



ANALYSIS OF PRE-SERVICE TEACHERS' ICT COMPETENCIES IN INDONESIA AND JAPAN

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ABSTRACT

The development of Information and Communication Technology (ICT) has an impact on education 5.0, improving educators' competence in using technology to support learning. The purpose of this study is to analyze the ICT competence of pre-service teachers in Indonesia and Japan. The research method used in this study is a survey to obtain information about the ICT competence of pre-service teachers in Indonesia. The research sample comprised 317 teacher study program students from two universities. The research instrument was a 30-item questionnaire administered via Google Forms to assess pre-service teachers' ICT competence. The results showed differences in the ICT competencies of pre-service teachers in Indonesia and Japan. Indonesian and Japanese pre-service teachers differ in their abilities in aspects such as understanding, technical skills, and teacher professional development. The average results of pre-service teachers' ICT competence in Indonesia and Japan, by aspect, show differences. All averages for aspects of ICT competence are 3-5, indicating good or very good criteria. Based on the study's results, it can be concluded that the ICT competence of pre-service teachers in Indonesia and Japan falls into the good category.

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Keywords: ICT competency; Indonesia; Japan; Pre-service teachers; Science education

INTRODUCTION

The rapid development of Information and Communication Technology (ICT) has made digital competence an essential skill for pre-service teachers in the era of Education 5.0. Future teachers are required not only to integrate ICT into their teaching practices but also to use it to design innovative pedagogical strategies, foster collaboration, and build students' critical and creative thinking skills (Mastur & Zainuddin, 2023). In the world of education, UNESCO and major government agencies worldwide have established ICT competency standards as guidelines for te-

acher development, particularly in integrating technology into teaching and learning. The Asia-Pacific Ministerial Forum also emphasizes that ICT plays a crucial role in supporting teachers' professional development from pre-service to in-service. The presence of ICT has transformed learning processes globally by strengthening the demand for technology integration (Bharti et al., 2024).

ICT has become inseparable from daily life, including in educational contexts. Teachers are therefore required to master a wide range of competencies, including pedagogical, technological, and digital content development skills. Prior research has confirmed that ICT competencies

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contribute significantly to teachers' ability to create effective learning environments (Rubach & Lazarides, 2021), design engaging instruction aligned with students' needs (Taguines & Mahmoud, 2025), improve motivation (Sergeeva et al., 2024), and foster critical thinking (Lestari et al., 2025), problem-solving (Vilppola et al., 2022), creativity (Mastur & Zainuddin, 2023), collaboration, and communication skills (Mutohhari et al., 2021) with the increasing variety of learning technologies from digital simulations to multimedia-based platforms, ICT serves as a foundation for designing, implementing, and evaluating 21st-century learning.

ICT has been widely implemented in many countries, including Indonesia. Its integration in Indonesia is significantly influenced by curriculum reforms emphasizing character education, independent learning, and the use of digital resources. In Education 5.0, ICT literacy is increasingly seen as a strategic competency (Haleem et al., 2022; Gowda, 2023; Hamedani et al., 2024). As a result, pre-service teachers in vocational universities are expected to master ICT at a more advanced level beyond technical operation, encompassing pedagogical integration and digital content development. Studies from various countries highlight discrepancies in pre-service teachers' ICT competencies. Le Thai et al. (2022) show that although pre-service teachers in Vietnam frequently use computers and digital platforms, their skills are still limited to basic and technical functions. Hong Kong pre-service teachers demonstrate higher competency levels, though they remain focused on pedagogical aspects and the integration of applications (Taufiq et al., 2021). In Indonesia, Rahim et al. (2023) and Chen et al. (2025) highlight competencies related to information literacy, communication, collaboration, and the use of educational applications. However, the indicators used in these studies remain fragmented and do not fully examine the broader spectrum of teacher professionalism and ICT-related learning management.

These findings show that ICT competencies among pre-service teachers remain inconsistent and have not been assessed using comprehensive and standardized indicators. A more holistic framework is needed, one that integrates understanding of ICT's role in education, pedagogical readiness, digital resource creation, classroom management, and continuous professional development (Mahdum et al., 2019; Rahim et al., 2023; Rubach & Lazarides, 2021).

ICT implementation also varies significantly across countries, particularly between

Indonesia and Japan (Baharuldin et al., 2019; Nuncio, 2020). Japan is globally recognized for its technological leadership, including in education. The launch of the Society 5.0 initiative in 2019 demonstrates Japan's commitment to creating a technologically integrated society supported by smart learning ecosystems (Zulfa et al., 2023). Under the e-Japan Strategy and ICT4E programs initiated by MEXT and MIC, Japan has systematically embedded ICT in curriculum development, pedagogy, teacher training, school infrastructure, and administrative systems (Herselman et al., 2020; Nuncio, 2020; Hamedani et al., 2024). Although both countries have relatively high literacy rates, it remains unclear whether the gap in information, media, and ICT literacy between Japan and Indonesia is as wide as expected (Amri et al., 2024).

Japan's approach is characterized by consistent investment in digital infrastructure, structured ICT training for pre-service teachers, and strong policy alignment across ministries. Consequently, pre-service teachers in Japan are generally more accustomed to integrating ICT into lesson design and classroom activities. Conversely, ICT adoption in Indonesia is more dependent on curriculum shifts and local policy variations, resulting in unequal access to ICT training and infrastructure. These differences provide a compelling rationale for comparing the ICT competence of pre-service teachers in both countries. Such a comparison not only reveals structural differences but also provides insights into how contextual factors influence ICT mastery among future educators in the era of Education 5.0.

Therefore, this study aims to investigate and compare the ICT competencies of pre-service teachers in Indonesia and Japan using comprehensive indicators consisting of: (1) understanding the role of ICT in education; (2) study programs and assessment; (3) pedagogical practices; (4) ICT-based techniques and software; (5) organization and management of the educational process; and (6) teacher professional development. This research is important because ICT competence is a fundamental requirement for future educators to prepare for Education 5.0. Findings from this study are expected to contribute to a better understanding of ICT competency development in different educational contexts and provide actionable recommendations for curriculum designers and teacher education institutions.

Although many studies have examined ICT competencies among pre-service teachers in single-country settings, research comparing ICT competence across countries, especially between

Indonesia and Japan, remains limited. Previous studies have focused on partial indicators, mainly technical skills, information literacy, or basic pedagogical integration, without examining the broader dimensions of professional development, digital content creation, and learning process management. In addition, none of the existing studies explicitly compares how systemic differences in policy support, curriculum design, teacher training structures, and technological infrastructure shape ICT competencies in contrasting national contexts. This lack of comprehensive, cross-country evidence creates a significant research gap. Therefore, this study fills the gap by providing a holistic comparison of ICT competencies between Indonesia and Japan based on multidimensional indicators, offering a deeper understanding of how contextual and structural factors influence pre-service teachers' readiness to face Education 5.0.

METHODS

This study used a survey design to assess pre-service teachers' digital skills. The use of a survey design in this study was chosen because it aligned with the research objectives, which focused on quantitatively and comparatively mapping the ICT competencies of pre-service teachers across two countries. Surveys allow data to be collected from a relatively large number of respondents in a short period of time, enabling results to describe the general trends in the ICT compe-

tencies of pre-service teachers in Indonesia and Japan. The participants completed the questionnaire online. The questionnaire instrument was translated into Japanese through a forward translation process by the researcher, with assistance from a Japanese language expert lecturer, and tested for readability and comprehension with a small group of students before being distributed widely. Reliability tests using Cronbach's Alpha were conducted on both language versions (Indonesian and Japanese) to ensure the instrument's internal consistency. This study used a survey design to assess pre-service teachers' digital skills. To collect data, researchers sent questionnaires via social media to universities in Indonesia and Japan, allowing students to respond. Researchers designed the questionnaire using Google Forms and sent the link to lecturers. In the first section, researchers asked participants about their willingness to participate in the study. The distribution of questionnaires in Indonesia was conducted by lecturers teaching courses in the teacher education program at Universitas Negeri Semarang, while in Japan, it was conducted by lecturers supervising teacher education students at Miyazaki University. The distribution procedure in both countries was the same: the Google Form questionnaire link was distributed through lecturers to reach the appropriate target students. In this study, 317 students completed the questionnaire. The research flowchart is presented in Figure 1.

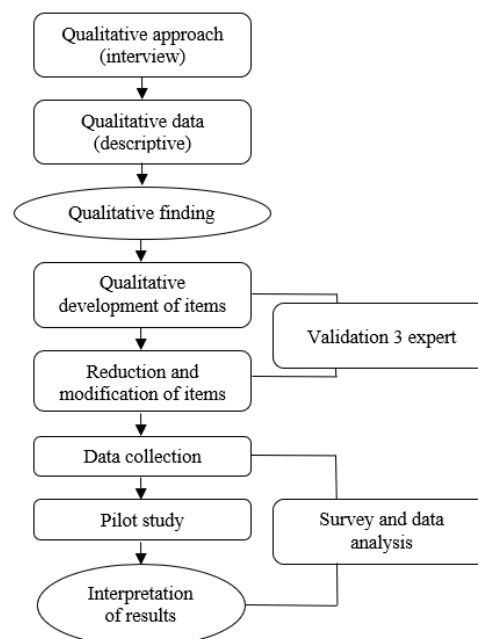


Figure 1. Research Flowchart

Participants in this study consisted of 240 women and 77 men. Among them, 72% were fourth-semester students, 18% were fifth-semester students, and 10% were fourth-semester students at the university. The research participants consisted of pre-service teachers enrolled in teacher education programs at Universitas Negeri Semarang, Indonesia, and Miyazaki University, Japan. Before completing the online questionnaire, each respondent was asked to sign a consent form outlining the purpose of the study, data confidentiality, and their right to withdraw from participation at any time. Thus, the research procedure was not only ethical but also ensured that the data collected could be compared equally between countries.

This study used a questionnaire to collect data, developed based on the ICT competency framework for pre-service teachers. The instrument development drew on several previous studies, which were modified to suit the needs of pre-service teachers. ICT competence in this study was measured by considering several indicators, including: 1) understanding of the role of ICT in education; 2) study program and assessment; 3) Pedagogical practices; 4) Technical and software ICT means; 5) Organization and management of the educational process; 6) Professional development of teachers. The questionnaire contained 30 items, with each indicator represented by 5 items.

Before the research was conducted, the instrument's validity was tested. The validity test aims to ensure that the questionnaire used is valid by experts in the field of education. After ensuring that the questionnaire instrument was appropriate, the researcher decided to use it in this study.

The research data were collected by distributing online questionnaires to pre-service teacher students at Universitas Negeri Semarang, Indonesia. Respondents completed the questionnaire independently via a Google Form. The questionnaire results were then analyzed by sco-

ring each item's responses on a 5-point Likert scale: 5 = strongly agree; 4 = agree; 3 = neutral; 2 = disagree; and 1 = strongly disagree.

Data collection for this study was conducted simultaneously from August to December 2024 at two research locations, namely Universitas Negeri Semarang (Indonesia) and Miyazaki University (Japan). Data collection was carried out within the same time frame to minimize bias arising from differences in temporal context across countries. To maintain data integrity, each respondent was asked to access the questionnaire via a special link shared only by the lecturer in charge of the course with the target students. The Google Form system was used with the setting set to one response per institutional email account, thereby preventing duplicate entries from the same respondent. In addition, the researchers manually checked the raw data to identify potential duplications or incomplete responses, and only data that met the criteria of completeness and consistency were analyzed further. To reduce research bias, researchers matched samples by selecting pre-service science and mathematics teachers who were in their fifth or sixth semester in both countries. Participants were selected only from science and mathematics education programs and had completed at least basic ICT courses.

Data analysis consisted of validity assessments by experts and analyses of pre-service teachers' responses to the ICT competence questionnaire. Furthermore, data analysis was conducted on the results of the ICT competence questionnaire for pre-service teachers in Indonesia and Japan. The research data were analyzed using SPSS to find the mean value and Standard Deviation (SD) on pre-service teachers' ICT competence in learning. The instrument uses a 5-point Likert-type scale: Strongly Agree (SA), Agree (A), Neutral (N), Disagree (DA), and Strongly Disagree (SD). The questionnaire used in this study is presented in Table 1.

Table 1. Aspects of ICT Competence for Pre-Service Teachers in Implementing Learning

No	Indicators	Aspects	Item
1	Understanding of the role of ICT in education (adapted from Mahdum et al. (2019))	Aspect 1	The use of ICT can make the learning process more effective.
		Aspect 2	The use of ICT can increase students' motivation.
		Aspect 3	The use of ICT can foster positive attitudes of students towards learning.
		Aspect 4	The use of ICT can help students better understand how technology affects their lives.
		Aspect 5	The use of ICT can improve my teaching performance.

2	Study program and assessment (adapted from Rubach & Lazarides (2021))	Aspect 6	I can reflect on the opportunities and risks of my own media use.
		Aspect 7	I can analyze the benefits of business activities and services in digital environments.
		Aspect 8	I can analyze the risks of business activities and services in the digital space.
		Aspect 9	The use of ICT provides convenience in assessing the students' progress.
		Aspect 10	I can evaluate and improve the quality of digital learning materials.
3	Pedagogical practices (adapted from Mahdum et al. (2019) and Rubach & Lazarides (2021))	Aspect 11	The use of ICT in learning activities is straightforward and not troublesome.
		Aspect 12	The use of ICT provides convenience in meeting learning resource needs.
		Aspect 13	I can design my digital products in various formats.
		Aspect 14	The use of ICTs provides convenience in storing teachers' and students' documents.
		Aspect 15	I can use technology to create engaging and effective presentations.
4	Technical and software ICT means (adapted from Rahim et al. (2023) and Rubach & Lazarides (2021))	Aspect 16	I can use familiar apps and programs as needed.
		Aspect 17	I can edit and merge digital content in different formats.
		Aspect 18	I can present digital content in different formats.
		Aspect 19	I can create charming and useful digital content (<i>e.g.</i> , blogs, websites, podcasts) for students.
		Aspect 20	I can create interesting media assets (<i>e.g.</i> , images, graphics, or short videos) to convey information effectively.
5	Organization and management of the educational process (adapted from Mahdum et al. (2019))	Aspect 21	The use of ICT can help students work more actively and in a problem-based way.
		Aspect 22	The use of ICT can inspire and enable students to express themselves.
		Aspect 23	I enjoy creating new digital learning materials and feel inspired to do so.
		Aspect 24	I am confident in creating captivating digital content that captures students' attention.
		Aspect 25	The use of ICT in various formats helps manage the learning process.
6	Professional development of teachers (adapted from Rubach & Lazarides (2021))	Aspect 26	I can search various websites to find teaching resources.
		Aspect 27	I can identify and use appropriate sources in digital environments based on my information needs.
		Aspect 28	I can select and use the appropriate digital tools and applications to create learning materials.
		Aspect 29	I am skilled at integrating visual and audio elements in the creation of digital learning materials.
		Aspect 30	I can create new digital teaching materials so that students enjoy the learning process, skills, and have a deep understanding.

RESULTS AND DISCUSSION

This study analyses the ICT competence of pre-service teachers in Indonesia and Japan in the implementation of technology in learning. The results are divided into two parts: the development of the ICT competence questionnaire instrument and the analysis of questionnaire responses from pre-service teachers in Indonesia

and Japan. Initially, the ICT competence questionnaire was validated by education experts. After validation, the valid questionnaire was implemented in the research. The questionnaire results were analyzed using SPSS to determine the mean and Standard Deviation (SD) for the ICT component of pre-service teachers' implementation of learning, as shown in Table 2.

Table 2. Distributional Statistics for Domains of ICT Competency

	Indicator 1	Indicator 2	Indicator 3	Indicator 4	Indicator 5	Indicator 6
N	317	317	317	317	317	317
Valid missing	0	0	0	0	0	0
Mean	23.11	20.74	21.30	19.90	22.95	22.95
Std. Deviation	.802	.700	.875	.723	.758	.793
Variance	12.263	10.150	11.571	8.577	11.765	11.948
Minimum	20	15	23	11	19	19
Maximum	28	25	30	25	26	27
Sum	8.852	7.249	9.431	7.515	8.382	8.637

Table 2 presents the distribution statistics for the ICT competency domain in pre-service teachers' learning. The questionnaires filled out by participants were then analyzed per statement item. The results of the analysis per item aspect show the mean, standard deviation, and p-value for each ICT competency indicator. This shows the level of ICT competency of pre-service teachers. Based on Table 2, the indicator with the highest average is Indicator 1 (23.11), which reflects understanding of the role of ICT in education, while the lowest average is in Indicator 4 (19.90), which concerns technical and software skills. This shows that pre-service teachers in both countries already have a high awareness of the importance of ICT in learning, but still face challenges in technical application, particularly in the use of applications, software, and digital content production. In addition, Indicators 5 and 6 (both with an average of 22.95), which relate to learning process management and teacher professional development, also show strong achievements, indicating that ICT integration is understood as an important part of the teacher's role.

The data show acceptable variance and standard deviation, indicating that the distribution across indicators is relatively normal and free of extreme deviations. Indicators with higher variance (indicators 3, 5, and 6) suggest greater heterogeneity in respon-

dents' skills, especially in areas requiring operational and application-based ICT tasks. Meanwhile, indicators with lower variance exhibit more uniform abilities among participants. The correlations between indicators, although not shown in the table, indicate moderate positive relationships, suggesting that competencies such as understanding ICT, managing digital learning processes, and applying ICT tools tend to reinforce one another. This pattern suggests that ICT competence among pre-service teachers is multidimensional but interconnected.

These findings are consistent with the results of the Indonesia-Japan comparison, where significant differences mainly appear in technical skills (such as editing, producing, and combining digital content) and ICT-based evaluation skills. Thus, the notable trend is that the main gap is not in attitude or awareness, but in more specific operational skills. This condition underscores the need for strategies to enhance pre-service teachers' technical competence through intensive training and hands-on practice, so that awareness of the importance of ICT can be balanced with concrete skills for supporting learning in the era of Education 5.0. A p-value ≤ 0.05 indicates the presence of differentiating factors in pre-service teachers' ICT competence between Indonesia and Japan, as shown in Table 3.

Table 3. Mean and Standard Deviation of Pre-service Teachers' ICT Competence in Indonesia and Japan

No	ICT Competency Item	Indonesia		Japan		p	Mean difference
		Mean	SD	Mean	SD		
1	Aspect 1	4.018	.736	4.352	.781	.000*	.334
2	Aspect 2	4.291	.759	4.228	.598	.376	.063
3	Aspect 3	3.982	.749	4.000	.949	.590	.018
4	Aspect 4	4.471	.765	4.592	.661	.029	.121
5	Aspect 5	4.382	.726	4.528	.866	.169	.146
6	Aspect 6	3.786	.733	3.892	.902	.083	.106
7	Aspect 7	3.381	.719	3.963	.889	.001*	.582
8	Aspect 8	3.196	.701	3.497	.813	.151	.301
9	Aspect 9	3.522	.733	3.887	.983	.002*	.365
10	Aspect 10	3.234	.768	3.924	.974	.000*	.690
11	Aspect 11	4.681	.799	4.692	.907	.321	.011
12	Aspect 12	4.653	.701	4.768	.949	.071	.115
13	Aspect 13	4.561	.715	4.604	.852	.151	.043
14	Aspect 14	4.702	.736	4.818	.929	.138	.108
15	Aspect 15	4.026	.746	4.000	.905	.028	.026
16	Aspect 16	4.121	.718	4.479	.901	.007*	.358
17	Aspect 17	4.040	.820	4.339	.917	.001*	.299
18	Aspect 18	3.941	.747	4.187	.935	.311	.246
19	Aspect 19	3.473	.767	3.820	.887	.000*	.347
20	Aspect 20	3.501	.737	3.894	.949	.000*	.393
21	Aspect 21	4.126	.770	4.349	.900	.057	.223
22	Aspect 22	4.554	.743	4.497	.900	.191	.057
23	Aspect 23	4.114	.732	4.287	.935	.216	.173
24	Aspect 24	4.655	.749	4.797	.935	.000*	.132
25	Aspect 25	4.790	.764	4.683	.917	.527	.107
26	Aspect 26	4.585	.749	4.613	.917	.111	.028
27	Aspect 27	4.518	.765	4.627	.900	.384	.109
28	Aspect 28	3.472	.735	3.810	.858	.000*	.338
29	Aspect 29	3.966	.764	4.105	.900	.664	.139
30	Aspect 30	3.543	.742	3.857	.868	.004*	.314

Note: * $p \leq 0.05$

Table 3 shows differences in the ICT competencies of pre-service teachers in Indonesia and Japan. Indonesian and Japanese pre-service teachers differ in their abilities in aspects 1, 7, 9, 10, 16, 17, 19, 20, 24, 28, and 30, with a significance level ($p \leq 0.05$).

Table 3 presents the comparative analysis between Indonesia and Japan. Rather than repeating the numerical values, the results highlight that several competencies differ significantly ($p \leq 0.05$), particularly in technical skills such as di-

gital content editing and integrating multimodal resources, ICT-based assessment, and learning material development. The results show that most significant differences fall within the small-to-medium range, indicating meaningful but not substantial discrepancies. This suggests that although both countries share a similar foundational understanding of ICT, Japan shows marginally higher proficiency in technical operational skills, while Indonesia shows strengths in ICT awareness and pedagogical use.

These findings fulfill the research objective by identifying which aspects of ICT competence differ across the two countries and explaining how the distribution and inter-indicator relationships shape pre-service teachers' readiness for ICT integration. The results underscore the need for targeted capacity-building, especially in technical ICT competencies, so that strong conceptual awareness can be matched with practical digital skills that support innovative science teaching in the era of Education 5.0.

Teachers' ICT competence affects their success in teaching (Muallimin et al., 2023). The average results of pre-service teachers' ICT competence in Indonesia and Japan, by aspect, show differences. All averages for aspects of ICT competence are 3-5, indicating good or very good criteria. Based on Table 3, the study program, assessment, and ICT technical and software indicators obtained significant scores. This will have an impact on teachers' high general ICT competence, increased expertise in improving science education, and success in optimizing student learning outcomes in the high category. Teachers' understanding of the role of ICT in education is key to preparing the next generation to become effective and productive citizens. Compared to Amri et al. (2024), this research introduces a cross-national comparison between Indonesia and Japan, focusing on pre-service teachers, a topic that has not been widely explored in the last five years. The novelty lies in identifying specific ICT competence aspects that significantly differ between the two countries, thereby providing evidence-based recommendations for targeted competency improvement. This contrasts with earlier studies that predominantly assessed ICT competence within a single country or failed to specify critical areas for improvement.

According to a survey, most pre-service teachers agree that the use of ICT can make the learning process more effective. Various types of ICT can be applied to improve the quality and effectiveness of classroom learning (Soriano-Sánchez, 2025). Pre-service teachers also understand that the utilization of ICT can increase motivation and foster students' positive attitude towards learning. This shows that pre-service teachers understand that the use of ICT makes learning more engaging, enabling students to pay attention and participate optimally. In addition, pre-service teachers understand that ICT can help students better understand how technology affects their lives. In learning, teachers can simultaneously develop students' digital literacy by teaching them to recognize, access, and evaluate

information from various digital sources (Muallimin et al., 2023). This helps them filter correct and relevant information while improving their critical thinking skills. Not only that, but students are also invited to understand the ethics of using technology, such as maintaining privacy and data security, so they can use ICT responsibly and be aware of the consequences of their digital actions (Ika et al., 2024).

Another indicator analyzed in this research is the study program and assessment. The ICT competence indicator relates to the teacher's ability to reflect on the opportunities and risks of using media in science learning (Althubayani, 2024). ICT offers teachers great opportunities to access extensive information sources, develop innovative learning methods, and improve interactions with students (Msambwa et al., 2024). Teachers can optimize this potential, create a more dynamic learning environment, and be responsive to needs. On the other hand, the use of digital media also poses risks, such as the spread of misinformation and potential distractions during the learning process. This requires teachers to critically assess the content or platforms used and implement strategies to minimize the negative impact. Based on the questionnaire survey, pre-service teachers can also assess student progress. Digital applications or platforms make it easy for teachers to obtain assessment data directly from test results, quizzes, and learning activities (Pangestu & Fahrudin, 2024). This helps to quickly identify student progress or obstacles and identify areas that need improvement. In addition, the use of ICT in evaluating and improving the quality of digital learning materials supports teachers in continuing to innovate, producing materials that are effective, interesting, and responsive to student needs.

The next indicator measured is pedagogical practices. In this indicator, several statement items assess pre-service teachers' ICT competence in the pedagogical aspect during the learning process, including demonstrating that pre-service teachers can use ICT to support learning easily and without hassle (Toma et al., 2023).

Teachers can integrate ICT in a way that is easily accessible to students independently, with simple procedures, to offer more flexible learning activities. According to Abdulrahman et al. (2020), teachers can design digital products in various formats to meet students' learning resource needs and distribute them digitally, both in the form of visuals (posters, photos, infographics, interactive PPT, and augmented reality), audio (music or recordings), and multimedia (animated

videos, virtual simulations, virtual reality, and various other media). In addition, pre-service teachers find it easy to organize and store documents in learning and manage schedules to share them with students (Adipat et al., 2021).

The indicator of technical and software ICT means was also analyzed in the study. This indicator concerns pre-service teachers' ability to use applications and programs that meet their needs. The more applications and programs that pre-service teachers master, the more diverse the types of digital technology used in learning (Wekerle & Kollar, 2022). This also affects pre-service teachers' ability to edit, combine, and present digital content in the form of websites, blogs, podcasts, and other formats. ICT technical and software skills enhance teachers' ability to create engaging media assets, such as images, graphics, and short videos, to convey knowledge more effectively during instruction (Widiyatmoko et al., 2023). Pre-service teachers with strong abilities in this indicator will be able to meet their needs in fulfilling their role as educators in the classroom. However, based on the questionnaire, this item received lower scores than other items.

From a science education perspective, the results align with the TPACK and SAMR frameworks. Pre-service teachers with a strong study program and assessment competence are likely to have more developed TPK (Technological Pedagogical Knowledge), enabling them to design assessments that capture students' thinking in scientific contexts using digital tools. Meanwhile, lower scores in ICT technical and software skills, especially among Indonesian pre-service teachers, signal limited TK (Technological Knowledge), which constrains their ability to move technology use from substitution toward higher-level transformation stages (modification–redefinition) in the SAMR model. This affects how effectively they can implement digital science learning policies such as virtual labs, interactive simulations, and real-time data analysis platforms, which are increasingly promoted under national digital learning reforms.

The cross-national differences can be explained by systemic and pedagogical factors rather than normative assumptions. Japan's stronger performance in the assessment and software-related indicators reflects its integration of digital tools in teacher preparation, structured practicum access to technology-rich environments, and the national School Initiative, which guarantees one student one device infrastructure. These policies create consistent exposure to digital tools that support scientific inquiry and assessment. In

contrast, variation in ICT infrastructure across Indonesian institutions, uneven access to updated devices, and teacher education curricula that emphasize theoretical knowledge over digital production skills are likely to contribute to lower technical and software competence. This highlights the importance of redesigning teacher training modules to emphasize hands-on creation of scientific digital media.

Regarding the ICT technical and software skills indicator, the significantly lower results in Indonesia may reflect limited opportunities to practice complex media production or software-based scientific visualizations. Science education today demands competence in generating simulations, handling digital laboratory tools, editing scientific media, and using interactive platforms. The survey data also indicate that pre-service teachers in both countries understand the pedagogical value of ICT, particularly in enhancing motivation, supporting scientific thinking, and promoting digital literacy. Their positive perception aligns with the science education literature, which positions ICT as central to fostering scientific inquiry and higher-order thinking. This gap between perception and performance underscores the need for more targeted competency-based training in teacher education programs.

Efforts are needed to improve pre-service teachers' competence in ICT, technical, and software indicators. According to Velázquez et al. (2020), training activities are one of the steps in developing teachers' competence in using applications and programs that support learning. The training can be organized by the government or by parties engaged in developing pre-service teachers' capacity at the regional and national levels. ICT competence is one part that cannot be separated from the implementation of learning. This study also analyzed the organization and management of the educational process indicators possessed by pre-service teachers. Almost all participants in the study reported using ICT to encourage students to learn actively, help students express themselves, and support the implementation of problem-based learning. The survey results align with Yani & Widiyatmoko (2023): ICT use makes students participate in learning more actively and interactively. Pre-service teachers also indicated that they feel inspired to create new digital learning materials and are confident in creating engaging digital content to avoid boring learning for students. In this study, pre-service teachers realized that the use of ICT in various formats, such as text, images, audio, video, and animation, can help manage the learning process

more effectively and efficiently. ICT enables teachers to organize and manage learning materials through a digital platform or a Learning Management System (LMS) (Alia, 2022; Widiyatmoko et al., 2022). This facilitates the distribution of materials, assignment management, and real-time monitoring of student learning progress (Lengyel, 2020). The use of ICT even makes it easier for teachers and students to communicate directly through platforms such as discussion forums, videoconferencing, or instant messaging. Pre-service teachers realize that the presence of ICT helps organize the learning process and evaluate student learning outcomes.

The final ICT competency indicator in this study is teachers' professional development. This indicator is closely related to the ability to search for teaching resources across various websites to meet the needs of pre-service teachers (Bowman et al., 2022). Teachers must have professional abilities in conducting learning, including the ability to use digital technology to find, evaluate, and integrate relevant, up-to-date teaching materials from the internet to enrich the learning process with a broader perspective and pedagogical innovation (Smeins et al., 2022). In addition, this indicator concerns pre-service teachers' selection and use of appropriate digital tools and applications to create learning materials. The professional level of pre-service teachers in using appropriate digital tools or applications to create learning materials by integrating visual and audio elements refers to their ability to effectively utilize digital technology to produce learning materials that are interesting, interactive, and easy to understand (Indriyani et al., 2023). According to Meutia and Ramadani (2024), this professionalism includes the selection and mastery of appropriate software or applications to combine visual elements such as images, graphics, and videos, with audio elements such as narration or music, so that the materials produced not only convey information clearly, but also create a holistic learning experience, adaptive to student needs, improve student skills and understanding in depth.

To reduce potential sample bias, the researchers matched participants by selecting pre-service science teachers who were in their fifth or sixth semester in both countries. Only students from science education programs who had completed at least one basic ICT course were included to ensure comparable academic backgrounds. Based on research, the ICT competence of pre-service teachers in Indonesia and Japan is at a good level. The ICT competencies of pre-service teachers, as outlined in the good criteria, include

the ability to effectively integrate various digital tools and applications to design and deliver innovative and engaging learning materials (Hennessy et al., 2022; Marais, 2023). Pre-service teachers who possess this competency can use the various technologies available today to create interactive, adaptive, and contextually relevant learning experiences tailored to students' needs (Akyuz, 2023). By mastering technology, pre-service teachers can optimize classroom management, provide real-time feedback, and support a more objective and accurate evaluation process. Thus, strong ICT competence not only improves the quality of learning but also contributes to achieving quality education responsive to the digital era (Demirtaş & Mumcu, 2021).

The differences in ICT competency identified between pre-service teachers in Indonesia and Japan may be influenced by several contextual factors, such as learning cultures, education systems, and ICT infrastructure readiness. Japan has an educational tradition that emphasizes order, consistency, and early integration of technology, so that pre-service teachers are accustomed to using ICT not only as a tool, but also as part of a structured pedagogical strategy. In contrast, in Indonesia, despite the increasing use of ICT, infrastructure limitations in some regions and variations in the quality of teacher training have led to slower development of technical competencies, particularly software skills. Low scores on technical skill indicators may be due to limited access to the latest devices and applications, as well as teacher training curricula that do not fully emphasize the development of digital creativity. To overcome this, concrete strategies are needed, including intensive training programs focused on digital content production, cross-country collaboration in developing ICT-based modules, and integrating digital literacy as a core competency into the teacher education curriculum. These efforts align with the objectives of Education 5.0, which emphasize mastery of smart technology, digital literacy, and the use of ICT to create more personalized, collaborative, and innovative learning.

In summary, the key novelty of this study lies in the detailed cross-national identification of ICT competence gaps and strengths at the indicator level, something not commonly addressed in prior research. The implications are clear: targeted competency-building strategies should be tailored to address specific weaknesses, such as ICT technical & software skills in Indonesia and pedagogical application breadth in Japan, while reinforcing existing strengths. This research

contributes to strengthening ICT technical skills in Indonesia, and increasing the breadth of pedagogical integration in Japan can improve the quality of digital science learning. Furthermore, the results provide actionable insights for curriculum developers to redesign teacher education programs to more explicitly integrate TPACK competencies, particularly in digital science assessment and content creation. Third, the results of this study can guide policymakers in refining digital learning initiatives by ensuring equitable access to the tools, training, and software essential for transforming science education to align with the demands of Education 5.0.

CONCLUSION

The findings of this study highlight that differences in ICT competence between Indonesian and Japanese pre-service teachers are shaped not only by access to technology but also by how each country conceptualizes the role of digital tools in science education. These differences emphasize that ICT competence is more than a technical skill; it is a core pedagogical capacity that determines how future science teachers design inquiry-based activities, facilitate data-rich investigations, and support students' scientific reasoning in digital environments. Thus, the central theoretical insight from this study is that ICT competence should be understood as an integrated pedagogical construct, closely aligned with TPACK and digital science literacy, rather than a standalone technical attribute. This study also underscores the need to strengthen teacher candidates' capacity to use ICT for scientific modeling, simulation-based experimentation, and formative assessment, as an essential element for developing 21st-century scientific competencies. The results reinforce the argument that ICT mastery is foundational for transforming science learning from procedural content delivery into authentic learning.

This research has implications for science education, calling for the integration of ICT into scientific inquiry frameworks to ensure that digital tools support experimentation, modeling, argumentation, and data interpretation. For teacher training institutions, structured ICT practicum modules should be integrated into real classroom settings, enabling pre-service teachers to practice producing digital science content. This research also has implications for policymakers, who should revise the curriculum to include competency-based digital literacy aligned with TPACK for science teaching.

Several limitations should be acknowledged. Although sample matching was conducted, the study involved participants from only one institution per country, limiting the generalizability of cross-national patterns. Cultural and institutional variations in ICT infrastructure, availability of practicum technology, and curriculum exposure may also influence results. Future studies should use multi-institutional sampling, triangulate self-reports with performance-based assessments, and incorporate experimental or longitudinal designs to examine how ICT competence develops over time.

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