Exploration of The Tpack Ability of Pre-Service Teacher Professional Education Students in The Perspective of Mastery of 21st Century Skills

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ABSTRACT

The government's action to improve the quality of education is carried out by initiating an independent learning curriculum. The 21st century skills are skills related to critical thinking, creative thinking, innovation, problem solving, communicative and collaborative. These abilities can be trained and developed in teaching and learning activities at school. To train and develop these abilities, a big role is needed from educators. Educators should master four competencies which include professional, personality, pedagogical and social competencies. The framework that can facilitate the four competencies, especially pedagogical and professional competencies, is Technological, Pedagogical and Content Knowledge (TPACK). Mastery of TPACK is very important to be owned by educators and prospective educators, including pre-service teacher professional education students of the UNESA PGSD Study Program, who are prospective elementary school teachers. The aim to be achieved in this study is to describe the Technological, pedagogical and content knowledge (TPACK) abilities of pre-service teacher professional education students of PGSD Study Program in the Perspective of Mastery of 21st Century Skills. The urgency of this research is as a reference for developing a professional elementary school teacher candidate program. This research is descriptive which is exploratory in nature to explore the TPACK knowledge of pre-service teacher professional education students who are prospective elementary school teachers. Data collection techniques were carried out using test and FGD methods. The data analysis technique uses the Miles and Huberman model. which includes data collection, data condensation, data presentation and conclusion drawing. Triangulation of data using triangulation of sources and techniques

Keywords— TPACK, 21st Century Skills, Pre-service Teacher Professional Education Students

INTRODUCTION

Improving the quality of education in Indonesia continues to be pursued through various strategic policies, one of which is through the implementation of the Merdeka Belajar Curriculum. This curriculum aims to produce a superior generation that is adaptive to the times and able to face global challenges (Hunaepi & Suharta, 2024),(Hadi et al., 2023). The main essence of the Merdeka Belajar Curriculum is to provide freedom of thought for teachers and students. With this freedom, students can develop cognitive, affective, and psychomotor potential, while teachers have the space to innovate in learning. Another positive impact of this curriculum is the improvement of students' self-quality, self-confidence, and social care (Mustaghfiroh, 2020). Therefore, Merdeka Belajar Curriculum is considered in line with 21st century skill needs.

21st century skills include critical thinking, creativity, problem solving, communication, and collaboration. These skills are important provisions for students to be able to compete in the era of the Industrial Revolution

4.0 and adapt in social life. Recent research shows that the Project-Based Learning model is effective in fostering 4C skills (critical thinking, creativity, collaboration, communication) in students from an early age (Shiddiq et al., 2024). In addition, the STEAM-PjBL approach is proven to strengthen 21st century skills through cross-disciplinary project-based learning (Suryaningsih et al., 2024). This confirms that teachers play an important role in designing learning that not only transfers knowledge, but also encourages the development of higher order thinking skills (HOTS).

In the context of teacher professionalism, Law No. 14/2005 on Teachers and Lecturers emphasizes that educators must master four competencies, namely pedagogical, professional, personality, and social (Fatma Yulita et al., 2025). One framework that supports the strengthening of pedagogical and professional competencies is Technological, Pedagogical, and Content Knowledge (TPACK). This framework emphasizes the integration of mastery of technology, content, and pedagogical strategies so that learning is more relevant to the needs of the 21st century. Research showed that TPACK integration can improve content and technology mastery while strengthening teachers' confidence in designing lessons (Rahayu et al., 2024), (Arifuddin et al., 2025). Recent studies have also revealed that micro-teaching activities play a significant role in improving the TPACK skills of student teachers (Humaera et al., 2024).

However, although research on TPACK is growing, the focus of studies on the pre-service realm, especially Pre-service education students in the PGSD Study Program, is still limited. In fact, Pre-service education students are prospective elementary school teachers who are expected to be able to implement the Merdeka Curriculum while fostering 21st century skills in students (Husnul Haq & Wakidi, 2024). Research trends show that there are new dynamics in the integration of TPACK in Indonesia, especially regarding the implementation of the Merdeka Curriculum (Utari et al., 2025),(Feifei & Abdullah, 2023). Therefore, it is very important to explore the TPACK abilities of Pre-service education students in the PGSD Study Program to fill this void.

In addition, the development of digital technology has significantly changed the paradigm of education. The presence of technology is no longer just a tool, but the main means in 21st century learning. Teachers are now required to have qualified digital literacy in order to design technology-based learning according to the needs of students. Research asserts that the use of Artificial Intelligence (AI) in learning has proven effective in improving creativity, collaboration, and critical thinking skills of elementary school students (Susanti, 2025),(Prayoga et al., 2025). This condition shows that mastering TPACK for prospective teachers cannot be delayed, considering that technology is increasingly becoming the core of the modern learning process.

Changes in teacher competency needs require universities, especially PPG organizing institutions, to provide comprehensive provisions for pre-service students. Research showed that micro-teaching activities have a major role in strengthening pedagogical skills as well as technology integration. Through this activity, student teachers can practice TPACK skills in a simulated situation so that they are better prepared when they go directly to school (Humaera et al., 2024). Thus, the exploration of Pre-service education students' TPACK skills is not only academically important, but also practical in supporting their readiness as prospective professional teachers.

Furthermore, mastery of TPACK has been shown to have a close relationship with the development of 21st century skills in students. Research in a systematic review found that TPACK facilitates collaborative learning, utilizes interactive technology, and encourages students to think critically (Humaera et al., 2024),(Ma et al., 2024). This is in line with the objectives of the Merdeka Curriculum, which emphasizes students' freedom, creativity, and active participation in the learning process. Therefore, research on the TPACK of Pre-service education students in the PGSD Study Program is very relevant to determine the extent of their readiness to meet the demands of the curriculum.

In addition to TPACK, teachers also need to have sensitivity to the characteristics of elementary school students. Another research explained that STEAM-based learning is able to integrate various disciplines while still paying attention to students' cognitive, social and emotional development (Mussey, 2022),(Thi Nho & Thi Thiep, 2024). This emphasizes that prospective teachers need to master innovative learning models that can accommodate students' needs holistically. In this case, TPACK serves as a framework that brings together technology, pedagogy, and content, so that teachers can adjust teaching strategies according to the diverse characteristics of

students.

Finally, research on the exploration of the TPACK abilities of Pre-service education students in the UNESA PGSD Study Program has a strong urgency. The results of this study are expected to not only provide theoretical contributions, but also become material for evaluation as well as development of the PPG curriculum. With a good understanding of TPACK, prospective teacher students can improve their professionalism, support the implementation of the Merdeka Curriculum, and contribute to producing a generation with resilient and adaptive 21st century skills.

METHOD

This study used an exploratory descriptive approach with the subject of 30 PPG Pre-Service students of PGSD Study Program at Surabaya State University. Data were collected through TPACK learning performance, Focus Group Discussion (FGD) which explored the results of student learning practices and interviews. Data analysis used the Miles & Huberman model which includes four stages: data collection, data condensation, data presentation, and conclusion drawing (Santika et al., 2023) . Data validity was tested through source triangulation and technique triangulation.

Data Collection Instruments and Procedures

Three main instruments were used to collect data:

1. Questionnaire on TPACK and 21st Century Skills – The questionnaire consisted of 20 items covering seven TPACK domains (TK, PK, CK, TPK, TCK, PCK, and TPACK integration) and four 21st-century skill domains (communication & collaboration, creativity & innovation, critical thinking & problem-solving, and digital literacy). Each item used a five-point Likert scale (1 = strongly disagree to 5 = strongly agree).

2. Validity and Reliability: The questionnaire underwent expert validation by three university lecturers specializing in educational technology and pedagogy. The content validity index (CVI) reached 0.87, categorized as "high," and internal consistency reliability was tested using Cronbach's Alpha = 0.91, indicating strong reliability.

3. Classroom Observation Sheet – Used to evaluate how participants applied TPACK principles during their microteaching sessions and school practice. The observation focused on indicators of technological integration, pedagogical strategy, and content relevance. Two observers conducted the evaluations to enhance inter-rater reliability, achieving a Cohen's Kappa value of 0.82, which indicates substantial agreement.

4. Focus Group Discussion (FGD) and Semi-Structured Interviews – Conducted to gain qualitative insights into students' experiences, perceptions, and challenges in applying TPACK. FGDs were organized in groups of five to seven participants and lasted approximately 60–90 minutes per session. Interview guides were developed based on themes emerging from questionnaire responses.

Data Analysis Techniques

Data were analyzed using the Miles & Huberman interactive model, which includes (Asipi et al., 2022),(Mustadi, Wibowo, et al., 2024),(Erislan, 2023):

(1) Data collection,

(2) Data condensation,

(3) Data display, and

(4) Conclusion drawing and verification.

Quantitative data from the questionnaire were analyzed using descriptive statistics (mean, standard deviation, and category interpretation), while qualitative data from FGDs and observations were coded thematically. The integration of quantitative and qualitative findings followed a convergent parallel mixed-method logic, allowing both data strands to complement each other for a more comprehensive understanding.

Data Validity and Triangulation

Data credibility was ensured through triangulation of sources (questionnaire, observation, FGD) and triangulation of methods. Triangulation is widely recognized as a key strategy for enhancing the credibility, validity, and trustworthiness of research findings by integrating multiple data sources (such as questionnaires, observations, and focus group discussions) and methods (qualitative and quantitative) (Noble & Heale, 2019), (Santos et al., 2020), (Vivek et al., 2023). When findings from various sources and methods converge, this strengthens the credibility of the conclusions; however, even when data diverge, triangulation provides a framework for understanding inconsistencies and identifying areas for further investigation (Campbell et al., 2020), (Kern, 2018)

FINDING AND DISCUSSION

A. Finding

Learning outcomes that apply TPACK in differentiated learning of the first group on behalf of : Difky Aldi Mahendra, a student of pre-service teacher professional education, PGSD study program.

This learning observation was conducted to analyze the implementation of Technological, Pedagogical, and Content Knowledge (TPACK) in teaching and learning activities in the classroom. The implementation of TPACK is one of the important demands for prospective teachers in integrating mastery of technology, pedagogy, and learning content harmoniously. This observation activity focuses on how educators utilize digital technology as a presentation medium, manage the class interactively, and link learning materials with relevant pedagogical strategies.

In the implementation, teachers are seen utilizing projector technology to present materials visually. This supports the technological knowledge (TK) aspect, where digital media plays a role in clarifying the information presented (Al-Rahmi et al., 2023). Furthermore, teachers use a small group discussion approach to actively engage students. This strategy reflects pedagogical knowledge (PK) which emphasizes student involvement in building knowledge through interaction and collaboration.

In terms of content knowledge (CK), teachers try to explain the material according to the structure and context of ongoing learning (Hastie, 2022). The material is presented systematically, then connected to real life to make it more meaningful to students. The integration of these three aspects shows that TPACK can facilitate the creation of learning that is more interesting, contextual, and in accordance with 21st century needs.

In general, the observation results show that the application of TPACK is able to increase student activeness, clarify concept delivery, and strengthen collaborative skills. However, development is still needed in the aspect of creativity in using digital learning media and strengthening technology-based evaluation. This is important so that learning is not only informative, but also transformative in fostering critical, creative, communicative, and collaborative thinking skills (4C).

Fig. 1 Exploring the TPACK abilities of pre-service teachers in an active discussion, essential for mastering 21st century skills.

Fig. 2 Collaboration and communication sessions, reflecting efforts to develop TPACK and 21st century skills for future educators.

Fig. 3 Interactive learning activities as part of efforts to improve the TPACK of Pre-service education students, in line with the demands of 21st century skills.
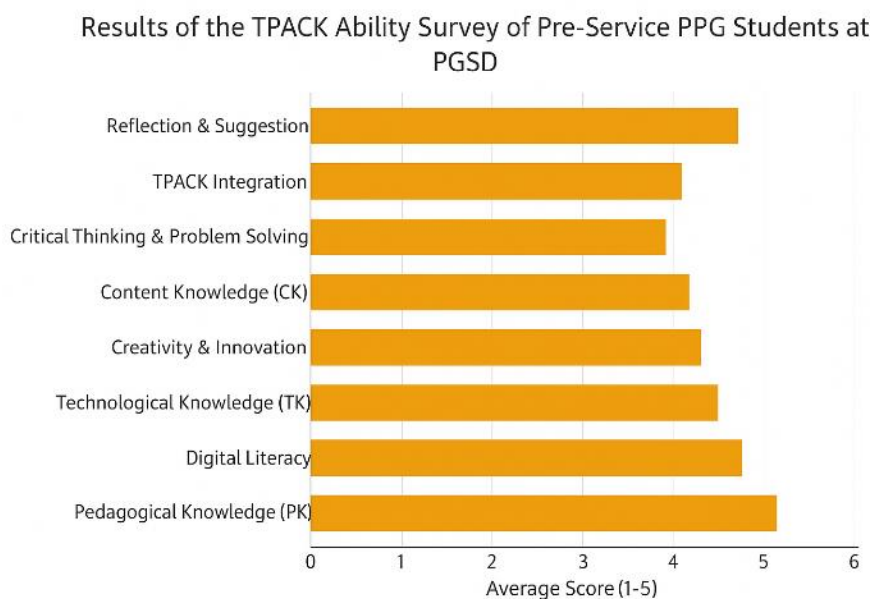
Table 1 Indicators of TPACK Components Observed in Teaching Practice

Code	Indicator	Description
TK 1	Insights related to technology both low-tech (paper, pencil, etc) and digital technology (software, internet, etc).	In the learning process carried out by the teacher, it is already low-tech. Because the process already features digital technology. For example, the teacher displays a learning video through a projector in the classroom.
TK 2	Insights related to the ability to use technology.	In the learning process, teachers have used technology in learning well and correctly.
TK 3	Mastery in using technology as a tool for communication, goal achievement and problem solving.	In the learning process, teachers have mastered the use of technology through learning videos played through projectors so that they can help teachers achieve learning objectives.
PK 1	Insights related to learning methods and procedures.	In the learning process, teachers have done differentiated learning. The differentiation that teachers choose is process differentiation.
PK2	Mastery of student learning strategies, class mastery, ability to design learning and ability to evaluate learning.	In the learning process, teachers have mastered various things, namely in applying student learning strategies, class mastery, ability to design learning and ability to evaluate learning.
CK1	Insights related to learning materials that include facts, concepts, theories and procedures.	In the learning process, the teacher has mastery in explaining the learning material. This can be proven by the teacher has included elements of facts and also procedures into the learning material "decorative drawing".
TP1	Insight into the shift in learning strategies and procedures due to the use of technology.	During the learning process, teachers only use technology in the form of learning videos as a means of supporting their learning.
TCK 1	Insights relating to the use of technology to create new representations of learning materials and help students understand those materials.	During the learning process, the teacher has made new representations systematically so that students understand the material that the teacher has delivered.
TCK 2	Insights relating to how to select the best technology that can be used to achieve learning objectives.	During the learning process, teachers have chosen the best technology to use in achieving learning objectives, namely using learning videos.
TCK 3	Insights relating to the effectiveness of using technology for learning materials and vice versa.	The selection of learning videos used by teachers is effective because the target is low-grade students who like pictures so that learning looks more interesting.

Code	Indicator	Description
PCK 1	Insights relating to learning development strategies with the incorporation of learning materials and pedagogy.	In the learning process, teachers have used development strategies that have systematic learning objectives and have evaluation activities. Teachers also cover pedagogics during learning. In the learning process, teachers have used development strategies that have systematic learning objectives and have evaluation activities. Teachers also cover pedagogics during learning.

Questionnaire results

The results of the questionnaire given to 30 Pre-service education students in the PGSD Study Program show an overview of their ability to answer 20 statement items related to aspects of Technological, Pedagogical, and Content Knowledge (TPACK) in the perspective of 21st century skills. Each item is filled in with a score range of 1-5, where a high score indicates a better level of mastery or agreement with the statement given.

Results of the TPACK Ability Survey of Pre-Service PPG Students at PGSD

In general, the questionnaire results show that the TPACK ability of Pre-service education students in the PGSD Study Program is in a fairly good category, with variations in the level of mastery between aspects. Based on the average score, the Pedagogical Knowledge (3.63) and Communication & Collaboration (3.50) aspects occupy the highest position. This shows that students have readiness in designing differentiated learning and are able to build positive collaborative interactions with students. These two aspects reflect that students have sufficient understanding of 21st century learning principles that emphasize communication and collaboration.

Meanwhile, aspects of Digital Literacy (3.40) and Technological Knowledge (3.37) also showed good results. Students are accustomed to using digital technology in the learning process and have adequate digital literacy, although they still need to improve in terms of ethical use of technology and technical problem solving skills. This finding is in line with the demands of the Merdeka Curriculum, which encourages teachers to integrate technology intelligently and responsibly in the teaching and learning process.

In the Creativity & Innovation aspect (3.23), students show openness to digital innovation, but still tend to be passive in creating new learning media. This shows that they more often adapt the technology that is already available rather than developing their own innovations. Similarly, the TPACK Integration aspect (2.93) shows

that most students are still at an early stage in integrating technology, pedagogy and content elements thoroughly.

The aspects with the lowest scores were Content Knowledge (2.87) and Critical Thinking & Problem Solving (2.79). The low scores on these two aspects indicate that prospective teachers still need to deepen their mastery of teaching materials and improve their critical thinking and contextual problem solving skills. This is an important note, because strong content mastery and higher order thinking skills are the basis for designing meaningful learning for elementary school students.

Overall, the questionnaire results illustrate that students have shown good potential in mastering TPACK and 21st century skills, especially in terms of pedagogy, collaboration, and digital literacy. However, strengthening is still needed in the aspects of content mastery, creativity, and technology integration in project-based learning and problem-based learning (PBL). These results are an important basis for the PPG program to design training interventions, reflective guidance, and technology-based microteaching so that prospective elementary teachers are increasingly ready to face the demands of the Merdeka Curriculum and adaptive, innovative, and collaborative 21st century learning.

DISCUSSION

The findings from this study provide a comprehensive overview of the TPACK profile of Pre-service education students in the PGSD Study Program, illustrating both their strengths and developmental needs in mastering 21st-century skills. The overall trend shows that participants demonstrate adequate pedagogical competence and technological awareness, yet their mastery of content knowledge and critical thinking remains comparatively limited. This disparity reflects deeper structural and contextual challenges in pre-service teacher education within Indonesia.

The observation results show that teachers have begun integrating technology in learning through the use of projectors to display materials visually. The use of digital media has proven effective in increasing student attention and clarifying concepts presented, aligning with the findings of Prytyka who emphasized that interactive technology enhances student focus and comprehension (Prytyka, 2023). However, creativity in media use remains limited, as most teachers prefer simple presentation-based technologies over innovative digital tools that promote active engagement. This indicates that technological knowledge (TK) among pre-service teachers is still in a transitional phase adequate for basic instructional delivery but not yet transformative in shaping interactive learning experiences.

The strong performance in pedagogical knowledge (PK), as seen in the effective use of group discussion and classroom management strategies, reflects that participants are competent in student-centered approaches that foster collaboration and communication. Such pedagogical behavior aligns with 21st-century learning paradigms emphasizing engagement and active participation (Suryaningsih et al., 2024) Nevertheless, the findings also suggest that pedagogical innovation particularly through problem-based or project-based learning has yet to be fully integrated into their practice. Teachers tend to prioritize curriculum coverage and structured tasks over inquiry or reflective dialogue, potentially limiting opportunities for critical and creative thinking to develop (Lorenzana & Roleda, 2024).

From the content perspective, teachers generally demonstrate basic mastery of the learning material, such as in the topic of "decorative drawing." They can convey facts and procedures accurately, indicating solid foundational knowledge. However, this content knowledge (CK) remains procedural rather than conceptual. Teachers rarely connect subject matter to interdisciplinary or real-life contexts, as highlighted by Zhao & Abdullah, who argued that integrating STEAM-based and problem-oriented learning enhances the relevance of material while fostering creativity (Zhao & Abdullah, 2025). The limited integration observed in this study suggests that the PPG curriculum may not yet emphasize cross-disciplinary linkages, which are essential for deepening understanding and cultivating students' higher-order thinking skills.

The low CK score may also stem from the structure of Indonesian teacher preparation itself. The PPG program, while intensive, often compresses pedagogical and content learning into a short duration. Consequently,

participants have little time for subject enrichment beyond what is required for lesson design. This results in surface-level content mastery that prioritizes lesson completion rather than deep conceptual engagement. Research noted that such tendencies limit teachers' ability to contextualize knowledge, leading to lessons that are informative but not transformative (Berlian, 2022).

The limited critical thinking and problem-solving competencies revealed in the study reflect a similar structural issue. Many participants admitted during FGDs that the format of teaching practice assessments prioritizes procedural compliance over creativity. The focus on meeting lesson-plan rubrics, as required in microteaching, may inadvertently discourage risk-taking or open-ended inquiry. Research emphasize, TPACK-based learning models such as flipped classroom and PBL are effective in promoting critical and creative thinking, yet these models require flexibility in assessment and institutional support (Mustadi, Fakhrudin, et al., 2024). The absence of such flexibility in current PPG structures may explain why pre-service teachers still hesitate to apply these approaches extensively.

Furthermore, technological pedagogical knowledge (TPK) among participants appears to function at a foundational level. Teachers are adept at using projectors or videos, which supports visualization of abstract concepts (Fajardo-Garcia, 2025), but they rarely employ interactive tools that foster two-way engagement. Research found, the major challenge in primary education is moving from passive use of technology to designing interactive, student-centered digital learning (Rokayah & Rahayu, 2024). This study observed similar constraints: while pre-service teachers recognize the benefits of technology, limited access to devices, connectivity, and digital resources restricts them from experimenting beyond basic applications. Some research likewise highlight that effective TPACK practice requires institutions to provide consistent exposure to collaborative, technologically rich environments an area still developing in Indonesian teacher education (Mora et al., 2020), (Maričić & Lavicza, 2024).

The FGDs further revealed that technological limitations are often compounded by institutional and cultural barriers. Partner schools for teaching practice vary in terms of digital readiness, with some lacking sufficient infrastructure to support interactive technologies or AI-assisted tools. As a result, teachers adapt to low-tech contexts by using videos or printed materials rather than online simulations or gamified learning. This aligns with research, who argues that teacher education should combine reflective and technology-integrated pedagogy so that teachers can adapt to varying levels of digital infrastructure without losing instructional innovation (Tobondo, 2025).

Another factor influencing the uneven mastery of TPACK components is the lack of systematic reflection in the learning cycle. Although reflection is encouraged, many participants admitted conducting it informally, often without structured feedback. This gap weakens their ability to identify instructional weaknesses or technology misalignment. Research emphasized that structured reflective practice enables teachers to transform descriptive awareness into analytical insights, leading to sustained improvement in instructional design (Rokayah & Rahayu, 2024),(Zwozdiak-Myers, 2023), (Agnihotri, 2024). Without such reflection, pre-service teachers tend to replicate existing models rather than evolving their teaching strategies based on evidence.

The cultural orientation of Indonesian teacher education also contributes to these disparities. Historically, instructional training emphasizes compliance with curricular standards and demonstration of teaching procedures (Gage et al., 2018), (Yu, 2023), (SAPIYEVA et al., 2024). Consequently, pre-service teachers often equate "good teaching" with accurate delivery rather than adaptive facilitation. This procedural mindset contrasts with the demands of the *Merdeka Belajar* Curriculum, which values innovation, critical inquiry, and flexibility (Zainudin et al., 2025), (Hunaepi & Suharta, 2024),(Hadi et al., 2023). Thus, while pre-service teachers exhibit strong discipline and professionalism, they still need greater autonomy and reflective depth to fully embody the principles of independent learning (Tolosa, 2021), (R. Yuan & Mak, 2018).

The integration of TPACK in observed lessons also demonstrates a linear rather than dynamic relationship among technology, pedagogy, and content. Technology tends to serve as a supportive tool rather than an integrated learning scaffold. Research suggested, true TPACK integration occurs when these domains intersect fluidly technology transforms pedagogy, content shapes technology use, and pedagogy drives content adaptation.

In this study, however, the three domains often operate separately, which limits innovation (Baran & Uygun, 2016). This underscores the need for guided reflection and continuous professional development so that future teachers can build synergy among these components.

The implications extend beyond individual competency. So, report says that teacher digital literacy and reflective competence are global indicators of readiness for sustainable, inclusive education. Strengthening these competencies requires not only workshops but also institutional reform, ensuring that digital pedagogy is embedded in pre-service curricula (Betancourt-Odio et al., 2021). For instance, integrating AI-assisted lesson planning and authentic assessment approaches can help bridge the gap between technological familiarity and pedagogical innovation (Susanti, 2025), (Cholifah et al., 2024).

In summary, the observed imbalance high pedagogical and technological readiness but low content and critical thinking mastery does not simply reflect individual weakness. Instead, it reveals systemic challenges in teacher preparation: time-limited content deepening, rigid assessment structures, uneven technological infrastructure, and insufficient reflective guidance. Addressing these issues requires a holistic reform of teacher education that includes (1) sustained digital pedagogy training, (2) interdisciplinary content integration, (3) structured reflective supervision, and (4) equitable technological access during practicum placements. Research demonstrate, microteaching integrated with collaborative reflection and feedback can significantly enhance pre-service teachers' TPACK mastery, preparing them to meet the demands of the *Merdeka Belajar* era and the evolving digital learning landscape (Lorenzana & Roleda, 2024), (Z. Yuan et al., 2025), (Tembrevilla et al., 2024).

CONCLUSION

The results of this study indicate that the TPACK abilities of Pre-service education students in the PGSD Study Program are at a moderate to high level, particularly in pedagogical competence, collaboration, and digital literacy. However, the integration of content knowledge, critical thinking, and innovative technology use remains limited. These findings highlight the urgent need to strengthen both the depth of disciplinary mastery and the transformative use of technology in teacher education programs.

From an analytical perspective, the imbalance between pedagogical proficiency and content or critical-thinking competence is not merely an individual gap but a reflection of systemic issues within the structure of pre-service teacher education in Indonesia. Time constraints, assessment rigidity, and unequal technological infrastructure contribute to this disparity. Consequently, teacher preparation programs must adopt comprehensive reforms that integrate digital, reflective, and interdisciplinary pedagogies more intentionally into their curriculum design.

Policy and Practice Implications

Embedding Reflective Micro-Teaching Cycles

Teacher education institutions should integrate reflective micro-teaching sessions into every PPG practicum cycle. These sessions must go beyond performance assessment to include structured feedback, peer observation, and guided self-reflection facilitated by mentors. Research shows that continuous reflective cycles enhance teachers' pedagogical adaptability and critical awareness, allowing them to connect theory with classroom realities more effectively (Rokayah & Rahayu, 2024).

AI-Assisted Lesson Planning and Digital Pedagogy Training

To align with the technological demands of the *Merdeka Belajar* era, universities should implement AI-supported lesson design workshops that train pre-service teachers to use educational AI tools for differentiated instruction, assessment, and media creation. Research emphasizes, artificial intelligence can serve as a catalyst for creative and analytical thinking if used as a pedagogical partner rather than a substitute (Susanti, 2025). Additionally, integrating a "Digital Pedagogy and Design Thinking" course into the PPG curriculum will prepare future teachers to design interactive, inclusive, and technology-enhanced learning environments.

Strengthening Interdisciplinary Content Integration

Teacher education curricula should promote cross-disciplinary projects that connect core subjects with STEAM and socio-emotional learning frameworks. This approach aligns with the findings of some research, who demonstrated that interdisciplinary integration enhances both creativity and holistic understanding (Zhao & Abdullah, 2025), (Mussey, 2022). Embedding such projects in PPG coursework can improve content mastery while simultaneously developing 21st-century competencies.

Institutional and Infrastructure Support

Universities and government agencies must collaborate to ensure equitable access to technological infrastructure across partner schools. Providing stable internet connectivity, digital classrooms, and access to open educational resources (OER) will allow pre-service teachers to experiment with technology meaningfully. As research highlight, equitable digital competence among teachers depends on systemic support rather than individual initiative alone (Betancourt-Odio et al., 2021).

Reform of Evaluation and Mentorship Systems

The current evaluation model in micro-teaching often rewards procedural accuracy rather than innovation. Therefore, assessment rubrics should be redesigned to emphasize creativity, reflection, and critical problem-solving as key indicators of professional growth. Moreover, the mentorship system must evolve from supervision-based to coaching-oriented guidance, fostering a collaborative culture where feedback becomes developmental rather than judgmental.

 Closing Remarks

In summary, the mastery of TPACK and 21st-century skills among pre-service teachers is both a pedagogical and institutional challenge. Universities organizing PPG programs should not only train students to use technology but also cultivate reflective, critical, and innovative educators who are responsive to the demands of digital transformation. Strengthening teacher preparation through reflective micro-teaching, AI-supported pedagogy, interdisciplinary learning, and equitable infrastructure will ensure that Indonesia's future elementary teachers are not only competent in teaching but also visionary in shaping the learning ecosystems of the 21st century.

ACKNOWLEDGMENT

REFERENCES

1. Agnihotri, Dr. S. (2024). The Role of Reflective Practice in Enhancing Teacher Efficacy. Educational Administration: Theory and Practice, 1689–1696. https://doi.org/10.53555/kuey.v30i6.5574
2. Al-Rahmi, W. M., Al-Adwan, A. S., Al-Maatouk, Q., Othman, M. S., Alsaud, A. R., Almogren, A. S., & Al-Rahmi, A. M. (2023). Integrating Communication and Task–Technology Fit Theories: The Adoption of Digital Media in Learning. Sustainability, 15(10), 8144. https://doi.org/10.3390/su15108144
3. Arifuddin, A., Khoiriyah, S., Sugianto, H., & Karim, A. R. (2025). Integrating technological pedagogical content knowledge in Learning: A systematic review. Journal of Research in Instructional, 5(1), 16–39. https://doi.org/10.30862/jri.v5i1.429
4. Asipi, L. S., Rosalina, U., & Nopiyadi, D. (2022). The Analysis of Reading Habits Using Miles and Huberman Interactive Model to Empower Students' Literacy at IPB Cirebon. International Journal of Education and Humanities, 2(3), 117–125. https://doi.org/10.58557/ijeh.v2i3.98
5. Baran, E., & Uygun, E. (2016). Putting technological, pedagogical, and content knowledge (TPACK) in action: An integrated TPACK-design-based learning (DBL) approach. Australasian Journal of Educational Technology. https://doi.org/10.14742/ajet.2551

6. Berlian, Z. (2022). Analysis of the Need for Increasing Professional Competence of Elementary School Teachers. AL-ISHLAH: Jurnal Pendidikan, 14(3), 4177–4186. https://doi.org/10.35445/alishlah.v14i3.2619

7. Betancourt-Odio, M. A., Sartor-Harada, A., Ulloa-Guerra, O., & Azevedo-Gomes, J. (2021). Self-Perceptions on Digital Competences for M-Learning and Education Sustainability: A Study with Teachers from Different Countries. Sustainability, 13(1), 343. https://doi.org/10.3390/su13010343

8. Campbell, R., Goodman-Williams, R., Feeney, H., & Fehler-Cabral, G. (2020). Assessing Triangulation Across Methodologies, Methods, and Stakeholder Groups: The Joys, Woes, and Politics of Interpreting Convergent and Divergent Data. American Journal of Evaluation, 41(1), 125–144. https://doi.org/10.1177/1098214018804195

9. Cholifah, N., Atmoko, A., Bustamam, M., & Kusumaningrum, S. R. (2024). Authentic Assessment Techniques in IPAS Learning in Elementary School : A Case Study. Jurnal Paedagogy, 11(2), 431. https://doi.org/10.33394/jp.v11i2.11198

10. Erislan, E. (2023). Application of Big Data Analytics for Decision Making in Digital Marketing. Return : Study of Management, Economic and Bussines, 3(1), 22–27. https://doi.org/10.57096/return.v3i1.205

11. Fajardo-Garcia, L. M. (2025). Estrategias de enseñanza basadas en el contexto sociocultural en la asignatura de educación para la ciudadanía. Revista Científica Zambos, 4(1), 61–73. https://doi.org/10.69484/rcz/v4/n1/76

12. Fatma Yulita, Deslina Fitri, & Muhamad Yahya. (2025). Strategies to Strengthen Teacher Professionalism Through Competency Development. Al Bahri: Journal of Islamic Education, 2(1), 37–45. https://doi.org/10.69880/albahri.v2i1.263

13. Feifei, C., & Abdullah, R. (2023). A 30-year Perspective of Bibliometric Analysis on Teacher Cognition: Toward Teacher Development. International Journal of Instruction, 16(4), 209–230. https://doi.org/10.29333/iji.2023.16413a

14. Gage, N. A., Scott, T., Hirn, R., & MacSuga-Gage, A. S. (2018). The Relationship Between Teachers' Implementation of Classroom Management Practices and Student Behavior in Elementary School. Behavioral Disorders, 43(2), 302–315. https://doi.org/10.1177/0198742917714809

15. Hadi, A., Marniati, M., Ngindana, R., Kurdi, M. S., Kurdi, M. S., & Fauziah, F. (2023). New Paradigm of Merdeka Belajar Curriculum in Schools. AL-ISHLAH: Jurnal Pendidikan, 15(2), 1497–1510. https://doi.org/10.35445/alishlah.v15i2.3126

16. Hastie, P. A. (2022). A Primer on Content Knowledge in Physical Education Research. Journal of Teaching in Physical Education, 41(1), 165–170. https://doi.org/10.1123/jtpe.2020-0221

17. Humaera, I., Salija, K., Amin, F. H., Nasrullah, N., M. Jufrianto, M. J., & Reskyani, R. (2024). Investigating TPACK Development among Pre-service Teachers in Micro Teaching in Indonesia. The Eastasouth Journal of Learning and Educations, 2(03), 200–208. https://doi.org/10.58812/esle.v2i03.328

18. Hunaepi, H., & Suharta, I. G. P. (2024). Transforming Education in Indonesia: The Impact and Challenges of the Merdeka Belajar Curriculum. Path of Science, 10(6), 5026–5039. https://doi.org/10.22178/pos.105-31

19. Husnul Haq, & Wakidi. (2024). Evaluation of the Implementation of the Merdeka Belajar Curriculum in Secondary Schools in the Digital Era. International Journal of Post Axial: Futuristic Teaching and Learning, 215–228. https://doi.org/10.59944/postaxial.v2i4.391

20. Kern, F. G. (2018). The Trials and Tribulations of Applied Triangulation: Weighing Different Data Sources. Journal of Mixed Methods Research, 12(2), 166–181. https://doi.org/10.1177/1558689816651032

21. Lorenzana, A. A., & Roleda, L. S. (2024). Enhancing TPACK skills through CFR-based microteaching:Pre-service teachers' learning experiences. Proceedings of the 2024 15th International Conference on E-Education, E-Business, E-Management and E-Learning, 24–29. https://doi.org/10.1145/3670013.3670045

22. Ma, Q., Lee, H. T. H., Gao, X. (Andy), & Chai, C. (2024). Learning by design: Enhancing online collaboration in developing pre-service TESOL teachers' TPACK for teaching with corpus technology. British Journal of Educational Technology, 55(6), 2639–2667. https://doi.org/10.1111/bjet.13458

23. Maričić, M., & Lavicza, Z. (2024). Enhancing student engagement through emerging technology integration in STEAM learning environments. Education and Information Technologies, 29(17), 23361–

23389. https://doi.org/10.1007/s10639-024-12710-2

24. Mora, H., Signes-Pont, M. T., Fuster-Guilló, A., & Pertegal-Felices, M. L. (2020). A collaborative working model for enhancing the learning process of science & engineering students. Computers in Human Behavior, 103, 140–150. https://doi.org/10.1016/j.chb.2019.09.008

25. Mussey, S. (2022). Social-Emotional Learning Through STEAM Projects, Grades 4–5. Routledge. https://doi.org/10.4324/9781003247449

26. Mustadi, A., Fakhrudin, A., & Azizi, M. (2024). PROMOTING STUDENTS' CRITICAL THINKING AND CREATIVITY THROUGH TPACK BASED FLIPPED CLASSROOM LEARNING MODEL. EduStream: Jurnal Pendidikan Dasar, 8(1), 71–82. https://doi.org/10.26740/eds.v8n1.p71-82

27. Mustadi, A., Wibowo, S. E., & Prehadini, T. (2024). Analysis of the Need for Interactive Multimedia Development for Second Language Learning in Primary Schools. Journal of Ecohumanism, 3(7). https://doi.org/10.62754/joe.v3i7.4580

28. Mustaghfiroh, S. (2020). Konsep "Merdeka Belajar" Perspektif Aliran Progresivisme John Dewey. Jurnal Studi Guru Dan Pembelajaran, 3(1), 141–147. https://doi.org/10.30605/jsgp.3.1.2020.248

29. Noble, H., & Heale, R. (2019). Triangulation in research, with examples. Evidence Based Nursing, 22(3), 67–68. https://doi.org/10.1136/ebnurs-2019-103145

30. Prayoga, G., Muhamad Habib, Jauharotul Mufieda, Fathurohim, & Pipit Muliyah. (2025). Analysis of the Application and Impact of Artificial Intelligence in Elementary School Learning: A Literature Review. PROCEEDING AL GHAZALI International Conference, 2, 106–113. https://doi.org/10.52802/aicp.v1i1.1221

31. Prytyka, O. I. (2023). The concept of interactive learning technologies. HUMANITARIAN STUDIOS: PEDAGOGICS, PSYCHOLOGY, PHILOSOPHY, 14(3), 76–80. https://doi.org/10.31548/hspedagog14(3).2023.76-80

32. Rahayu, A. H., Widodo, A., Saud, U. S., & Muslim, M. (2024). Improving Technological Pedagogical Content Knowledge (TPACK) of Elementary School Teachers through Training with a Collaborative, Practical and Reflective Approach. Mimbar Sekolah Dasar, 11(4), 642–658. https://doi.org/10.53400/mimbar-sd.v11i4.78644

33. Rokayah, R., & Rahayu, A. H. (2024). A Survey of Elementary School Teachers' Self-Reflection Skills: Uncovering the Role of Reflection in Improving Learning Quality. Mimbar Sekolah Dasar, 11(4), 677–687. https://doi.org/10.53400/mimbar-sd.v11i4.78699

34. Santika, D., Amini Saragih, A., & Nur Hanifah, M. (2023). Benefits of Information Technology in Education. Integrasi: Jurnal Studi Islam Dan Humaniora, 1(1), 27–36. https://doi.org/10.56114/ijiee.v1i1.526

35. Santos, K. da S., Ribeiro, M. C., Queiroga, D. E. U. de, Silva, I. A. P. da, & Ferreira, S. M. S. (2020). O uso de triangulação múltipla como estratégia de validação em um estudo qualitativo. Ciência & Saúde Coletiva, 25(2), 655–664. https://doi.org/10.1590/1413-81232020252.12302018

36. SAPIYEVA, M. S., RAIMBEKOVA, ZH. A., & NABATNIKOVA, T. I. (2024). PROFESSIONAL STANDARDS AND EDUCATIONAL PROGRAMS: ANALYSIS OF PEDAGOGICAL CORRESPONDENCE. PEDAGOGY AND PSYCHOLOGY, 61(4). https://doi.org/10.51889/2960-1649.2024.61.4.013

37. Shiddiq, A. A. N. K., Sutama, I. W., & Astuti, W. (2024). Advancing 21st-Century Skills in Early Childhood Through the Project-Based Learning Model: Evidence from Children Aged 5–6 Years. Jurnal Pendidikan Anak Usia Dini Undiksha, 12(2), 263–271. https://doi.org/10.23887/paud.v12i2.75057

38. Suryaningsih, S., Agung, S., Barke, H.-D., & Nisa, F. A. (2024). BUILDING 21st-CENTURY SKILLS WITH STEAM-PjBL. EDUSAINS, 16(2), 128–139. https://doi.org/10.15408/es.v16i2.41779

39. Susanti, A. D. D. (2025). Developing 21st-Century Skills in Elementary School Students Through Artificial Intelligence. Pedagogik Journal of Islamic Elementary School, 66–77. https://doi.org/10.24256/pijies.v8i1.6362

40. Tembrevilla, G., Toma, M. J., & Milner-Bolotin, M. (2024). Enhancing STEM Education: Integrating Collaborative Technologies in Micro-Teaching for Pre-service Teachers. 2024 ASEE Annual Conference & Exposition Proceedings. https://doi.org/10.18260/1-2--47315

41. Thi Nho, H., & Thi Thiep, T. (2024). INTEGRATING SOCIAL AND EMOTIONAL LEARNING THROUGH STEAM ACTIVITIES IN INCLUSIVE EARLY CHILDHOOD CURRICULUM. Journal

of Science Educational Science, 309–321. https://doi.org/10.18173/2354-1075.2024-0106

42. Tobondo, Y. A. (2025). Reflective and Technology-Integrated Pedagogy for Mathematics Teacher Education. Journal of Education Method and Learning Strategy, 3(02), 250–262. https://doi.org/10.59653/jemls.v3i02.1587

43. Tolosa, C. (2021). Structured Reflection to Support Pre-Service Language Teachers' Autonomy Development (pp. 161–179). https://doi.org/10.1007/978-3-030-74958-3_8

44. Utari, V. T., Maryani, I., Hasanah, E., Suyatno, S., Mardati, A., Bastian, N., Karimi, A., & Reotutor, M. A. C. (2025). Exploring the Intersection of TPACK and Professional Competence: A Study on Differentiated Instruction Development within Indonesia's Merdeka Curriculum. Indonesian Journal on Learning and Advanced Education (IJOLAE), 136–153. https://doi.org/10.23917/ijolae.v7i1.23450

45. Vivek, R., Nanthagopan, Y., & Piriyatharshan, S. (2023). Beyond Methods: Theoretical Underpinnings of Triangulation in Qualitative and Multi-Method Studies". SEEU Review, 18(2), 105–122. https://doi.org/10.2478/seeur-2023-0088

46. Yu, D. (2023). The Construction and Implementation of Classroom Teaching Based on the Curriculum Standards of Teacher Education. Curriculum and Teaching Methodology, 6(20). https://doi.org/10.23977/curtm.2023.062016

47. Yuan, R., & Mak, P. (2018). Reflective learning and identity construction in practice, discourse and activity: Experiences of pre-service language teachers in Hong Kong. Teaching and Teacher Education, 74, 205–214. https://doi.org/10.1016/j.tate.2018.05.009

48. Yuan, Z., Zhong, X., Huang, W., Li, Z., Tang, X., & Tan, Q. (2025). GenAI-enabled microteaching lesson study: developing prospective secondary mathematics teachers' TPACK in an online summer camp. International Journal for Lesson & Learning Studies, 14(3), 298–317. https://doi.org/10.1108/IJLLS-11-2024-0273

49. Zainudin, A., Hepni, H., Nawangsari, D., & Ubaidillah, U. (2025). Analysis of the Independent Curriculum (Independent Learning, Independent Transformation, and Independent Sharing). FALASIFA : Jurnal Studi Keislaman, 16(01), 29–36. https://doi.org/10.62097/falasifa.v16i01.2054

50. Zhao, S., & Abdullah, A. H. (2025). Integrated STEAM and Problem-Based Learning: A Teaching Framework to Enhance Undergraduates' Creative Thinking. International Journal of Academic Research in Progressive Education and Development, 14(1). https://doi.org/10.6007/IJARPED/v14-i1/24490

51. Zwozdiak-Myers, P. N. (2023). The Teacher's Reflective Practice Handbook. Routledge. https://doi.org/10.4324/9781003307143