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Transforming Mathematics Learning: Students' Integrative Skills in Technology and Pedagogy

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Abstract

In the digital age, mastering the topic or developing pedagogical design skills alone is no longer sufficient for instructors or aspiring math educators. They also need to be able to make connections between the two. In addition, other specialized abilities are required, such as the ability to use technology for learning (technological skills). Technological Pedagogical and Content Knowledge (TPACK) is a common term for this skill. TPACK is a framework that helps educators integrate technology into learning effectively. TPACK covers three main types of knowledge-Technology, Pedagogy, and Content, and how the combination of these three elements creates a more meaningful learning experience for students. This study aims to assess the TPACK teaching abilities of aspiring mathematics teachers in the Microteaching course. This research uses a qualitative descriptive method, which describes the object of research in its original form without quantitative measurement or manipulation of variables but focuses on describing the observed phenomena. In this instance, the study provides a general picture of how well math education students comprehend and utilize their TPACK. A Likert scale measures an individual's or group's attitudes, views, and perceptions concerning social phenomena to ascertain their understanding of TPACK. Twenty University of Mataram students enrolled in the Microteaching course in Mathematics Education served as the research subjects. Based on the findings of the research and discussion, it can be said that students applying TPACK to learning have an average score of 3.88 medium categories for technological pedagogical knowledge, 3.82 medium categories for pedagogical knowledge, and 3.63 medium categories for content knowledge. Since most students are already familiar with the TPACK instrument, their total TPACK ability has an average score of 3.89, which is considered to be medium.

Keywords: TPACK, Transforming, Mathematics learning, Technology, Pedagogy

1. Introduction

The quality of a country's education depends on the quality of its teachers, which can be improved through better welfare, professionalism, and teaching skills [1]. Both teachers and prospective educators must prepare thoroughly through higher education. While many teachers rely on lectures, integrating multimedia can enhance learning diversity, student motivation, and teacher development. Continuous knowledge upgrades, innovation, and lifelong learning are essential for teaching success [2].

Integrating technology and AI can enhance teaching and learning. AI tools should align with educational contexts, while students benefit from practice and feedback. Teachers can use self-paced, peer, and formative assessments to support student progress [3], [4], [5]. To improve the quality of teaching and learning, it is essential to focus on the professional development of teachers and the use of effective teaching methods. Teachers should be encouraged to participate in workshops, seminars, and training programs that focus on enhancing their teaching skills and knowledge. This will help them stay updated with the latest research and best practices in education. Teachers should be trained in using multimedia tools and technology to enhance their teaching methods [6], [8], [9]. This will help create a more engaging and interactive learning environment for students. Schools and educational institutions should provide the necessary resources and support for teachers to implement new teaching strategies and techniques. This can include access to technology, teaching materials, and mentoring programs [10]. Teachers should focus on designing learning experiences that are tailored to the needs and interests of their students. This can be done through project-based learning, group work, and other interactive activities that promote active student engagement [11]. It is important to

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effectively implement theories concerning educational concepts, learning strategies, educational evaluation, and teaching materials that students acquire in class as future educators. Researchers and teachers can evaluate learning materials and designs based on a theory-based model that offers a functionalistic approach to learning materials as tools helping the user with solving specific problems related to learning and teaching using a holistic framework for doing so [12]. The teaching and learning process can be improved by the use of efficient teaching techniques and tools. To interest students and aid in their learning of the material, teachers should be innovative and skilled in the use of a variety of tools and strategies [13]. In the process of teaching and learning, learning comes first. To promote successful learning, teachers should create lessons that support students in achieving the targeted learning outcomes and continually assess their development [14], [15].

In a course called microteaching, aspiring teachers can practice using the information they have learned. Microteaching is a training environment where aspiring instructors can put their newly acquired information to use. It is a useful strategy for learning good teaching and offers teachers the chance to develop their presenting and reinforcement skills, which will help them teach more effectively [16]. According to research by Msimanga [17], micro-teaching should continue to be a crucial component of teacher education since it helps student teachers improve in a variety of ways, including the development of teacher professional abilities. The study comes to the further conclusion that development in the execution of micro lessons can help student teachers build their professional skills. The number of students presenting can be decreased from many to, the kinds of groupings are changed, from students choosing their topics to students being given topics, the content is presented from lower grades to higher grades, and the roles of the students during the presentation are changed [18].

Technological advances, especially in computer and internet use, have significantly impacted education. These tools help student complete assignments faster, save time, and access additional learning resources. In the digital era, teachers and future mathematics instructors must not only master subject and pedagogical knowledge but also integrate them with technology—known TPACK [19], [20]. The strategies, techniques, and approaches teachers employ to help their pupils learn and understand things effectively are referred to as pedagogical skills in teaching. These abilities are crucial for developing a supportive and interesting learning environment, encouraging student participation and cooperation, and making sure that students understand and put the lessons they are learning into practice [21]. The study discovered that pre-service teachers who had high levels of TPACK, which is essential for teacher development programs, did so in an intriguing fashion. They have skilled TPACK instructional strategies for integrating technology through a variety of topics and pedagogies. A TPACK should be developed and integrated into the curriculum and instruction of teacher preparation programs [22], [23].

Based on the author's experience in fostering Micro Teaching courses, shows that many students lack mastery of teaching materials, appropriate learning strategies, and effective use of educational technology. This gap contributes to low student achievement. From the description above, the research question posed is how the teaching ability of mathematics education students is in terms of TPACK. In detail, the research question is how is the student's teaching ability seen from Technological Knowledge (TK), Pedagogical Knowledge (PK), Content Knowledge (CK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), Pedagogical Content Knowledge (PCK), and from the TPACK point of view?

2. Literature Review

A descriptive qualitative technique was utilized in this study, which is a method that uses sample or population data to describe the topic under investigation as it is [23]. In this instance, researchers employ the descriptive technique as a tool to examine the outcomes of technology pedagogical and subject-matter knowledge of mathematics education students.

2.1. Participants

The subjects of this study were 20 or more University of Mataram mathematics education students who were enrolled in microteaching courses. Purposive sampling was employed, which is a method of selecting data sources while taking into account several factors, such as who is most qualified to answer the research question [24], [25]. An instrument in the form of a questionnaire with a statement sheet on TPACK was used to gather data for this study [26], [27].

University research subjects in mathematics education are chosen based on a variety of factors, including their degree of technological proficiency, their background as teachers, or their aptitude for mathematics.

This study used purposive sampling, selecting participants based on certain criteria relevant to the research questions. Participants were Mataram University mathematics education students enrolled in microteaching courses, with criteria such as technology proficiency, teaching background, and mathematical skills. The researcher identified students who met the criteria and could provide relevant insights, especially those with experience in technology use or strong pedagogical skills. Students best suited to provide information on TPACK were selected, taking into account their education, teaching experience, and technological proficiency.

2.2. Data Collection

By calculating the scores for each statement on the Likert scale created by Ransis Likert, researchers were able to gauge participants' level of familiarity with TPACK [29], [30], [31], and [32]. The Likert scale is a scale that is used to control a person's or a group's attitudes, views, and perceptions of social phenomena. This scale is popular because it is simple to design, allows for the free entry of pertinent statements and questions, is highly reliable, and is simple to use in a variety of applications. In this study, respondents were given several statements and given the option of one of five responses: Strongly Disagree, Disagree, Hesitate, Agree, or Strongly Agree. According to the TPACK criteria, students were divided into three groups using the questionnaire in this study: high, medium, and low like table 1.

Table 1. TPACK Capability Tier Categories

No	Category	Average Value	Percentage
1	High	4.00 – 5.00	Percentage ≥ 80%
2	Medium	3.00 – 3.99	60% ≤ Percentage < 79%
3	Low	1.00 – 2.99	< 60%

Table 1 above shows the categories, average values, and percentages used in the study. A percentage of ≥ 80% indicates that respondents have a high mastery or understanding of the material measured in this category. This number reflects good or excellent performance, where most answers are in the high-value range. With 60% ≤ Percentage < 79%, indicates a moderate or sufficient level of mastery. Respondents in this category have a good understanding, but not as strong as in the high category. This means adequate understanding, although there is still room for improvement. A percentage of < 60% indicates that respondents in this category have low mastery of the material measured. Lower percentage figures reflect a limited or less-than-optimal level of understanding.

Using TPACK, the conceptual framework of this study examines the teaching abilities of aspiring math teachers [33]. The information from this study is used to describe the components of TPACK, which include CK, PK, TK, PCK, TCK, TPK, TPACK. There are three in TPACK or technological pedagogical content knowledge. Content knowledge, instructional knowledge, and technology knowledge make up the three primary parts. There is communication between the three elements and the other two. Figure 1 displays a relationship chart of the TPACK's parts.

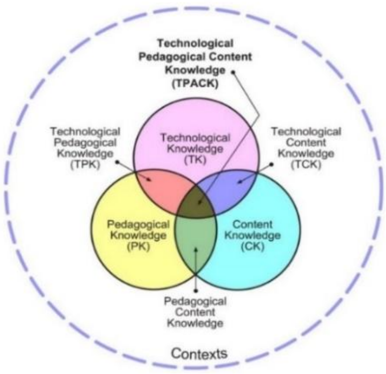

Figure 1. TPACK framework [34], [35]

Figure 1 shows that a TPACK slice is made up of the three primary components and their interactions, making a total of seven components that are detailed in the section findings and discussions.

2.3. Interviews with respondents

The interview approach was selected to gain a thorough understanding of students' opinions, attitudes, and experiences with the incorporation of TPACK into mathematics instruction [35]. The interview questions focused on the TPACK components: content, pedagogy, and technology. They explored students' experiences with technology in math learning, teaching methods, and understanding of concepts. Interviews recorded responses, expressions, and explanations, emphasizing how students used technology to enhance learning, their teaching approaches, and subject comprehension.

3. Methodology

The validity test is carried out to determine whether each statement on the questionnaire can measure what should be measured. All r count values in the table 2 are greater than the r table = 0.44. This means all items are valid. For examples Item 1: r count=0.48 > r table = 0.44 valid. Item 20: r count=0.84 > r table=0.44 valid. The reliability test determines the extent to which the questionnaire consistently produces the same results if repeated. Reliability is measured using Cronbach's Alpha value. After going through the calculation, the Cronbach's Alpha value is 0.92, greater than the 0.70 threshold. This shows that the questionnaire in this study is reliable and reliable.

Table 2. Validity Test Results

Validity Test							
Questionnaire Statement (QS)	**r Count**	**r Table**	**Decision**	**Questionnaire Statement (QS)**	**r Count**	**r Table**	**Decision**
1	0.48	0.44	valid	18	0.69	0.44	valid
2	0.46	0.44	valid	19	0.67	0.44	valid
3	0.56	0.44	valid	20	0.84	0.44	valid
4	0.48	0.44	valid	21	0.69	0.44	valid
5	0.46	0.44	valid	22	0.67	0.44	valid
6	0.54	0.44	valid	23	0.6	0.44	valid
7	0.58	0.44	valid	24	0.73	0.44	valid
8	0.53	0.44	valid	25	0.46	0.44	valid
9	0.46	0.44	valid	26	0.48	0.44	valid
10	0.47	0.44	valid	27	0.58	0.44	valid
11	0.59	0.44	valid	28	0.46	0.44	valid
12	0.71	0.44	valid	29	0.47	0.44	valid
13	0.7	0.44	valid	30	0.7	0.44	valid
14	0.61	0.44	valid	31	0.6	0.44	valid
15	0.72	0.44	valid	32	0.66	0.44	valid
16	0.5	0.44	valid	33	0.68	0.44	valid
17	0.67	0.44	valid	34	0.64	0.44	valid

Included in the descriptive data are mean, mode, median, and standard deviation. The median is the midway value of the data cluster that has been sorted from the smallest to the largest data, while the mean is the computed average and the mode is the value of the data that has the highest frequency. A common way to measure departure from the mean is with the standard deviation. Table 3 displays the outcomes of respondents' questionnaire responses.

Table 3. Data From the Calculation of Respondent Questionnaire Descriptions

No	Questionnaire Statement (QS)	Number of respondents	Minimum value	Maximum value	Mean	Std. Deviation
1	QS 1	20	3	5	5	0
2	QS 2	20	3	5	4.75	0.55
3	QS 3	20	2	5	4.05	0.82
4	QS 4	20	3	5	4.3	0.73
5	QS 5	20	3	5	4.5	0.60
6	QS 5	20	3	5	3.7	0.65
7	QS 7	20	3	5	3.6	0.68
8	QS 8	20	3	5	3.95	0.76
9	QS 9	20	3	5	3.95	0.68
10	QS 10	20	3	5	3.65	0.74
11	QS 11	20	3	5	4.1	0.78
12	QS 12	20	2	5	3.8	0.83
13	QS 13	20	2	5	3.7	0.80
14	QS 14	20	2	5	3.45	0.75
15	QS 15	20	2	5	3.75	0.85
16	QS 16	20	1	5	3.45	1.05
17	QS 17	20	1	5	3.65	0.98
18	QS 18	20	3	5	3.95	0.75
19	QS 19	20	2	5	4.1	0.91
20	QS 20	20	2	5	3.85	0.87
21	QS 21	20	1	5	3.95	1.05
22	QS 22	20	2	5	3.8	0.83
23	QS 23	20	2	5	3.65	0.81
24	QS 24	20	3	5	4	0.64
25	QS 25	20	2	5	3.95	0.82
26	QS 26	20	2	5	4.35	0.87
27	QS 27	20	3	5	4.2	0.69
28	QS 28	20	1	5	3.7	0.97
29	QS 29	20	3	5	4.2	0.69
30	QS 30	20	3	5	4	0.64
31	QS 31	20	3	5	3.9	0.71
32	QS 32	20	3	5	4	0.64
33	QS 33	20	2	5	3.75	0.91
34	QS 34	20	2	5	3.8	0.83

In table 3 it can be seen that 20 respondents answered the question. The minimum score given was 3, and the maximum score was 5. The mean score was 5, indicating that, on average, respondents rated this question as 5. The standard deviation is 0, meaning all responses were identical, there was no variability. The analysis shows the highest mean score (5) in question 1, indicating strong agreement. Mean scores mostly ranged from 3.45 to 4.35, with the lowest (3.45) in questions 14 and 16, suggesting some uncertainty. The highest standard deviation (1.05) in questions 16 and 21 shows significant response variation, while the lowest (0.55) in question 2 indicates consistency. Most deviations were under 0.8, with low variation and mean scores of 4 in questions 24, 30, and 32. Higher deviations (over 0.9) in questions 17, 19, 28, and 33 reflect varied perceptions.

3.1. Technological knowledge (TK)

Technological knowledge is the understanding of technology, and those who possess it can use and learn from already existing technologies. The questionnaire scores of prospective mathematics teacher students are shown in figure 2 and table 3 based on the findings of data analysis.

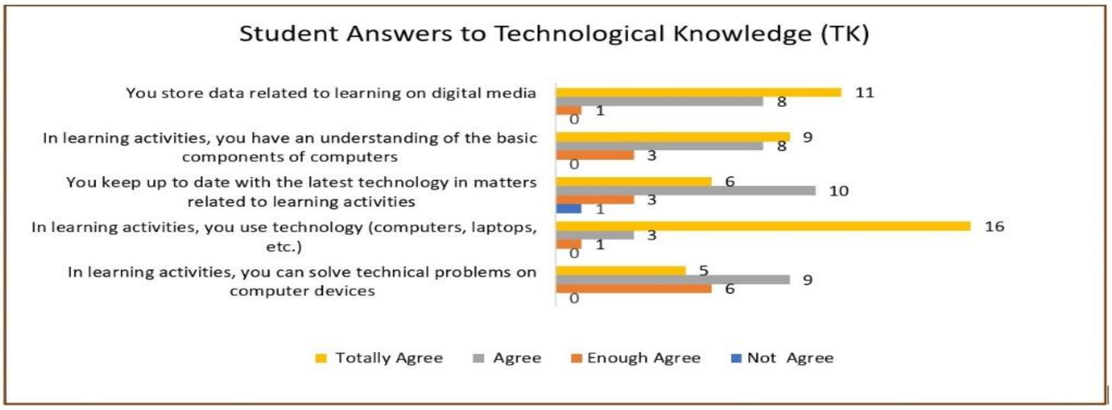

Figure 2. Student answers to technological knowledge (TK)

Figure 2 represents a survey on technology usage in learning activities, with respondents rating their abilities. Statement 1 assesses the ability to solve technical problems on computer devices, where respondents rated themselves highly (5 out of 6). Statement 2 evaluates the frequency of technology use in learning activities. Table 4 shows that prospective mathematics teachers have strong technological skills, with a high average score. The highest score (4.75) is for using technology (computers, laptops, etc.), while the lowest score (3.95) is for solving technical problems. Overall, students demonstrate good technological understanding, with an average score of 4.31, though improvement is still needed.

Table 4. Student scores for (TK), (PK), and (CK)

TPACK Components	Question Item	Mean	Std. Deviation	%	Criteria
Student score for Technological Knowledge (TK)	In learning activities, you can solve technical problems on computer devices	3.95	0.75	79	Moderate
	In learning activities, you use technology (computers, laptops, etc.)	4.75	0.50	95	High
	You keep up to date with the latest technology in matters related to learning activities	4.05	0.82	81	High
	In learning activities, you have an understanding of the basic components of computers	4.30	0.73	86	High
	You store data related to learning on digital media	4.50	0.60	90	High
	Average	**4.31**	**0.69**	**86.2**	**High**
Student Score for Pedagogical Knowledge (PK)	You know about assessing students' abilities in the class.	3.7	0.65	74	Moderate
	In learning activities, you use varied assessment methods and techniques.	3.6	0.68	72	Moderate
	In learning activities, you implement diverse teaching strategies.	3.95	0.75	79	Moderate
	In learning activities, you are aware of possible misconceptions and learning difficulties among students.	3.95	0.68	79	Moderate
	You manage and control the class effectively.	3.65	0.74	73	Moderate
	You engage in reflective actions for the improvement of the quality of learning activities.	4.10	0.78	82	High
	Average	**3.82**	**0.71**	**76.5**	**Moderate**

Student score for Content Knowledge (CK)	You are knowledgeable about the development of mathematics learning.	3.80	0.83	76	Moderate
	You design and conduct mathematical experiments for learning activities.	3.70	0.80	74	Moderate
	You understand mathematical concepts, laws, and their flexible application.	3.45	0.75	69	Moderate
	You use the latest sources to enrich your knowledge of mathematics.	3.75	0.85	75	Moderate
	To broaden your knowledge, you attend seminars or activities related to the field of mathematics.	3.45	1.05	69	Moderate
	Average	**3.63**	**0.85**	**72.6**	**Moderate**

3.2. Pedagogical Knowledge (PK)

The term "pedagogical knowledge" (PK) refers to the knowledge's subject matter, which includes knowledge of languages, mathematics, the natural sciences, and other topics [36], [37]. This information pertains to the real material that needs to be learned or taught [38]. Student PK profiles are shown in figure 3 and table 3 based on data analysis.

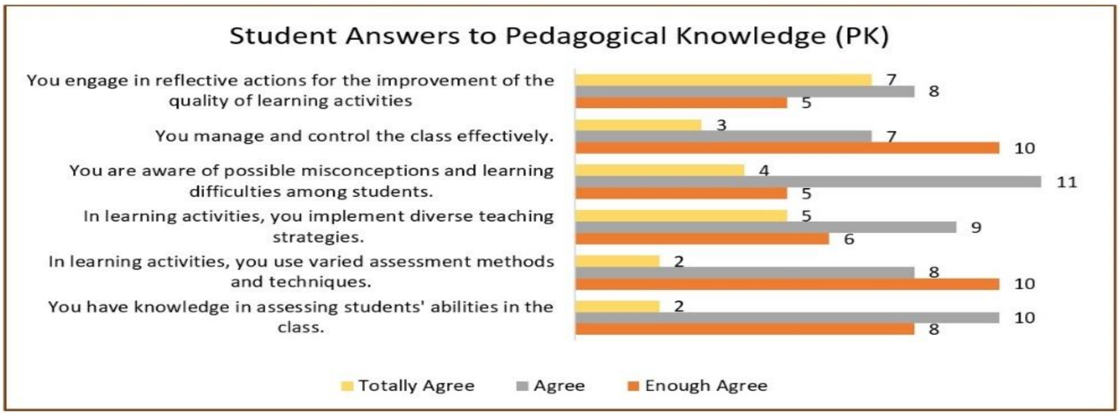

Figure 3. Student answers to pedagogical knowledge (PK)

Figure 3 shows that the highest score is 11 and the lowest is 2, reflecting the range of skills and knowledge mathematics education students have in teaching and classroom interaction. A higher score indicates better ability in these areas. Teachers should be able to provide individualized instruction to meet the diverse needs of their students [39]. Teachers should be able to facilitate collaborative learning among their students to promote learning and engagement [40], [41], [42], [43], and [44].

Table 3 shows that educators' assessment knowledge is fairly good (mean score 3.7) but can be improved. Effective assessment helps identify students' needs and strengths. Educators need to deepen their understanding of assessment techniques. The ability to use diverse assessment methods is medium (average 3.6), indicating room for improvement. This is important for evaluating all aspects of students' abilities. With an average of 3.95, educators show good knowledge of learning strategies, but there is room for flexibility. Classroom management skills are moderate (3.65), and improving this will create a better learning environment.

3.3. Content Knowledge (CK)

Controlling student learning is the responsibility of CK. Teachers' comprehension of the subject is known as CK, whereas their ability to instruct students effectively in that subject is known as PCK [44]. This information relates to the formulation of lesson plans, management evaluation, and student learning processes and ways of learning. Based on data analysis, the student CK profiles shown in figure 4 and table 3 were created.

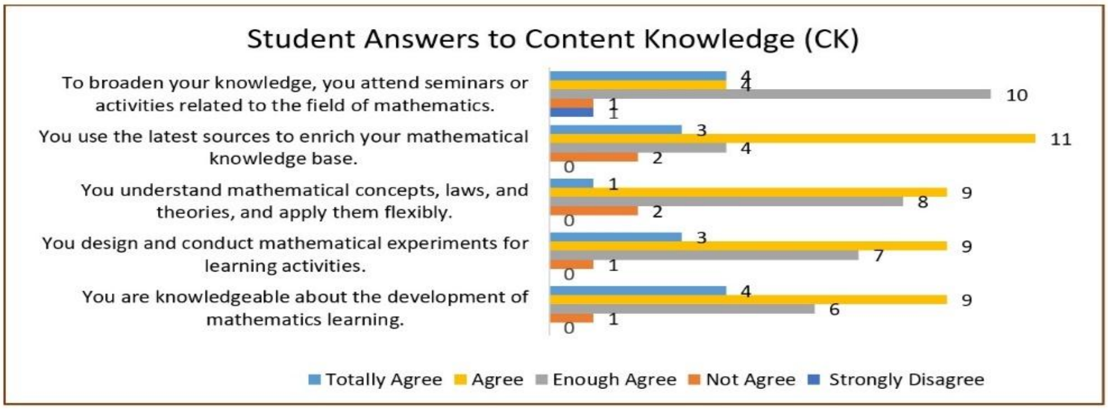

Figure 4. Student answers to content knowledge (CK)

Figure 4 shows strong knowledge and skills in some areas, with improvement needed in others. The individual actively attends math-related seminars to deepen understanding, reflecting strengths and growth areas. According to table 3, the average CK score is medium, with the highest rating of 3.80 on understanding math learning developments. This indicates that prospective math teachers keep up with new developments, possess solid content knowledge, and feel confident in teaching mathematics. A different thing is explained in the results of [45], which state that in the relation material, not every student prospective math teacher with high academic ability will have CK at the highest level. In the CK section, the ability to design mathematical experiments and an understanding of the development of mathematics learning still require more attention. The number of students who chose Not Agree on several statements indicates that additional support is needed, both through training and enrichment. Additional training or workshops are needed to help students design math experiments and understand the development of mathematics learning in more depth. Educational institutions could encourage students to be more active in attending seminars or using the latest resources, and provide greater access to cutting-edge learning materials.

3.4. Technological Pedagogical Knowledge (TPK)

Understanding how technology can support instructional tactics like using forums to promote social knowledge development is known as TPK. TPK can be thought of as a comprehension of the broad academic techniques utilized to include technology. By acknowledging their advantages and disadvantages, teachers must integrate technological tools and resources with appropriate instructional designs and tactics. Effective teaching with technology requires TPK because it empowers teachers to decide when and how to utilize technology to promote student learning and comprehension [46]. Figure 5 and table 4 show the student TPK profile that was created via data analysis.

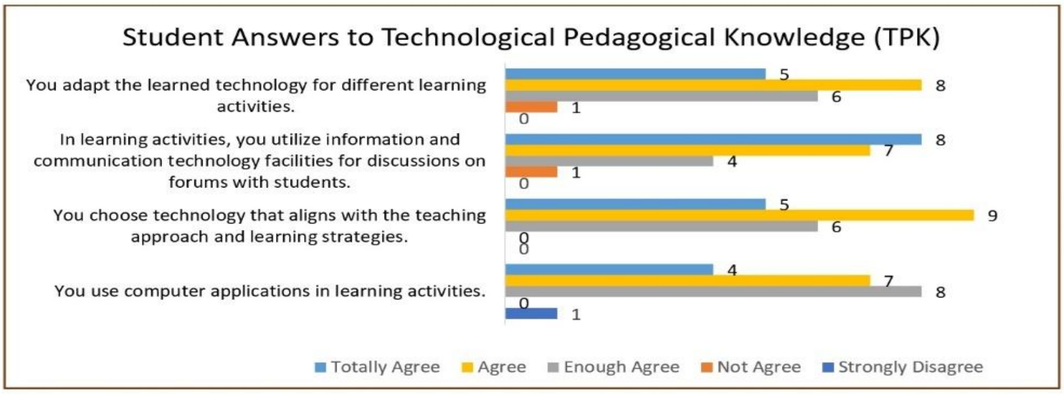

Figure 5. Student answers to technological pedagogical knowledge (TPK)

Figure 5 shows that students use computer applications in learning, though not consistently, suggesting room for more structured use. They choose appropriate technology for their teaching methods, enhancing learning effectiveness and supporting diverse activities. Table 5 indicates a medium TPK score, with the highest average of 4.10 for using technology in discussion forums, showing frequent use of tech facilities in academic forums, especially during learning.

Table 5. Student score for (TPK), (TCK), (PCK), and (TPACK)

TPACK Components	Question Item	Mean	Std. Deviation	%	Criteria
Student Score for Technological Pedagogical Knowledge (TPK)	You use computer applications in learning activities.	3.65	0.98	73	Moderate
	You choose technology that aligns with the teaching approach and learning strategies.	3.95	0.75	79	Moderate
	In learning activities, you utilize information and communication technology facilities for discussions on forums with students.	4.10	0.91	82	High
	You adapt the learned technology for different learning activities.	3.85	0.87	77	Moderate
	Average	**3.88**	**0.88**	**77.75**	**Moderate**
Student Score for Technological Content Knowledge (TCK)	In learning activities, you use technology to assist in understanding mathematical concepts, laws, and theories.	3.95	1.05	79	Moderate
	You are aware of computer applications related to mathematics.	3.8	0.83	76	Moderate
	You develop activities and assignments for students that involve the use of technology.	3.65	0.81	73	Moderate
	Average	**3.8**	**0.89**	**76**	**Moderate**
Student Score for Pedagogical Content Knowledge (PCK)	You choose learning approaches and strategies that are appropriate for the existing mathematical content.	4.0	0.64	80	High
	In learning activities, you develop the curriculum/syllabus.	3.95	0.82	79	Moderate
	In learning activities, you prepare lesson plans (RPP).	4.35	0.87	87	High
	You conduct educative and dialogic teaching.	4.2	0.69	84	High
	In learning activities, you transform difficult mathematical content into easily understandable materials for students.	3.7	0.97	74	Moderate
	In learning activities, you create questions to assess students' understanding of the taught material.	4.2	0.69	84	High
	Average	**4.06**	**0.78**	**81.33**	**High**
Student Score for Technological Pedagogical and Content Knowledge (TPACK)	You pick technologies and learning methodologies that are suited for presenting mathematical material in the learning activities.	4.0	0.64	80	High
	To ensure that students learn effectively, you must combine your mathematical expertise with your pedagogical and technology skills in learning activities.	3.9	0.71	78	Moderate
	You support the coordination of technological, pedagogical, and mathematical knowledge throughout learning activities.	4.0	0.64	80	High
	You employ several instructional methods and computer programs for mathematics education during learning activities.	3.75	0.91	75	Moderate
	In learning activities, you teach the subject matter effectively by integrating mathematical knowledge, pedagogical knowledge, and technological knowledge.	3.8	0.83	76	Moderate
	Average	**3.89**	**0.75**	**77.8**	**Moderate**

3.5. Technological Content Knowledge (TCK)

TCK is the understanding of how different technologies, including computer simulations, may represent different forms of information [47]. A component of the TPACK framework TCK describes the knowledge that educators need to successfully incorporate technology into the classroom. Data analysis was used to produce a student TCK profile, which is shown in figure 6 and table 5.

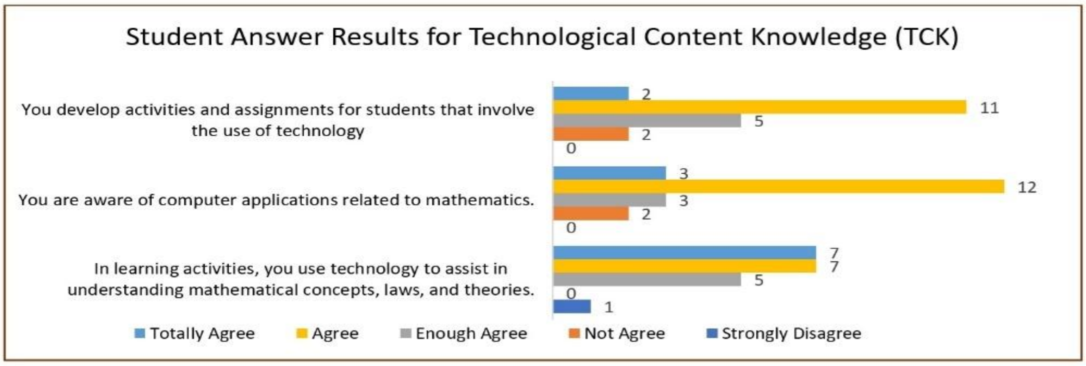

Figure 6. Student answer results for technological content knowledge (TCK)

Figure 6 shows that students use technology to enhance their understanding of mathematical concepts, integrating it effectively into learning. While they have a solid grasp of math-related applications, exploring more tools could enrich their experience. Students often create tech-based assignments, though there's room for more variety and advanced skills. According to table 5, students meet medium TCK standards, with a notable average score of 3.95 in using technology to clarify mathematical concepts, indicating their ability to make math ideas more accessible through technology.

3.6. Pedagogical Content Knowledge (PCK)

PCK, or pedagogical content knowledge, is the understanding of how to convey and frame a subject such that others may understand it [48]. Teachers have a special kind of knowledge called PCK, which is based on the integration of their subject matter knowledge and pedagogical knowledge (what they know about teaching and what they teach). When we talk about subject knowledge, we often refer to knowledge about the teaching process. Based on data analysis, the student PCK profiles obtained are shown in figure 7 and table 4.

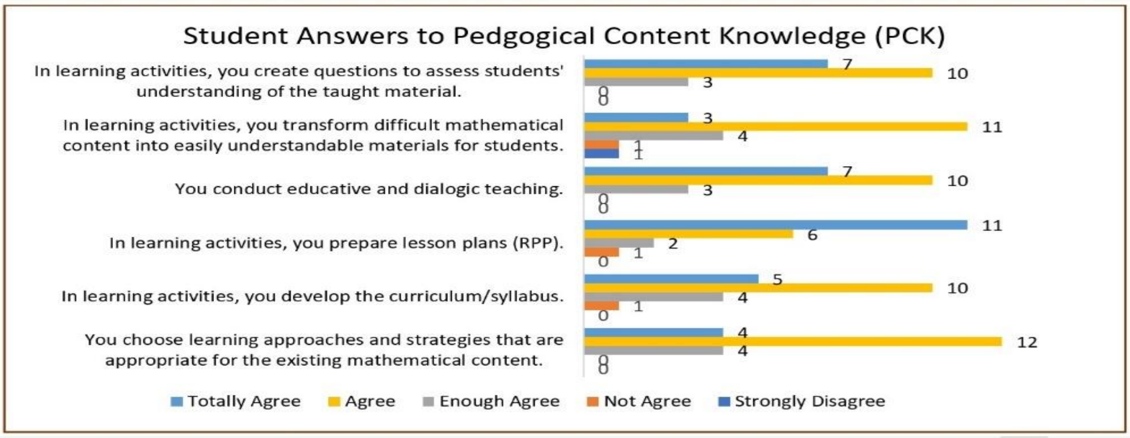

Figure 7. Student answers to pedagogical content knowledge (PCK)

Figure 7 shows that students actively choose learning strategies and engage in curriculum and lesson planning, fostering an engaging learning environment. However, there is room to improve consistency, depth in curriculum design, lesson plan creativity, and skills for deeper discussions. Table 4 reveals that students' average PCK score is high, with the highest score (4.35) for lesson planning, indicating strong preparation, particularly in creating learning media and assessment questions. Additionally, there is a noticeable improvement in PCK after students participate in the field experience program.

3.7. Technological Pedagogical and Content Knowledge (TPACK)

Understanding of effective pedagogical and technological methods for assisting students in learning from a particular topic. The term "pedagogic technology and content knowledge" relates to the understanding that teachers must include technology in their lesson plans. Student TPACK profiles are shown in figure 8 and table 4 based on data analysis.

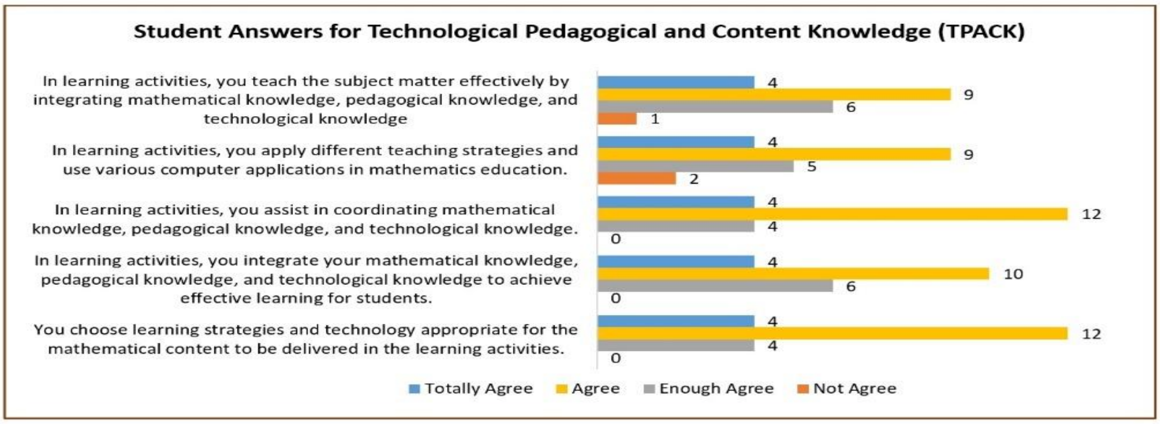

Figure 8. Student answers for technological pedagogical and content knowledge (TPACK)

Figure 8 shows that students are skilled in selecting strategies and technology for teaching math, with room to expand their variety and effectiveness. Table 4 indicates a moderate average TPACK score, with the highest (4.00) for aligning technology with math content and the lowest (3.75) for using diverse computer programs. Future educators must improve these skills, as TPACK is key to integrating technology into teaching [49]. Figure 9 summarizes students' TPACK skills.

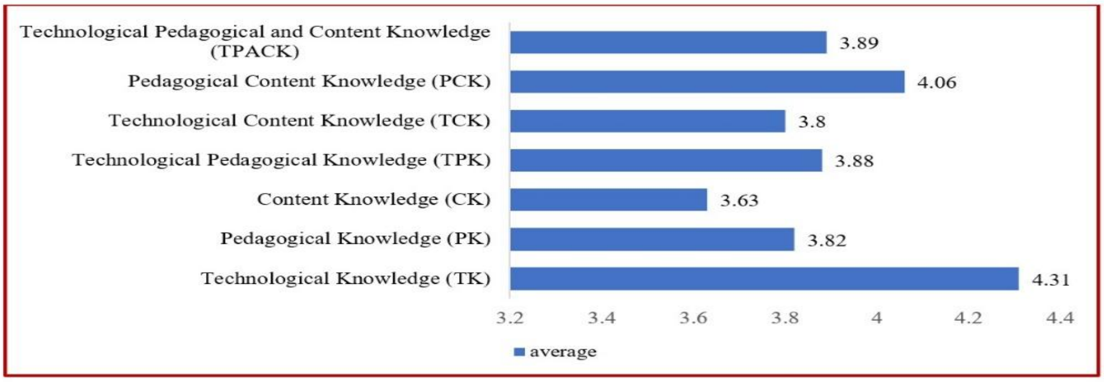

Figure 9. Average score of students TPACK subdomain

Figure 9 shows that teachers demonstrate strong technological tool knowledge with a high average score (4.31). Their PK is also solid, with an average score of 3.82, though there is room for improvement. CK scores slightly lower at 3.63, indicating a need for further subject mastery.

TPACK is the complete integration of TK, PK, and CK, reflecting teachers' ability to utilize technology, pedagogical strategies, and content understanding in an integrated manner. The average of TPACK is quite good, indicating that many respondents are already able to use these three components together in learning practices. However, scores slightly below TK and PK indicate that there is room to strengthen the comprehensive integration of technology. TK, PK, and CK as foundational components support each other in the formation of TPK, TCK, and PCK. The level of mastery of each basic component has a direct effect on the combination subdomains (TPK, TCK, and PCK), which then support the overall TPACK competency. The relatively lower CK scores indicate that content knowledge needs to be improved to support TCK and PCK, and ultimately, TPACK. On the other hand, high TK scores indicate

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respondents' readiness to adopt technology, although its integration could still be strengthened in the learning context. A good level of TPACK indicates teachers' ability to use technology, pedagogy, and content in an integrated manner, but improvements in the TCK and CK subdomains could further strengthen this ability.

Examples of applying TPACK in math teaching include using GeoGebra or Desmos for graphing functions, where students adjust parameters to see real-time graph changes. In statistics, educators can have students collect real-life data (e.g., class height), then use Excel or Google Sheets to calculate mean, median, and standard deviation, and create graphs. This approach combines CK in statistics, TK with spreadsheet tools, and PK to guide practical data analysis. To teach 3D shapes like cubes, blocks, or pyramids, educators can use Augmented Reality (AR) apps on tablets or smartphones, allowing students to explore and rotate 3D models. This combines CK of geometry, TK in AR, and PK for interactive learning. For fractions, animated videos showing objects divided into equal parts (like pizza) help students visualize fractions. This approach uses CK in fractions, TK for selecting animations, and PK to make abstract concepts more concrete and understandable.

Interviews reveal that respondents integrate technology, pedagogy, and math knowledge effectively in their teaching, with an average score of 3.89, indicating moderate maturity. They show a strong understanding of holistic knowledge integration for successful math learning. TPK (technology-pedagogy) scored 3.88, reflecting a moderate understanding of how to incorporate technology into lesson plans, while TCK (technology-content) scored 3.8, showing reasonable integration of tech and subject knowledge. PCK (pedagogy-content) scored 4.06, indicating strong integration of teaching methods and subject knowledge. Overall, the respondents demonstrate a solid understanding of TK and PCK but need more focus on CK, possibly through further training or curriculum development. Although TPACK scores are reasonable, there is still room to improve how technology is integrated into teaching for a more comprehensive learning environment. These results should inform the design of professional development programs, considering teaching contexts and available resources.

In mathematics learning, software such as GeoGebra allows students to visualize geometry concepts such as transformations, symmetry, and function graphs dynamically. This helps students understand the relationships between concepts intuitively, which is difficult to achieve with traditional learning methods. Example: Students can change the parameters of a function and immediately see how its graph changes. This enhances their understanding of the relationship between the equation and its visual representation. However, some technologies hinder learning outcomes. Poorly managed technology can distract students. For example, students using tablets or laptops in class may be tempted to go on social media or play games.

3.8. Discussion

The validity results showed that all questionnaire items were able to represent the measured constructs. This high validity reinforces that the instrument used can capture the dimensions of technological, pedagogical, and content knowledge thoroughly. In the context of educational research, good validity is a key component to ensure the data obtained can be used for accurate decision-making [50]. The reliability of the questionnaire was tested using Cronbach's Alpha value. The Cronbach's Alpha value of 0.92 indicates high reliability as it exceeds the threshold of 0.70 [51]. This means that the questionnaire has good internal consistency and produces consistent results if applied repeatedly under similar conditions.

Table 3 shows the distribution of mean, minimum, maximum, and standard deviation values for each questionnaire statement. The highest mean value was found in QS 1 (5.00, SD = 0), indicating full agreement among respondents. In contrast, the lowest mean scores were found in QS 14 and 16 (3.45, SD 0.75, and 1.05 respectively), indicating uncertainty or variation in respondents' views. The highest standard deviation in QS 16 (1.05) shows significant variation in responses, indicating that some respondents have different opinions on the statement. This could be influenced by a lack of understanding or experience related to the topic being measured.

The mean score for technological knowledge was 4.31, with a standard deviation of 0.69, reflecting a good command of technology among the mathematics pre-service teachers. The highest score (4.75) was found on the use of technology in learning, indicating that respondents were comfortable using devices such as computers or laptops for academic activities. However, the lowest score (3.95) on the ability to solve technical problems indicates the need for improved competence in this area. According to Iskandar [52], technological knowledge is an integral part of the TPACK framework, which entails the integration of technology with pedagogy and content to support effective learning. The average PK score is 3.82, with the highest score (4.10) on reflection to improve learning quality. This shows that students have a high awareness of the importance of reflection in the learning process [53]. However, an area that requires attention is the use of varied assessment methods (3.60), indicating a need to deepen insight into different evaluation methods. The average CK score was 3.63, indicating moderate mastery. The highest score (3.80) on understanding the development of mathematics learning demonstrates that students have good knowledge of mathematical concepts. However, low scores on the design of mathematical experiments (3.70) and the use of recent resources to enrich learning (3.75) indicate the need to provide additional training. According to Jingxian Li [54], mastery of mathematical content is central to teacher effectiveness, allowing them to deliver material with confidence and flexibility.

TK indicates respondents' understanding of the technology used in learning. Results show a high mean TK score (4.31), with the use of technology to store learning data getting the highest score (4.5). However, some respondents still struggle to overcome technical problems (mean = 3.95). This reflects the need for additional training to improve their technical skills. Pedagogical knowledge (PK) demonstrates the ability to assess, manage classes, and use varied learning methods. The mean PK score of 3.82 indicates a moderate level, with varying ratings on aspects of learning reflection (mean = 4.1) and classroom management (mean = 3.65). The analysis showed that the mean score for TPACK was 3.89, with the highest score on the use of technology-integrated learning methods (mean = 4.0). This indicates that student teachers can integrate technology with pedagogy and content effectively. However, there is an opportunity for improvement in the aspect of using technology to present mathematics materials (mean = 3.75). According to Ait Ali [55], the TPACK model emphasizes the importance of integrating the three components to create effective and relevant learning for the digital era. In this context, additional training that focuses on the development of technology in mathematics learning can strengthen student teachers' abilities.

4. Conclusion and Recommendation

Based on the findings of the research and discussion, it can be said that students applying TPACK to learning have an average score of 3.88 medium categories for technological pedagogical knowledge, 3.82 medium categories for pedagogical knowledge, and 3.63 medium categories for content knowledge. Since the majority of students are already familiar with the TPACK instrument, their total TPACK ability has an average score of 3.89, which is considered to be medium. To strengthen the conclusions, further research with a larger and more diverse sample would be needed to make the results more representative and the findings applicable in a broader context. This study recommends developing teaching strategies that utilize students' TPACK skills, with additional teacher training and a curriculum that reinforces TPACK components. Improving evaluation tools for more precise measurement of TPACK skills. This study will be used for further research with larger samples or more specific learning contexts.

5. Research Limitations

One of the main limitations of this study is the relatively small sample size of 20 participants. The small sample size may limit the ability to generalize the results of this study to a wider population. In the context of this study, such limitations have the potential to affect external validity, especially in concluding prospective teachers' TPACK skills across different educational contexts or geographical areas. To address this limitation, future research is recommended to use a larger and more diverse sample, covering a range of geographical, demographic, and professional backgrounds. This is expected to improve the generalizability of the results and provide a more thorough understanding of prospective teachers' TPACK skills. In addition, studies with larger sample sizes also allow for the application of more complex statistical analysis methods, such as multivariate analysis, to explore the relationships between variables in greater depth. Despite these limitations, the results still provide significant preliminary insights into prospective teachers' TPACK skills, which can serve as a basis for further research and educational policy development.

6. Declarations

6.1. Author Contributions

Conceptualization: M.T., N.H., and J.; Methodology: M.T.; Software: J.; Validation: M.T., N.H., and J.; Formal Analysis: M.T., N.H., and J.; Investigation: M.T.; Resources: N.H.; Data Curation: J.; Writing Original Draft Preparation: M.T., N.H., and J.; Writing Review and Editing: N.H., M.T., and J.; Visualization: M.T. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Institutional Review Board Statement

Not applicable.

6.5. Informed Consent Statement

Not applicable.

6.6. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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