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Transforming Mathematics Teaching Skills' Pre-Service Teachers Using Digital Project Learning

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Abstract

Technological Pedagogical Knowledge (TPK) is a skill that combines pedagogical and technological competencies to support teachers' professionalism in teaching mathematics in the era of digitalization. The purpose of this study is to determine the enhancement of TPK skills among Pre-Service Mathematics Teachers (PSMTs) who studied using a Digital Project Learning (DPL) approach compared to those who learned using a conventional approach. The research method used was an experiment with a posttest-only control group design. The research was conducted in the mathematics education study program at UIN Syarif Hidayatullah Jakarta during the 2023/2024 academic year, with the research sample comprising students from two classes enrolled in Mathematics Learning Strategy (MLS) courses. Seventy-two students enrolled in a mathematics learning strategies course were divided into an experimental group (n=34) and a control group (n=38). The instrument used in this study is a rubric-based observation sheet to assess students' TPK. The results showed that students in the experimental class had better TPK skills compared to PSMTs in the control class. This can be seen in the skills for designing learning and teaching, and in the diversity of technology use. Therefore, DPL is efficacious in improving the TPK skills of PSMTs.

Keyword: digital project learning; mathematics education; pre-service mathematics teachers; technological pedagogical knowledge

INTRODUCTION

Technological developments have a significant impact on all aspects of life, including education. Technology is also an important part of a teacher's professionalism. Therefore, teachers are required to have the ability to develop teaching materials, conduct the learning process, and design learning evaluations (Cifrian et al., 2020; Cirneanu & Moldoveanu, 2024). In addition, teachers are expected to be able to choose and use the right technology in the learning process to create a pleasant learning atmosphere (Burbules et al., 2020; Hanifah Salsabila et al., 2020). In mathematics learning, the integration between education and technology can make it easier for students to understand concepts and solve problems (Lee & Lee, 2020). In practice, the use of technology in mathematics not only helps students but also enriches the teaching experience of teachers. With digital tools such as simulations, visualisations, and interactive applications, teachers can deliver material in a more engaging and contextual way. This shows that the integration of technology in education is not just a trend, but a necessity that must be fulfilled by teachers.

Teachers who possess good pedagogical skills, master mathematical content, and have technological skills can be said to have *Technological Pedagogical and Content Knowledge* (TPACK) competencies (Tan et al., 2025; Zha et al., 2025). TPACK comprises seven interrelated components, namely: Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), Technological Pedagogical Knowledge (TPK) and TPACK itself (Koehler et al., 2013; Ozden et al., 2024; Tan et al., 2025). Each component interacts and contributes, creating effective and enjoyable learning integration for students.

Previous studies demonstrate that digital education is a critical part of sustainability of the education system in the long term (Burbules et al., 2020). For instance, in Indonesia, there are programs using digital project learning to encourange creativity among primary school student (Marini et al., 2025), analytical reasoning (Umam & Azhar, 2021), and innovative ability (Amey et al., 2020). The online learning environment also encourages independent engagement with mathematical concepts (Apriani & Nurhayati, 2023). Project based learning digitally mediated approaches have also been shown useful for promoting students' cognitive functions, especially in trigonometry (Ramadhan et al., 2024) and geometric transformations (Satriawati et al., 2023). Digital media can also benefit mathematics teaching materials (Fitroh & Zuhri, 2025; Lepore, 2024), as well as facilitate the growing of mathematical competences highlighted by NCTM (2000) such as concept understanding, reasoning and proof, problem solving, representation an communication (Fielding et al., 2022; Putri et al., 2024; Satriawati et al., 2023; Nusantara et al., 2025).

This research focuses on the development of TPK skills among PSMTs. These skills are useful for them in shifting the learning process to choose, adapt and deploy suitable technology that facilitate a range of instructional modes (Tan et al., 2025), and enhance overall student learning results (Dwirahayu et al., 2024; Ozden et al., 2024). TPK competencies of learning and development are related to four essential competencies of professional educators as determined in Regulation of the Minister of National Education of the Republic of Indonesia Number 16 of 2007. The four competencies represent: pedagogical competence, professional competence, personality competence, and social competence (Dwirahayu et al., 2020). Pedagogical competencies encompass knowledge of educational concepts, learning theories, student demographics, educational psychology, and effective teaching methods. Professional competences include thorough understanding of material content including mathematics, which comprises five core subjects: numbers and number operations, arithmetic, algebra, geometry and measurement, and statistics and probability (Coronata & Alsina, 2014; NCTM, 2000).

The acquisition of TPK competences is important for PSMTs. Not only are these prepared to master the content and pedagogy of mathematics content, they need also to build technology into the learning of mathematics. Nonetheless, according to the study's findings, many hopeful mathematics instructors still struggle with this important aspect. Thus, for example, they create learning videos and other digital media but do not make effective use of these tools in their teaching practice (Satriawati et al., 2022). So many of them still play off the existing learning framework without pedagogical or technological advancements.

However, there are still gaps in the development of TPK competencies; evidenced by the no initiative and creativity used to use digital tools. The application of technology in learning has mostly been limited and has not considerably improved the quality of learning. This condition validates the importance of training programs, which focus not only on the technical part of using technology, but on the pedagogical aspects too (Dwirahayu et al., 2020). Technology integration is difficult at most of the school settings, mainly in under-resourced remote places, because there is lack of infrastructure (computer, projector and stable internet connections), and so on; Furthermore, in a remote or online environment, students sometimes experience barriers (such as connectivity or limited data at home) hindering a seamless and efficient learning experience.

As earlier described, DPL is based on constructivist learning theory which asserts that learners construct knowledge actively through experience, discovery, and reflection. This encourages young math teachers to take part in projects that have a value and process to learn something meaningful and to use inquiry to develop knowledge, ability, and attitude (Hamidah et al., 2020). Project based learning consists of several structured stages, namely: identifying problems, designing solutions, conducting investigations, producing products, and presenting results (Lee & Lee, 2020; Marini et al., 2025; Tan et al., 2025). Furthermore, this approach stresses integrating learning with contexts of reality in the real world, so students can cope with various tasks and challenges outside the classroom (Xing & Chen, 2022).

And this study was conducted in the MLS class only. The aim of this course is to provide students with knowledge of different theories of learning, the skills of explanation and design of learning mathematics with different methods of explanation, their application of strategies to subsubject areas and use of technology. But this course implementation shows that the teaching and learning process is still dominated by traditional learning methods. This influences PSMTs' low levels of engagement and independence with learning and shallow understanding. This leads, very frequently, to memorization, not meaningful understanding or application in the context of real life. Thus, such learning innovations are necessary that will stimulate students to be actively constructing knowledge by expressing creativity and by pursuing their interests in constructive ways (Amey et al., 2020; Burbules et al., 2020; Dwi Susanti, 2021).

Considering this, the proposed approach is a digital learning approach. It hopes to pave way a very dynamic way of teaching PSMT in MLS course. They can collaborate, solve authentic problems, and create actual learning products. But more critically to improving their ability to bridge pedagogical content and technology to their future teaching in more effective and strategic ways (Dwirahayu et al., 2024; Ozden et al., 2024; Satriawati et al., 2022).

METHOD

This study uses a quantitative, *quasi-experimental* design with a *posttest-only control group* and two treatment groups. After treatment, the TPK skills of pre-service mathematics teachers from both groups were evaluated using rubric-based observation sheets. The experimental class in this study applied *digital project learning (DPL)*, while the control class used expository learning. The research was conducted at UIN Syarif Hidayatullah Jakarta during the odd semester of the 2023/2024 academic year. The research population includes all PSMTs in the fifth semester of the mathematics education study program who take the MLS course. The sample was selected using *a cluster-randomized sampling* technique, with class 5.1 as the experimental class (34 subjects) and class 5.3 as the control class (38 subjects). The data collection instrument was a rubric-based observation sheet to measure pre-service mathematics teachers' TPK skills. The indicators in the observation sheet were developed based on the framework put forward by Koehler, Mishra, Akcaoglu, and colleagues (2013), which has been adapted to the context of mathematics learning. In this study, TPK is assessed into three main components: TK, PK, and TPK. Table 1 shows the indicators for each skill.

Table 1. Indicators of measuring TK, PK and TPK

No	Skill	Indicator
1	TK	Identify the hardware/software used in learning mathematics Able to use various hardware and software tools to enhance the teaching and learning of mathematics
2	PK	Able to understand and analyze various learning strategies applied in classroom settings Explain the learning theories used as the basis for designing instructional strategies. Understands the key features and principles of learning strategies selected for instructional implementation
3	TPK	Able to integrate and apply technology effectively in standard educational practices Able to integrate and apply technology effectively in the teaching and learning process Able to integrate and apply technology in everyday life in learning

The combination of these three components provides a comprehensive picture of the readiness and competence of PSMTs in integrating technology into learning. Observation sheets are used during the implementation phase to record how they apply their knowledge in real-world teaching situations, thereby enabling an objective evaluation of the development of their TPK skills. This observation instrument has been validated through expert assessment by six mathematics education lecturers and one mathematics education practitioner. In total, seven expert validators used a three-category rating scale (Essential, Not Essential, Not Relevant), with an error rate of 5%. The minimum value required for an instrument item to be declared valid is 0.86 (Aiken, 1985). Table 2 shows the results of the validation of the instrument.

Table 2. Results of the validated observation instrument

Skill	No Item	CVR	Critical CVR Value	Status Item	Description
PK	1	1		Valid	Used
	2	1		Valid	Used
	3	1		Valid	Used
TK	4	0.71		Invalid	Not be used
	5	0.71		Invalid	Not be used
	6	1	0.86	Valid	Used
	7	1		Valid	Used
	8	1		Valid	Used
TPK	9	1		Valid	Used
	10	1		Valid	Used
	11	1		Valid	Used

The validity test results showed that eight instruments had *Content Validity Ratios* (CVRs) ≥ 0.86 and were declared valid. Instruments that were declared invalid would not be used. A valid instrument is a measuring instrument that accurately measures what it purports to measure (Arikunto & Jabar, 2009). The researcher observed the skills of PSMTs in TK, PK, and TPK during the implementation of the MLS course. The observation data is then converted into quantitative data based on the criteria listed in Table 3.

Table 3. *Assessment Criteria for TK, PK and TPK skills*

Score	TK	PK	TPK
Score 5	Able to identify various technological devices used in mathematics learning and demonstrate proficiency in operating two or more hardware devices or software applications	Able to understand, explain, and apply learning strategies effectively in the classroom	Possesses skills in using two or more technologies during the learning process and effectively integrates real-life contexts into learning
Score 4	Able to identify various technological devices used in mathematics learning and proficient in operating at least one hardware device or software application	Able to understand and explain learning strategies, but unable to apply them appropriately in the classroom	Possesses skills in using only one technology during the learning process and effectively utilizes real-life contexts in learning
Score 3	Able to identify various technological devices used in mathematics learning but unable to operate hardware or software	Able to understand learning strategies in a limited way, explain them inaccurately, and implement them inappropriately in the classroom	Possesses skills in using two or more technologies during the learning process but does not integrate real-life contexts into learning
Score 2	Able to identify one technological device used in mathematics learning but unable to operate hardware or software	Unable to understand, misinterpret, and implements learning strategies inappropriately in the classroom	Possesses skills in using only one technology during the learning process but does not incorporate real-life contexts into learning
Score 1	Does not know and is unable to use or operate hardware or software in mathematics learning	Unable to understand, explain, or apply learning strategies used in the classroom	Lacks skills in using technology during the learning process and does not integrate real-life contexts into learning.

The data analysis technique in this study aims to evaluate PSMTs' TPK skills. Given that the primary purpose of the study was to compare results between the experimental and control classes, the data were analyzed using the *Mann-Whitney* test because they were not normally distributed. The hypotheses tested in this study are:

H_0**:** The TPK skills of PSMTs in the experimental class are the same as those of the control class

H_1**:** The TPK skills of PSMTs in the experimental class are higher than those of the control class.

RESULTS

This section explains the results of TPK skills for PSMTs through a DPL process. The researcher collected data on the results of TPK skills using observation instruments applied to both sample classes. After the observation, data on TPK skills related to teaching and learning strategies were collected. This observation instrument was used in experimental classes that applied digital project learning, as well as in control classes that used expository learning. The results of the TPK skills of PSMTs from both classes are shown in Table 4.

Table 4. *Recapitulation of TPK for Experimental and Control Classes*

Class	N	$\bar{x}$	Me	X_{max}	X_{min}
Experiment	34	4.28	4.30	5.00	3.70
Control	38	3.87	4.00	5.00	2.70

Table 4 shows that the PSMTs' TPK skills in the experimental class were better than those of the control class. This conclusion was based on the average, maximum, and minimum scores for the TPK skill. Thus, the two samples have different final skills, indicating that the treatment of a DPL in the experimental class yielded better results than the control class. The next stage is analysing the data obtained. The experiment and control classes were analysed to test the research hypothesis or conclusion. The results of their TPK's skills were analysed using the *Mann-Whitney* test. Before performing the *Mann-Whitney* test, the prerequisite analyses are conducted: normality and homogeneity tests.

a. Normality Test

The normality test is used to determine whether a sample is normally distributed. The following is a summary of the results of the normality test using the *Kolmogorov-Smirnov* test in Table 5.

Table 5. *Normality Test Results of Pre-service mathematics teachers' TPK skill*

Class	Statistic	df	Sig	Decision
Experiment	0.303	34	0.000	Non-Normal
Control	0.147	38	0.038	Non-Normal

Based on Table 5. Results of normality test analysis for results the experimental and control classes at a significant level $\alpha = 0.05$ non-normally distributed.

b. Hypothesis Test

Based on the results of the analysis prerequisite tests, it was concluded that the homogeneity test did not need to be carried out because the results data for experimental and control classes show that the data is not normally distributed, so hypothesis testing is carried out using non-parametric statistical tests *Mann-Whitney*. The following is a summary of the results of the hypothesis test in Table 6.

Table 6. *Hypothesis Test Results*

Data	Mann-Whitney	Wilcoxon W	Z	U Asymp. Sig. (2-tailed)
Technological Pedagogical Knowledge	369.000	1110.000	-3.238	.001

Based on Table 6, this fulfils Sig. (two tails) = $0.001 < \alpha = 0.05$; therefore, H_0 is rejected. This means that the TPK skills of the experimental class are higher than those of the control class. Based on the data analysis, it can be concluded that their TPK skills in DPL are better than those who participate in conventional education. Thus, DPL has a significant influence on the learning process in the classroom. A comparison of the pedagogical knowledge of PSMTs in the experimental class and the control class is presented in Figure 1.

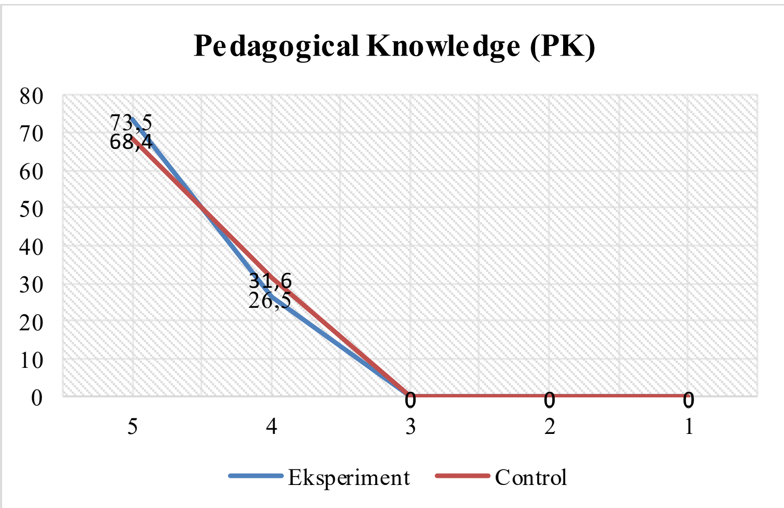

Figure 1. Percentage of pre-service mathematics teachers' PK Skills

It can be seen in Figure 1 that all PSMTs in the experimental class and in the control class had a score of 4 or 5. This shows that, in general, they who in experimental and control classes could design effective mathematics learning strategies. Based on the results of observations made by the researcher, it was found that PSMTs in experimental classes, most of them can design learning activities more effectively in the classroom and they are able to implement their designs in front of the class according to the stages that have been made. In contrast, in the control class, PSMTs were still able to understand and explain the learning strategies implemented in the classroom, but at the time of learning implementation, they were teaching not according to what they had designed.

To find out the skills of PSMTs, the researcher assigns them several learning strategies that must be developed in the form of projects. The following is a learning strategy project assignment developed by them in designing mathematics learning and their skill to implement of the strategy in the class. The following is presented comparison the technological skills of PSMTs in experimental class and control class.

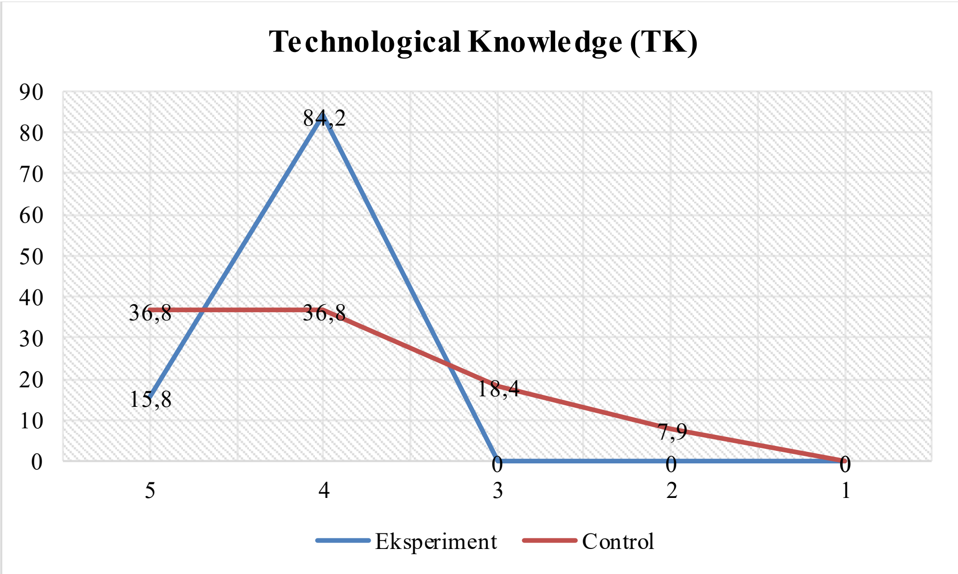

Figure 2. Percentage of PSMTs' TK Skills

Figure 2 shows that PSMTs in experimental classrooms have utilized hardware and software in their math learning. Meanwhile, in the control class, there are still PSMTs who have not utilized the hardware and software used in mathematics learning (score 2). Their skill to utilize technology in the experimental class is better than in the control class, because they are used to completing assignments on the website. In learning using digital project learning, they are asked to make learning videos and upload them to the website on the "project" page (Cifrian et al., 2020). Additionally, the DPL feature offers several math learning apps that students can use to complete assigned projects (Zha et al., 2025). The results of this study are in line with the statement that the use of websites improves the learning process, making it more effective, interesting, and easier for students to understand the concept of the material (Dwi Susanti, 2021; Ramadhan et al., 2024). Websites with project-based learning can be used as recommendations in mathematics learning (Satriawati et al., 2023). Figure 3 shows the results of an educational video project developed by PSMTs.

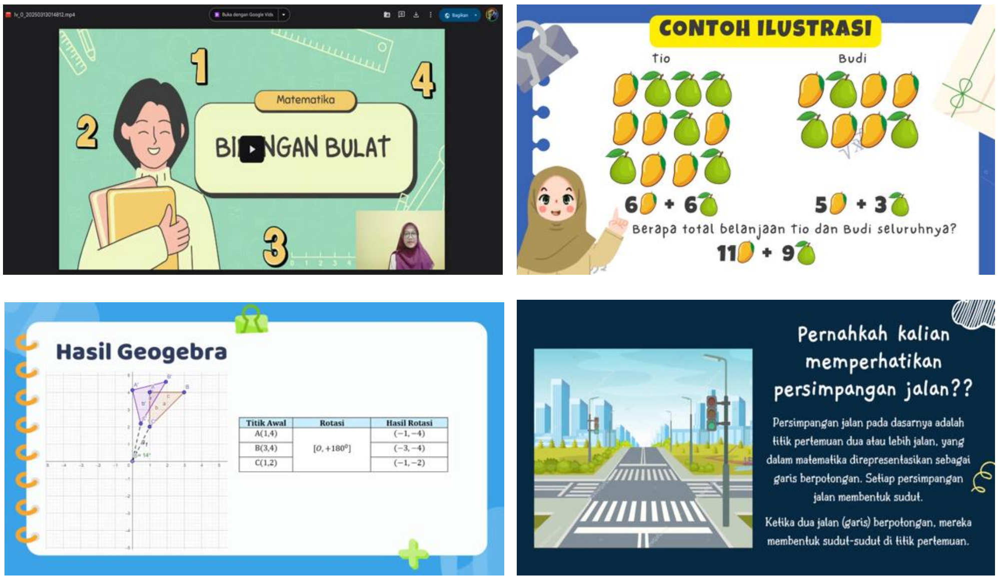

Figure 3. Example of a learning video project

In the last, the following presents data on the TPK of PSMTs in the experiment class and the control class.

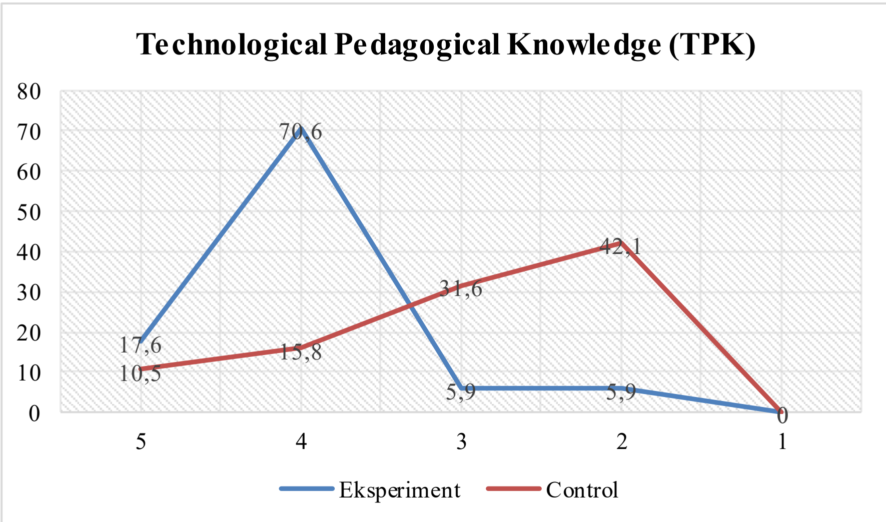

Figure 4. Percentage of pre-service mathematics teachers' TPK Skills

After we discuss technological and pedagogical knowledge, in general, PSMTs demonstrate strong skills in explaining concepts and theories of learning strategies and their applications in common education and mathematics. Furthermore, the analysis of technological pedagogical knowledge capabilities can be seen in Figure 4.

Figure 4 shows that PSMTs in the experimental and control classes scored between 2 and 5. This shows that when learning theory is combined with technology, their abilities are highly diverse. Some of them show strong skills in using technology in the learning process and in relating mathematical material to daily life. The results of this study are consistent with previous findings that they have strong abilities to develop learning plans and implement learning that integrates learning theories/strategies, materials, and technology (Satriawati et al., 2022). In addition, they can use various digital devices to design and solve mathematical modeling problems (Koyunkaya & Dede, 2024). However, it was also found that although they can explain the concepts of learning strategies and technology, in practice, they have not fully utilized technology in daily mathematics learning.

However, when viewed as the percentage of PSTMs who can use learning strategies efficiently and utilize technology in daily learning, their skills in the experimental class are higher (88.2%) than in the control class (26.3%). This is due to the learning environment in the technology-based experimental classroom and the availability of application features on the website. They can access the application, as well as technology-based lectures that help them become very familiar with technology. Figure 5 illustrates project activities in DPL.

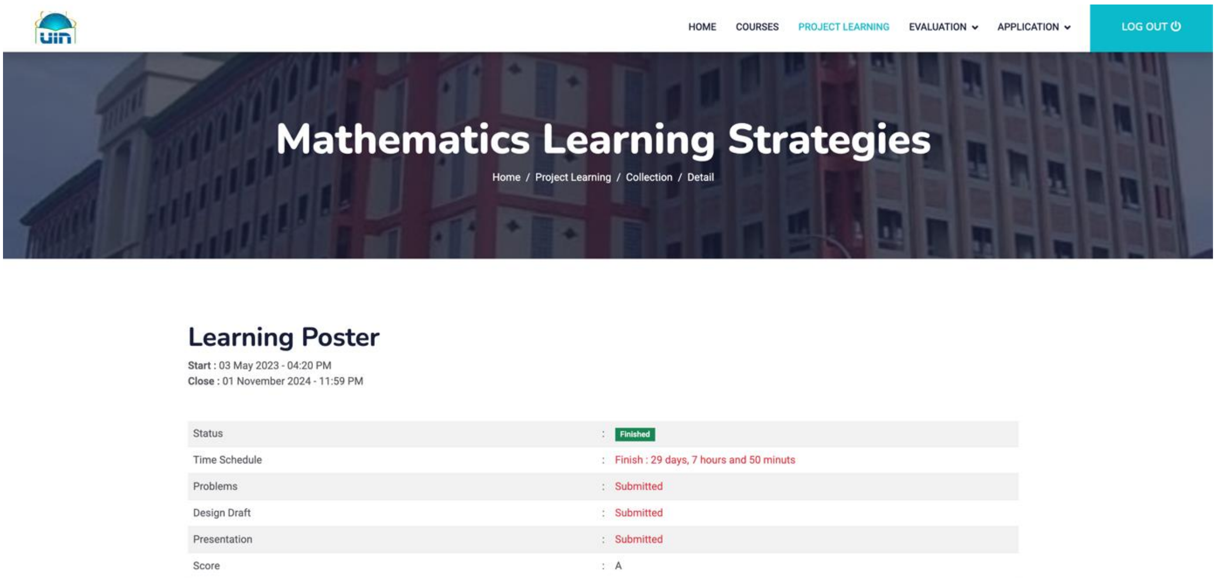

Figure 5. Project Stages in DPL (https://www.digitalprojectlearning.com/)

Problems: At this stage, lecturers present various issues related to mathematics learning. Furthermore, PSMTs are asked to explain the importance of mathematics learning from both educational and daily-life perspectives. They are asked to analyze problems arising from their personal experiences during the mathematics learning process in junior high school or senior high school. This analysis is expected to illustrate their understanding of the realities of mathematics learning they face. In addition, they are also asked to propose relevant solutions to these problems, considering the implementation of appropriate learning strategies and the use of learning media that are effective, innovative, and in accordance with the context of the problem.

Design: At this stage, PSMTs design a learning process to address the identified problems. Lecturers provide ten alternative learning strategies for them to choose from; they are expected to explain the definitions and systematically outline the learning stages. On the other hand, they should have the skills to describe the media or technology used to support the mathematics learning process to be more effective, relevant, and in accordance with the needs of students

Presentation: At this stage, pre-service mathematics teachers prepare presentation materials in front of the class as learning plans in PPT and upload the video to the website. The design must include components of technological, pedagogical, and technological-pedagogical knowledge, presented in a clear, structured manner, in accordance with the indicators in Table 1.

Assesment: At this stage, the researcher uses observation sheets to assess indicators of TK, PK, and TPK. Scoring from PSMTs, as long as the project based learning process is used, using the criteria in Table 2 converted into letters with criteria 5 = Very Good (A), 4 = Good (B), 3 = Fair (C), 2 = Poor (D), and 1 = Very Poor (E).

DISCUSSION

The success of PSMTs in the experimental classroom in designing learning strategies is due to the use of a DPL. It developed in this study is equipped with various features, including learning strategy materials, project resources for them, learning application features, assessment tools, and online discussion forums that they can use to find information or solutions to problems given by lecturers (Cifrian et al., 2020; Cirneanu & Moldoveanu, 2024). When given a problem, they can outline their pedagogical knowledge through the information available on the DPL. It can be accessed at any time by pre-tenured math teachers, allowing them to share knowledge. They can learn from discussion information on the DPL; they can also get information from lecturers or from their own friends who use the same learning strategy (Amey et al., 2020). Learning with technology becomes an integral part of the classroom, and teachers gain a deeper understanding of how to use it most effectively to create meaningful learning experiences (Yanuarto & Jaelani, 2021; Zha et al., 2025). In the control class, the learning process follows a conventional approach, in which PSMTs are given only PowerPoint presentations as reference material. They need to explore additional information beyond PowerPoint. The results of this study align with the claim that incorporating technological tools into the learning process can increase student engagement, personalize the learning experience, and improve academic performance (Amey et al., 2020; Cirneanu & Moldoveanu, 2024).

Some of the PSMTs' knowledge is related to applications used in learning mathematics in experimental and control classes, including GeoGebra, MATLAB, SPSS, Wolfram Alpha, Mathway, Desmos, Autograph, and Photomath. However, only a few applications are used to develop teaching materials, such as GeoGebra, Canva, learning videos, and barcodes. This indicates that they have not used many devices or software explicitly designed for mathematics learning, such as Math Lab, Wolfram, Autograph, and Photomath. The results of this study align with those of a previous study, which found that technological knowledge in designing student learning involves creating videos and animation PPTs (Satriawati et al., 2022). The results of this study also align with research by Turmuzi (2021), who noted that students' knowledge of computer applications related to mathematics and their use in mathematics learning remains limited (Turmuzi & Kurniawan, 2021).

This study shows that the learning environment and the context in which the teaching and learning process takes place can be purely digital, supporting DPL that is flexible, adaptable to the learning pace, and easily modified (Liontas & Karagoz, 2023). The results of this study indicate that PSMTs in the experimental class can design student-centered mathematics learning by utilizing technology relevant to daily life contexts. The results of this study support the claim that "good teaching" is student-centered, using relevant ICT tools and resources as meaningful pedagogical tools (Xing & Chen, 2022).

CONCLUSION

PSMTs' TPK Skills in DPL are relatively better. Their TPK Skills are taught through DPL, yielding an average TPK score of 4.28, they able to integrate and apply technology effectively in the teaching and learning process. Meanwhile, the TPK skill of PSMTs taught using the expository learning model obtained an average TPK score of 3.87; the TPK skill of the control class was lower than that of the experimental class. Their TPK Skills in DPL achieve higher posttest scores than those in expository learning. Thus, it shows that the DPL affects PSMTs' TPK Skills. The results of the study are expected to provide valuable insights into the development of more effective teaching strategies for DPL on PSMTs' TPK Skills. However, this study has limitations because it relies solely on observation sheets. Therefore, to obtain more comprehensive data, it is recommended to use various relevant instruments in each component (TK, PK, and TPK).

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DECLARATIONS

Author Contribution	:	GS : Conceptualization, Writing - Original Draft, Editing and Visualization; D : Validation and Supervision ECMA : Writing, Validation and Supervision, Review, Formal analysis, and Methodology BAP : Validation and Supervision, Review and Editing
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