachers, with 9th-semester pre-service teachers showing better results. Knowledge and skills improvements occur alongside academic progression and practical experiences with technology in teaching. In TPACK, more teaching practice experience using technology can broaden pre-service teachers' understanding of technology integration processes, teaching methods, and mathematical content. Final semester pre-service teachers frequently use technology and teaching strategies involving real-life situations to reinforce their TPACK knowledge. Koh et al [63] found no conceptual differences between TPACK domains but noted some differences in TPACK perceptions by teaching level, although not strongly.

Authentic experience using technology correlates positively with TPACK, influencing pre-service teachers' general attitudes towards technology [64]. This aligns with Hu [65], who stated that experiential learning and field practice in technology utilization contribute to enhancing students' professional technology competencies. TPACK, particularly the pedagogical content knowledge domain, significantly correlates with all TPACK domains. PCK is a crucial component of teachers' professional knowledge and is related to teaching practices [66]. The formation of digital skills in pre-service teachers begins with their habitual self-practice. In classrooms, lecturers often do not practice and simulate integration because curricula do not align with technological advancements and lack emphasis on digital competencies. This aligns with Ong & Annamalai's [67] view that 21st-century TPACK lacks emphasis on content knowledge and pedagogical content knowledge in planned curricula.

Significant correlations between TPACK domains suggest that improvement in one domain, such as pedagogical knowledge, can strengthen understanding and skills in other domains. This is consistent with TPACK theory, which emphasizes the synergistic integration of pedagogical, content, and technological knowledge for effective teaching [23]. The strong positive relationship between pedagogical knowledge and combined technological pedagogical content knowledge indicates that pedagogical competence serves as a roadmap for integrating technology into teaching. İdil & Narlı [68] found that pedagogical knowledge showed the highest effect, while technological knowledge showed the lowest effect in predicting TPACK domains derived from the interaction of basic domains (pedagogical knowledge, technological knowledge, and content knowledge).

This study's findings show that the significant influence of LMS and digital skills on TPACK development underscores the importance of digital skills and LMS in enhancing pre-service teachers' competencies. Pre-service teachers reported high proficiency in using LMS (as a form of ICT use in teaching) for information management, developing critical thinking, solving problems, and managing mobile devices [69]. To provide concrete examples of how LMS features were utilized to develop TPACK and digital skills, participants in this study frequently used quizzes and assignments to assess their understanding of mathematical concepts. These activities were integrated into the LMS, allowing participants to receive immediate feedback on their performance. For instance, quizzes within the LMS were used to test pre-service teachers' understanding of technological content knowledge by presenting problems that required the application of technology in mathematics. Additionally, assignments related to pedagogical content knowledge were uploaded via the LMS, where instructors provided personalized feedback that helped reinforce teaching strategies. These experiences enabled pre-service teachers to deepen their understanding of integrating technology with teaching methods and content.

Students' digital skills affect user experience and usability issues encountered when using LMS, and mastering digital skills, such as effective ICT use, has been proven to boost academic performance [70]. Omeh et al [71] explained that innovative teaching strategies, such as using digital tools like Google Classroom and Google Meet, help timely develop digital skills to engage learners in the learning process. LMS aids in managing learning content, student interactions, assessment tools, and progress reporting [72, 73]. Research on the relationship between the digital traces of students in Learning Management Systems (LMS) and their academic performance has traditionally been an area of interest in the field of learning analytics. Digital skills enable effective technology utilization in every learning process and support success in digital-based educational environments, such as mathematics lessons [74, 75].

One of the challenges faced by the participants in this study was the lack of formal training on how to use the LMS effectively. The participants did not receive structured training on the LMS features, which impacted on their ability to fully utilize these tools to support the teaching and learning process. Most participants learned how to use the LMS independently, primarily through self-study simulations. Although this method provided basic understanding, it may limit their ability to fully leverage the interactive and collaborative features of the LMS. The strong relationship between digital skills and LMS usage shows that developing digital skills can enhance educational technology usage. However, the study does not address how challenges such as technological infrastructure or educational policies in Indonesia may have influenced the reported results. LMS can be used as an indicator for assessing pre-service teachers' digital skills, although clear mapping between LMS activities and the skills to be measured is still needed [76]. Good digital skills facilitate more intensive and effective technology use in teaching [70, 77, 78]. Additionally, it is important to consider the role of technological infrastructure in enabling or limiting the effective use of LMS, as well as educational policies that may affect the adoption of such technologies in schools. The difference in digital skills based on gender also highlights the need for more inclusive approaches in technology training, ensuring that all pre-service teachers, regardless of gender, have equal opportunities to develop their digital skills. This aligns with Mirķe et al [79], who found significant differences in digital skills and online learning readiness based on gender, age group, or residence. Younger respondents, males, and those living in urban areas showed higher digital skills and online learning readiness levels.

## VI. CONCLUSION

This study indicates that prospective mathematics teachers have a positive perspective towards the TPACK domain, digital skills, and the use of LMS, with digital skills scoring the highest compared to the other domains. Significant differences were found between the seventh- and ninth-semester prospective teachers, with the ninth-semester group demonstrating better competencies in various aspects of TPACK. These findings confirm that higher academic experience and exposure to technology-based learning environments contribute to strengthening TPACK, particularly in the aspects of pedagogical knowledge, technological pedagogical knowledge, and technological content knowledge. Furthermore, this study shows a strong relationship between LMS and digital skills in the development of TPACK, with digital skills playing a crucial role in facilitating the use of technology in teaching. These findings provide empirical evidence that the effective integration of LMS can enhance prospective teachers' capacity to manage digital learning, develop interactive materials, and implement technology-based pedagogical strategies.

However, this study has some limitations. One of them is the limitation in curriculum design, which has not fully adapted to current technological developments, causing the integration of technology in teaching to still depend on individual initiatives of prospective teachers. Additionally, this study has not deeply considered external factors, such as the preparedness of educational institutions in providing adequate technological infrastructure and training support for educators. For future research, it is essential to explore more systematic curriculum-based training models to enhance prospective teachers' TPACK skills more comprehensively, as well as examine the role of demographic factors, cultural differences, and more innovative technology approaches in improving the effectiveness of technology integration in teaching.

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## Author Contribution

Conceptualization, Muh. Fitrah; methodology, Muh. Fitrah and Caly Setiawan; software, Nur Azizatur Rahmawati and Iskandar; validation, Anastasia Sofroniou, Widihastuti, and Caly Setiawan; formal analysis, Nur Azizatur Rahmawati and Iskandar; investigation, Arina, Sri Ratna Sari, and Iskandar; resources, Sri Ratna Sari, Nur Azizatur Rahmawati, Iskandar, and Arina; data curation, Muh. Fitrah and Nur Azizatur Rahmawati; writing—original draft preparation, Muh. Fitrah; writing—review and editing, Muh. Fitrah and Anastasia Sofroniou; visualization, Nur Azizatur Rahmawati, Sri Ratna Sari, and Arina; supervision, Caly Setiawan, Anastasia Sofroniou and Widihastuti; project administration, Sri Ratna Sari and Arina.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Data Availability Statement

Data are available from the authors upon request.

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