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Exploring pedagogical knowledge of prospective science teachers through project-based learning

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Abstract

The development of pedagogical competence is an important aspect of the education of prospective science teachers that enables them to design and implement effective and innovative learning experiences. This study aims to explore pedagogical knowledge, including Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Knowledge (TPK), of prospective science teachers in the context of Project-Based Learning (PjBL). This study used a quantitative descriptive design with 27 students from a Science Education Study Program as the participants. Data were collected through the evaluation of teaching modules and a pedagogical competence questionnaire, then analyzed using descriptive statistics in the form of means and percentages. The results of the teaching module assessment showed a progressive increase across the meetings, namely 59.9 (fair), 72.1 (good), and 78.5 (good). Meanwhile, the questionnaire results showed that the PK component obtained an average score of 77.7% (good), the PCK component achieved 88.8% (very good), and the TPK component reached 59.9% (fair). This indicates that students are stronger in integrating content and pedagogy than in utilizing technology in learning. These findings indicate that PjBL provides a meaningful learning experience and has the potential to support the development of pedagogical knowledge, especially in teaching module design; however, further improvement is needed in the TPK dimension to optimize technology integration in learning.

Abstrak. *Pengembangan kompetensi pedagogis merupakan aspek penting dalam pendidikan calon guru IPA agar mampu merancang dan melaksanakan pembelajaran yang efektif dan inovatif. Penelitian ini bertujuan untuk mengeksplorasi pengetahuan pedagogis yang meliputi Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), dan Technological Pedagogical Knowledge (TPK) calon guru IPA dalam konteks Pembelajaran Berbasis Proyek (PjBL). Penelitian ini menggunakan desain deskriptif kuantitatif dengan subjek sebanyak 27 mahasiswa program studi pendidikan IPA. Data dikumpulkan melalui penilaian modul ajar dan kuesioner kompetensi pedagogis, kemudian dianalisis menggunakan statistik deskriptif berupa rerata dan persentase. Hasil penilaian modul ajar menunjukkan peningkatan rerata pada setiap pertemuan, yaitu 59,9 (cukup), 72,1 (baik), dan 78,5 (baik). Sementara itu, hasil kuesioner menunjukkan bahwa komponen PK memperoleh rerata 77,7% (baik), PCK sebesar 88,8% (sangat baik), dan TPK sebesar 59,9% (cukup). Hal ini mengindikasikan bahwa mahasiswa lebih kuat dalam mengintegrasikan konten dan pedagogi dibandingkan pemanfaatan teknologi dalam pembelajaran. Temuan ini menunjukkan bahwa PjBL memberikan pengalaman belajar yang bermakna dan berpotensi mendukung pengembangan pengetahuan pedagogis, terutama dalam perancangan modul ajar, namun perlu penguatan pada aspek TPK agar integrasi teknologi dalam pembelajaran lebih optimal.*

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A. Introduction

In an increasingly dynamic era of education, the need for innovative approaches in the learning process is becoming more urgent. Teachers are required to master various pedagogical skills and to use technology appropriately as an effort to develop students' soft skills and their ability to evaluate and select information when using information and communication technology in learning (Valtonen et al., 2017). Technology in learning is an important tool that teachers can use to enhance student motivation and engagement (Lebedeva et al., 2022). Teachers must have adequate pedagogical knowledge and competence to achieve learning goals. Teachers also need to understand how to integrate technology in accordance with the characteristics of teaching materials to improve the quality of learning (Nasution et al., 2017). The choice of learning design and technology integration influences both teaching methods and student learning outcomes (Xu et al., 2022). One learning model that emphasizes students' active involvement in completing projects related to real-world problems is Project-Based Learning (PjBL).

The PjBL model is an innovative approach to education that prioritizes contextual learning by utilizing complex activities (Masruroh et al., 2021). The focus of learning is on the principles and concepts of a scientific discipline, where students investigate problems and work independently to build knowledge and produce tangible products (Lawe, 2019). Innovative approaches in the learning process are needed in education because they not only facilitate the acquisition of academic knowledge but also foster the development of pedagogical skills. PjBL is a learning method that places students in real-world situations and challenges them to investigate, collaborate, and produce final products as part of the learning process. This approach not only focuses on achieving measurable learning outcomes but also on developing skills that are relevant to the needs of the workplace and everyday life.

In the context of teacher education, PjBL provides an ideal platform for training prospective teachers' pedagogical competencies, especially in science education. The implementation of PjBL aims to improve students' understanding of designing innovative learning experiences and to facilitate the integration of conceptual knowledge and learning practices (Bukhori, 2024). The pedagogical competence of prospective science teachers covers various aspects, including designing effective learning, implementing innovative teaching methods, and evaluating student learning processes and outcomes. PjBL, with its emphasis on active and collaborative learning, provides opportunities for prospective teachers to hone these skills in a practical and relevant context. Through involvement in complex science-based projects, prospective teachers not only learn scientific theories and concepts but also apply them in situations that reflect the real-world challenges they may encounter in the classroom.

This approach allows prospective teachers to design and implement projects that integrate various aspects of science, practice effective assessment techniques, and collaborate with their peers. Thus, PjBL not only prepares them to teach science content in an engaging and effective manner but also equips them with the pedagogical skills necessary to create meaningful learning experiences for their students.

This research explores how the PjBL model can be effectively used to develop the pedagogical competencies of prospective science teachers by integrating the pedagogical components of the Technological Pedagogical Content Knowledge (TPACK) framework, namely Pedagogical Knowledge (PK), Pedagogical Content Knowledge (PCK), and Technological Pedagogical Knowledge (TPK). Prospective science teachers participating in this study were already familiar with the PjBL model; therefore, they were assigned a project to develop a teaching module. The implementation of the PjBL model is expected to provide prospective science teachers with practical experience in developing teaching modules as preparation for future teaching activities.

With a deeper understanding of PjBL, prospective science teachers are expected to optimize their learning process and contribute to the advancement of educational practice in the future.

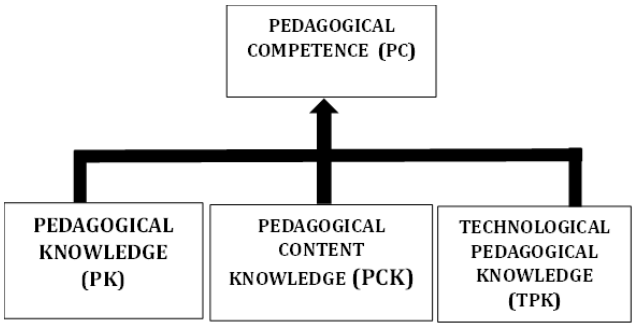

Figure 1
Pedagogical Competencies (PC) Model (Adapted from Koehler & Mishra, 2006)

Figure 1 illustrates the pedagogical competency framework, which is built upon the constructs of PK, PCK, and TPK. This research discusses the relationship between content, pedagogy, and technology and their influence on teaching and learning processes. Teachers must possess seven competencies within the TPACK framework, namely Content Knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK), Technological Content Knowledge (TCK), and Technological Pedagogical Content Knowledge (TPACK). Among these seven competencies, three are directly associated with pedagogical competence,

namely PK, PCK, and TPK (see Figure 1). Based on this framework, this research adapts the TPACK model to measure pedagogical competence using these three pedagogy-related constructs.

Pedagogical competence can generally be defined as a teacher's knowledge of appropriate teaching methods and strategies derived from general educational goals and aligned with students' characteristics. These methods and strategies are adapted to specific subject content while also recognizing the role of technology in supporting instructional practices. Pedagogical competence focuses on the teacher's ability to select teaching strategies and manage instructional processes, including lesson planning, classroom management, and assessment (Mishra & Koehler, 2006). Pedagogical Content Knowledge (PCK) relates to prospective teachers' understanding of how particular content, problems, or issues are organized, represented, and adapted to diverse student abilities and learning objectives (Gudmundsdottir & Shulman, 1987). Meanwhile, TPK refers to the ability of prospective teachers to select and utilize technology that aligns with specific learning strategies (Schmidt et al., 2014). The pedagogical competence of prospective science teachers was measured using a self-assessment questionnaire that examined their perceived knowledge and understanding of PK, PCK, and TPK.

Based on this framework, this research aims to describe the pedagogical competencies of prospective science teachers, including PK, PCK, and TPK. Pedagogical competence was evaluated through students' ability to develop teaching modules and conduct teaching simulations, which were assessed using a rubric, as well as through self-assessment questionnaires that captured students' perceptions of their own pedagogical competence.

B. Material and method

This research employed a quantitative approach using a survey method. The participants were 27 sixth-semester students from the Science Education Study Program, Faculty of Mathematics and Natural Sciences, Universitas Negeri Surabaya (UNESA), who were enrolled in an Innovative Learning course. The study implemented the PjBL model.

Data collection was conducted using teaching module assessment sheets and questionnaires. The module assessment sheet was developed based on teaching module components and the TPACK framework. This instrument was used to assess students' ability to design comprehensive teaching modules. The aspects assessed included: (1) completeness of the introduction, (2) appropriateness of learning model selection, (3) integration of TPACK components (particularly pedagogical aspects), (4) language use, and (5) time management at each stage of the activity. Each aspect was evaluated using a rubric with a 4-point Likert scale, with the following criteria: 1 (very poor), 2 (adequate), 3 (good), and 4 (very good). Student scores were then summed and averaged to reflect overall achievement.

The questionnaire consisted of 14 statements adapted from the study conducted by Lestari and Rahayu (2023) to measure the TPACK domain, focusing on pedagogical competencies, namely PK, PCK, and TPK. The collected data were analyzed using descriptive quantitative techniques. Responses on the Likert scale were converted into percentages using the formula (total score obtained / maximum possible score) × 100. The results of the data analysis were then interpreted according to the criteria presented in Table 1. As shown in Table 1, higher percentage scores indicate higher levels of pedagogical competence demonstrated by the students.

Table 1 Interpretation categories

Percentage of respondents (%)	Interpretation
1-19.9	Very lacking
20-39.9	Less
40-59.9	Fair
60-79.9	Good
80-100	Excellent

C. Results and discussion

Teaching module assessment data

This research implemented a project-based learning design through the application of the PjBL model. At the beginning of the learning process, students received an explanation of the project-based learning activities and procedures. Students were provided with guidance in the form of a Structured Teaching Module Guide Sheet (Lembar Panduan Terstruktur Modul Ajar/LPT-MA). They then prepared teaching modules in groups and presented them in class to obtain feedback from lecturers and peers. This activity was carried out repeatedly until the teaching modules met the criteria specified in the assessment rubric.

The progress of students' teaching module development is presented in Figure 2. Figure 2 presents the average student achievement scores in developing teaching modules based on individual performance across five indicators: introduction, learning model selection, integration of TPACK components (particularly pedagogical aspects), language use, and time management at each stage of the activity.

The results indicate a gradual improvement in students' performance after they received feedback from lecturers and peers. This finding provides preliminary evidence of the effectiveness of the implemented learning model in enhancing students' ability to develop teaching modules. These findings are consistent with previous studies reporting that structured learning models and module-based instruction contribute significantly to the improvement of student competencies and learning

outcomes (Novianti et al., 2025; Arifin & Ramadhan, 2025; Shanti et al., 2022).

Among the assessed aspects, the learning model selection component obtained a lower score than the other indicators. This suggests that students still require a deeper understanding of various learning models and their appropriate application in instructional design. Developing TPACK-based teaching modules has been shown to help teachers and prospective teachers integrate technology, pedagogy, and content in a more systematic manner (Faizal et al., 2023). This finding is also supported by previous research showing that mastery of TPACK influences prospective teachers' readiness to integrate technology into both learning planning and instructional implementation (Khasanah et al., 2025).

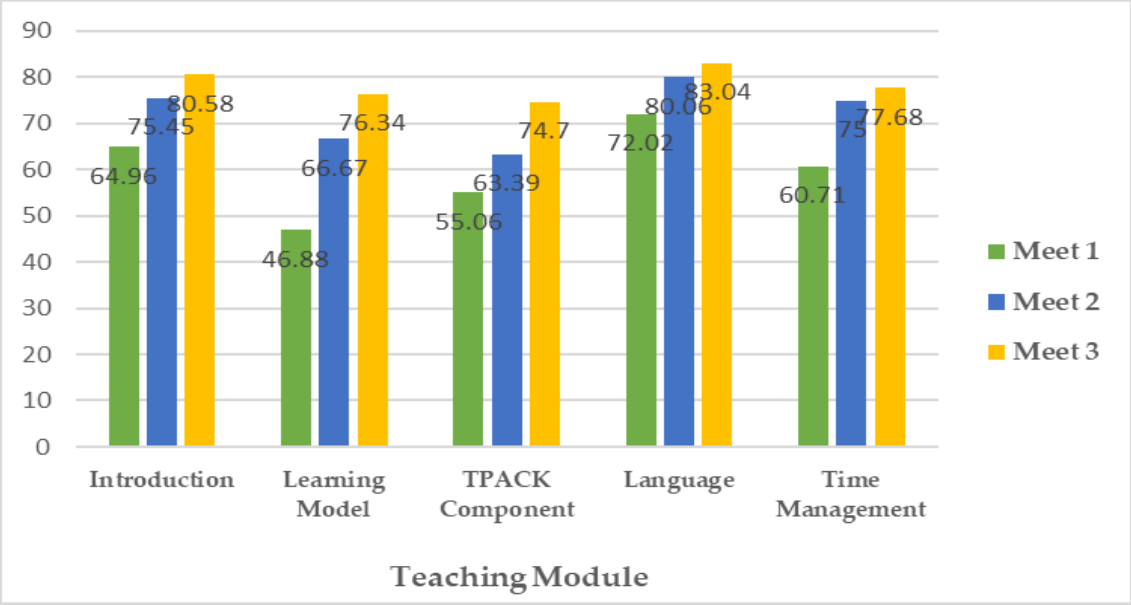

Figure 2 Progress of preparing teaching modules by student science teacher candidates

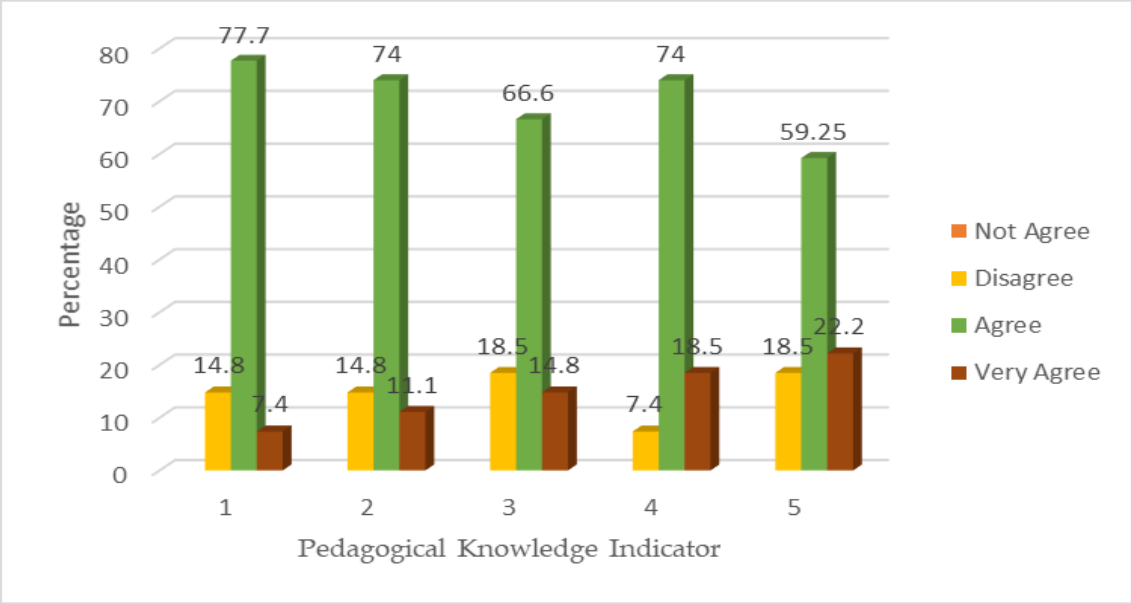

Figure 3 Results of pedagogical knowledge data analysis

Student self-assessment questionnaire data pedagogical knowledge (PK)

The Pedagogical Knowledge (PK) aspect shows that the majority of respondents agreed with almost all indicators, indicating that prospective teachers possess a relatively good understanding of pedagogy in designing, managing, and implementing learning activities. Figure 3 presents the self-assessment results of prospective science teacher students in the Pedagogical Knowledge domain.

Figure 3 illustrates the results of the PK analysis obtained through a self-assessment questionnaire

administered to prospective science teacher students. Pedagogical Knowledge consists of five indicators: (1) the ability to manage the classroom effectively, (2) the ability to use various instructional approaches, (3) the ability to implement learning models that align with students' characteristics, (4) the ability to apply various assessment methods to monitor student learning performance, and (5) the ability to enhance students' higher-order thinking skills through challenging learning tasks.

This study implies that the educational process experienced by prospective teachers contributes positively to the development of pedagogical competence. Pedagogical Knowledge is a crucial component of teacher professionalism because it encompasses an understanding of teaching strategies, classroom management, and student characteristics that support high-quality learning. Variations in the percentages across PK indicators suggest differences in the level of students' mastery of specific pedagogical competencies. The development of pedagogical knowledge is achieved not only through conceptual understanding but also through a process of continuous reflection on teaching practice (Li & Copur-Gencturk, 2024).

The indicator related to effective classroom management obtained the highest percentage score (77.7%), indicating that students perceive themselves as competent in organizing and managing classroom learning environments. Meanwhile, the indicator concerning the application of various assessment methods to monitor student learning performance showed only 7.4% disagreement, suggesting that most students were confident in their ability to employ diverse assessment strategies. This finding is supported by previous research indicating that pedagogical competencies developed through collaborative small-group training have a significant positive impact on prospective teachers' professional development (Havia et al., 2022). Teachers need to possess strong pedagogical competence because it directly influences student learning outcomes (Sudargini & Purwanto, 2020). Overall, these findings highlight the importance of combining pedagogical theory with practical teaching experiences to enhance prospective teachers' readiness for professional practice.

Pedagogical content knowledge (PCK)

Pedagogical Content Knowledge (PCK) refers to the competency to select and apply teaching approaches that are appropriate for specific subject matter so that the content can be learned effectively by students (Koehler & Mishra, 2009). Different types of content possess unique characteristics that require specific instructional strategies; therefore, PCK is considered one of the essential competencies that teachers must develop. The results of the self-assessment analysis of prospective science teacher students regarding the Pedagogical Content Knowledge domain are presented in Figure 4.

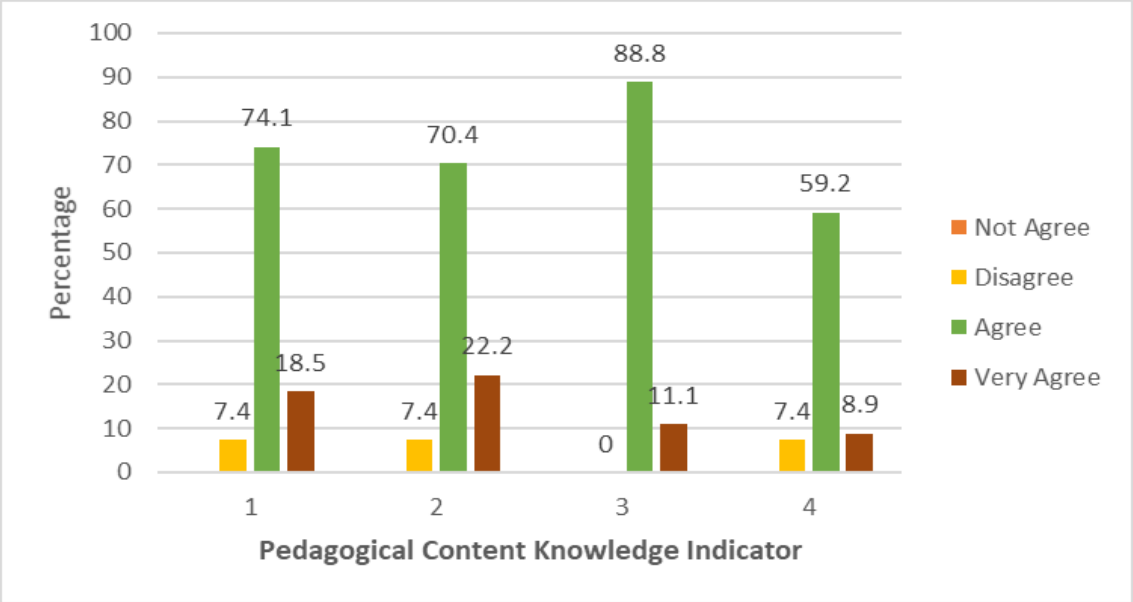

Figure 4 Results of pedagogical content knowledge data analysis

Based on Figure 4, the results of the PCK analysis for prospective science teacher students were obtained through a self-assessment questionnaire consisting of four indicators: (1) the ability to prepare appropriate and effective lesson plans for teaching science content; (2) the ability to understand instructional strategies that are suitable for science content and to develop corresponding lesson plans; (3) the ability to identify common difficulties encountered by students when learning science; and (4) the ability

to encourage students to engage in collaborative discussions on the topics being studied.

The findings indicate that some respondents were not yet fully confident in their ability to plan instruction, implement learning activities, and select appropriate instructional strategies. PCK encompasses more than expertise in subject matter or general pedagogical knowledge; it involves a specialized understanding of how content and pedagogy interact to facilitate effective learning. Therefore, prospective science teachers need to develop strong PCK competencies to improve the quality of instruction. This finding is consistent with previous studies emphasizing that pedagogical understanding and content knowledge are inseparable components of effective teaching (Sum & Taran, 2020; Uningal, 2020). Pedagogical Content Knowledge enables teachers to design and implement instructional practices that are aligned with the characteristics of the subject matter and students' learning needs (Nuangchalerm, 2020; Padmavathi, 2017).

The results suggest that prospective science teachers generally demonstrate a good level of PCK; however, some participants still experience difficulties in optimally integrating content knowledge with pedagogical knowledge. This limitation may affect their ability to present science concepts in ways that are contextualized and responsive to students' characteristics. Variations in the data indicate that the preparation of prospective science teachers should place greater emphasis on practical teaching experiences. This finding aligns with previous research showing that effective PCK development requires the integration of practice-based learning, reflective activities, and authentic teaching experiences (Sæleset & Friedrichsen, 2021). Teachers must understand the reciprocal relationship between pedagogy and content knowledge to implement instructional strategies that facilitate students' understanding of the material (Suryani et al., 2021; Susanti et al., 2022).

Based on these findings, teacher education programs should strengthen learning designs that integrate theoretical understanding with practical experience. Through such integration, prospective teachers are expected not only to understand PCK conceptually but also to apply it effectively according to the characteristics of the subject matter and students' needs. Strengthening this aspect is expected to enhance prospective teachers' mastery of PCK and contribute to the continuous improvement of science education quality (Munawwarah & Cahyani, 2025; Deng et al., 2024).

Technological pedagogical knowledge (TPK)

Technological Pedagogical Knowledge (TPK) refers to teachers' competence in selecting and utilizing appropriate technologies to support teaching and learning processes so that classroom instruction becomes more effective and engaging (Schmidt et al., 2009). Teachers integrate technology into learning as a tool or medium that supports the implementation of appropriate pedagogical strategies and enhances instructional effectiveness and efficiency. Within the context of teacher education, TPK relates to prospective teachers' knowledge of how technology can be integrated with pedagogical approaches to facilitate learning (Septiyanti et al., 2020). Figure 5 presents the results of the analysis of prospective science teacher students' perceptions regarding the TPK domain.

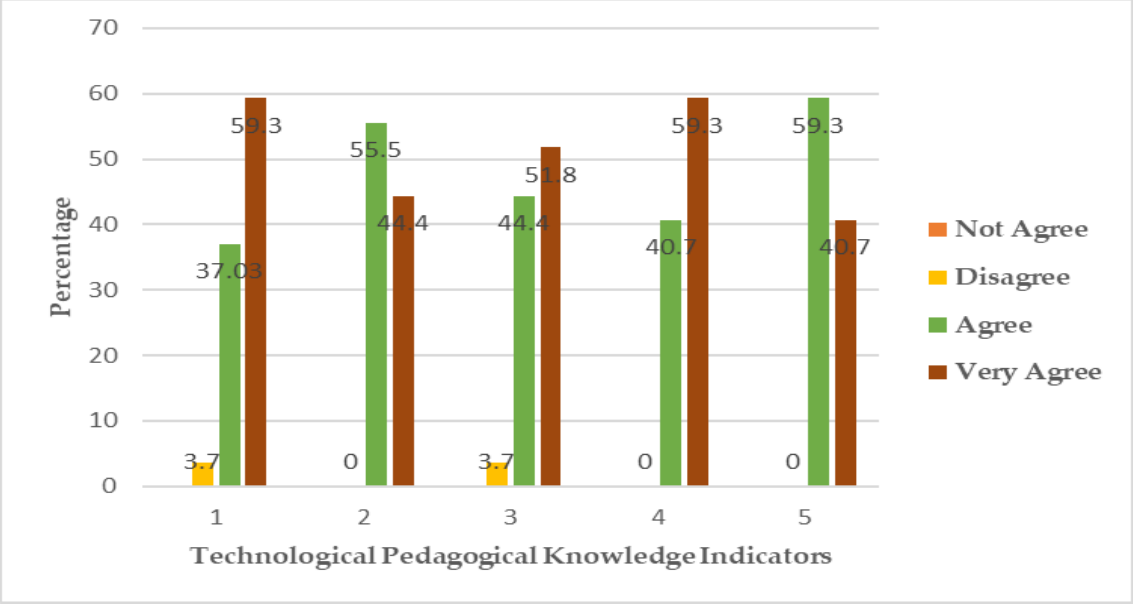

Figure 5 Results of technological pedagogical knowledge data analysis

Based on Figure 5, the perceptions of prospective science teacher students regarding Technological Pedagogical Knowledge were categorized as good to very good. This finding indicates that students generally feel confident and familiar with technologies that can be used to plan, organize, and evaluate learning activities according to students' needs. Such competencies may have been developed through educational courses such as Learning Media, Innovative Learning, and Curriculum Studies.

The TPK domain consisted of five indicators: (1) the ability to use internet search engines (e.g., Google) to prepare learning materials; (2) the ability to select appropriate technologies to support instructional approaches in the classroom; (3) the ability to teach science using online platforms (e.g., Zoom and Google Meet); (4) the ability to collaborate with students through technology-based platforms (e.g., social media and online learning management systems); and (5) the ability to reflect on the use of technology in online science learning.

The first indicator showed that 59.3% of students strongly agreed that they were capable of using internet search engines to support learning preparation. Similarly, 59.3% strongly agreed that they could collaborate with students through technology-based platforms, while 59.3% agreed that they were able to reflect on the use of technology in science learning. These findings suggest that prospective science teachers possess a relatively positive perception of their ability to integrate technology into pedagogical practice.

Future teachers are required to possess adequate technological knowledge, skills, and competencies to effectively integrate technology into learning processes and enhance instructional quality (Eurika, 2022; Indra et al., 2021; Nugraheni et al., 2022). In addition, effective teaching requires careful preparation because inadequate utilization of technology may limit the implementation of pedagogical competencies that have been developed (Setiyowati & Arifianto, 2020). Pedagogical competence encompasses an understanding of students' characteristics, mastery of subject matter, classroom management skills, the effective use of instructional media, and the application of appropriate teaching methods (Junianingsih, 2019). These competencies play a crucial role in determining student learning success (Zulfahmi et al., 2019).

D. Conclusion

This study demonstrated that prospective science teachers possessed generally good pedagogical competence, with the highest achievement observed in Pedagogical Content Knowledge (PCK), followed by Pedagogical Knowledge (PK), while Technological Pedagogical Knowledge (TPK) showed the lowest level of achievement. These findings indicate that prospective teachers are relatively capable of integrating content knowledge and pedagogical strategies in the learning process; however, their ability to integrate technology into pedagogical practice remains less developed. The implementation of Project-Based Learning (PjBL) contributed to the development of pedagogical competence by providing contextual, collaborative, and reflective learning experiences. This contribution was reflected in the progressive improvement of teaching module quality across the learning sessions. The iterative process of designing, presenting, revising, and refining teaching modules enabled prospective teachers to strengthen their pedagogical understanding and instructional planning skills. Therefore, PjBL can be considered an effective learning model for supporting the development of prospective science teachers' pedagogical competence. Nevertheless, greater emphasis should be placed on strengthening the TPK dimension through learning activities that explicitly promote meaningful technology integration in instructional planning and implementation. Such efforts are expected to better prepare prospective teachers to meet the demands of technology-enhanced learning environments in the future.

E. Acknowledgement

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