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Self-Assessment on Digital Pedagogy of Indonesian Gen Z Student-Teachers

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Abstract: *The rapid advancement of digital technology requires pre-service teachers to possess strong digital pedagogical skills to design and implement effective learning in the digital era. This study aimed to analyze the digital pedagogy skills of Generation Z pre-service chemistry teachers and examine differences based on gender and the number of software applications used. A survey method was employed involving 158 pre-service chemistry teachers from seven State Islamic Universities in Indonesia. Data were collected using a five-point Likert-scale questionnaire covering three dimensions: pedagogical orientation, pedagogical practices, and digital pedagogical competencies. The data were analyzed descriptively and using an independent samples t-test and one-way ANOVA. The findings showed that the respondents' digital pedagogy skills were generally in the good category, with pedagogical orientation obtaining the highest mean score, followed by pedagogical practices and digital pedagogical competencies. No significant differences were found based on gender or the number of software applications used. These results indicate that although Generation Z pre-service chemistry teachers are familiar with digital technology, their ability to integrate technology pedagogically still requires further strengthening through relevant training and practical learning experiences.*

Keywords: *digital pedagogy; gen z teachers; pre-service chemistry teachers.*

INTRODUCTION

The rapid advancement of digital technology has fundamentally transformed educational practices, making technology integration a primary need in modern education. Therefore, pre-service teachers need to develop skills in integrating technology into classroom learning activities, which is a key part of digital pedagogy. As highlighted in several studies within the Indonesian context, there is a significant demand for the development of digital-based chemistry learning media to meet these modern educational standards (Silaban & Panggabean, 2022). Digital pedagogy is not merely integrating technology into teaching and learning, as the conditions and goals of technology integration in digital pedagogy are to enrich or enhance learning effectiveness (Kivunja, 2013; Sailin & Mahmor, 2018). Therefore, pre-service teachers need technological and pedagogical skills, as well as the ability to integrate the two (Rawat et al., 2024). This necessity is crucial because the readiness of chemistry pre-service teachers is heavily dependent on their ICT competencies, which must be deeply integrated into the chemical substance itself (Dharma et al., 2020). Väätäjä & Ruokamo (2021) divide digital pedagogy into three dimensions: pedagogical orientation, which refers to teachers' perceptions of the learning process; pedagogical practices, which are a set of teaching strategies and methods used in the classroom (Khader & Jordan, 2012) and digital pedagogical competencies, which are the skills, attitudes, and knowledge needed by teachers to support student learning in today's digital world (Jorgen, 2017).

All pre-service teachers, including chemistry teachers, need strong digital pedagogy skills. Moreover, currently, pre-service chemistry teachers are dominated by Gen Z. In various literature, this generation is also often referred to as digital natives, post-millennials, net gen, gen tech, and iGen. One of the main characteristics of Gen Z is their high technological proficiency. Gen Z, as digital natives, is more intuitive with digital technology and already skilled because they were born as technological advancements were developing (Andrea et al., 2016). They are confident, quick to adapt, and can use technology for knowledge exploration, news tracking, and building limitless relationships. With that, the field of education is experiencing a new dynamic in this era. Their capacity to connect with material digitally and adapt to new technologies is changing the direction of education. Neolaka's (2024) research finding indicate that, when considering technology mastery, Gen Z teachers demonstrate high confidence. Therefore, these digital skills need to be empowered and leveraged to engage students in more active learning.

The presence of technology has had a significant impact on the field of chemical education (Cetin-Dindar et al., 2018). The role of technology in the classroom and chemistry laboratory continues to evolve. Various technologies that have already been developed, such as AR and VR as visual aids, interactive game applications, and digital learning software, have been proven to increase students' interest in chemistry (Ali et al., 2023). The integration of virtual laboratories in education has also yielded numerous benefits in chemistry teaching and learning. The effective implementation of virtual laboratories can significantly enhance students' motivation and learning experiences (Santos & Prudente, 2022). This not only stimulates their engagement but also optimizes their preparation for actual laboratory activities. Not only in practice, but technology can also be involved in learning resources. In today's digital world, electronic modules, commonly known as e-modules, are necessary learning resources because they can be accessed anywhere and anytime via tablets, laptops, computers, and mobile phones (Qoridatullah et al., 2021). The use of interactive multimedia-based e-modules in chemistry has been shown to provide learning flexibility while simultaneously improving conceptual understanding (Alhashem & Alfailakawi, 2023; Siregar & Harahap, 2020). Using e-modules in the learning process can also help students improve their critical thinking skills, maximize student engagement in the learning process, and create an interesting and creative environment (Budiarti et al., 2016; Erviyenni et al., 2023). Therefore, the use of technology in chemistry learning can lead to better learning outcomes if teachers use the technology extensively (Jammeh Abdou et al., 2022).

How teachers view and utilize technology directly impacts the effectiveness of learning (D' Souza etal., 2021). Currently, pre-service chemistry teachers are required to possess a new set of skills and perspectives related to the application of digital pedagogy. Pre-service teachers must be prepared not only to use technology and manage student learning activities but also to consider how technology can affect students' academic achievement, learning motivation, attitudes, personality, and even influence the teachers' own work (Røkenes & Krumsvik, 2016). Pre-service teachers should prepare themselves because teachers in this era must be able to keep learning fresh and relevant. One way to do this is by using various innovative devices to avoid falling behind.

Despite the abundance of research on digital tools, a significant research gap remains. Current literature has largely focused on general teacher skills (Loureiro et al., 2024; Rahayuningsih & Muhtar, 2022; Xin et al., 2024) or the effectiveness of specific chemistry media (Erviyenni et al., 2023). There is a critical lack of evidence regarding how Gen Z pre-service chemistry teachers perceive their own competence in the complex intersection of chemistry specific pedagogy and digital tools. However, high confidence in using technology does not always translate into effective digital pedagogical practices. Moreover, while gender and software variety have been hinted at as influential factors in digital and chemical literacy (Scherer et al., 2021), they have not been rigorously analyzed within a self-assessment framework for this specific cohort. Understanding these self-perceived competencies is essential for informing curriculum development and targeted training programs to move Gen Z from "tech-savvy individuals" to "digitally competent educators".

Therefore, this research aims to analyze the self-assessed digital pedagogy skills of Indonesian Gen Z pre-service chemistry teachers across three dimensions: pedagogical orientation, practices, and digital competencies. Specifically, this study seeks to determine whether significant differences exist in these competencies based on gender and the diversity of digital software utilized during their teacher training. By identifying these profiles, this study provides an operational baseline for improving digital pedagogy integration in chemistry teacher education programs.

METHODS

This research uses a survey method involving pre-service chemistry teacher students at seven Islamic Universities, namely UIN Sunan Kalijaga Yogyakarta, UIN Walisongo Semarang, UIN Syarif Hidayatullah Jakarta, UIN Sultan Syarif Kasim Riau, UIN Sunan Gunung Djati Bandung, UIN Ar-Raniry Aceh, and UIN Mahmud Yunus Batusangkar. A total of 158 respondents were selected using a simple random sampling technique from the participating institutions.

Before agreeing to participate in this study, potential respondents were given an information sheet about the study and a consent form to become respondents. After that, the pre-service respondents were given a closed questionnaire consisting of 30 statements: five statements about pedagogical orientation, ten statements about pedagogical practices, and fifteen statements related to digital pedagogical competencies (see Table 1). The respondents assessed their own digital pedagogy abilities. The questionnaire uses a Likert scale with responses ranging from very low, low, moderate, good, to very good (scores 1-5). The instrument was adapted from a previously developed questionnaire used in prior research. To verify the internal consistency for this specific sample, a reliability test was conducted, yielding a Cronbach's Alpha coefficient of 0.967, indicating excellent internal consistency.

Table 1. Aspects and statements of the questionnaire

Aspects and Statements
Pedagogical Orientation
1. My ability to design learning objectives based on Graduate Competency Standards, Core Competencies, Basic Competencies, and Competency Achievement Indicators
2. My ability to design learning objectives that take into account the various skills of students, including if there are students with disabilities
3. My ability to attract students' attention so that they want to learn and are actively involved in learning
4. My ability to create a friendly classroom environment, arrive early in class and greet them by name, and provide time after learning

Aspects and Statements
to allow students to ask questions either about or outside the material
5. My ability to provide opportunities for students to express (both orally and in writing) their condition, especially if they experience learning difficulties
Pedagogical Practices
1. My ability to choose the most suitable learning approach to teach a particular concept
2. My ability to choose the most suitable learning model to teach specific concepts
3. My ability to use varied learning strategies according to the learning objectives and material studied by students
4. My ability to adjust learning strategies based on student performance/feedback
5. My ability to use a student-centred approach and organize the class so that each student has various roles, for example, as moderator, facilitator, presenter, responder, assessor, recorder, note taker, and so on
6. My ability to provide opportunities for students to express the meaning of learning for everyday life
7. My ability to apply various online learning methods
8. My ability to meet the overall demands of online learning
9. My ability to select appropriate software for certain subjects according to student needs
10. My ability to develop assignments and project for students, provide them with broader and more profound knowledge, develop critical thinking, and instil creativity among students
Digital Pedagogical Competencies
1. My ability to create online learning (both synchronous/asynchronous) that allows students to build new knowledge and skills
2. My ability to search for helpful information from the Internet for developing lesson plans.
3. My ability to develop lesson plans that include students' use of technology in the learning process.
4. My ability to solve technical problems related to hardware (for example, internet connection, speakers, laptop, laptop camera)
5. My ability to troubleshoot various software-related computer problems (e.g., downloading appropriate plug-ins/applications, installing programs, creating breakout rooms on Zoom)
6. My ability to help students solve technical problems with their personal computers, laptops, tablets, cell phones or electronic devices
7. My ability to reduce interactivity between students in online learning. For example, when students chat alone, ignore the lesson, turn off the camera/video
8. My ability to encourage interactivity (e.g., active questions and answers, active discussions in chatrooms, active comments) between students in online learning
9. My ability to utilize various chat applications (e.g. WhatsApp, Instagram, Facebook, Twitter, and the like) to improve communication with students
10. My ability to manage classes using a Learning Management System (LMS), for example, Google Classroom, Schoology, Canva by Instructure, RuangKelas, Edmodo, Moodle, etc.
11. My ability to modify assessments using an online format (for example, using Google Forms, Quizzes, Kahoot, etc.)
12. My ability to produce printed documents such as student assignments, bulletins, communications, etc. using various software applications
13. My ability to manage student data and data management tools to manage learning efficiently
14. My ability to use technology to collect, organize and report information about student performance (for example, Excel)
15. My ability to develop tools for evaluating technology-based student projects (for example, word, spreadsheet, PowerPoint)

The questionnaire data was analyzed descriptively and quantitatively to examine the digital pedagogical abilities of pre-service chemistry teachers. The results of the descriptive analysis of the questionnaire responses were converted to a measurement scale as shown in Table 2.

Table 2. Interpretation of Average

Interval	Criteria
1.00-1.80	Very Poor
1.81-2.60	Poor
2.61-4.40	Fair
3.41-4.20	Good
4.21-5.00	Very Good

Before conducting inferential tests, statistical assumptions including normality and homogeneity of variance were verified. For the normality test, the results indicated that the data distribution deviated from normality ($p < 0.05$). However, following the Central Limit Theorem, parametric tests (Independent Samples t-test and One-way

ANOVA) remained appropriate due to the sample size (n=158) being sufficiently large (n > 30) to provide robust results. The homogeneity test, conducted via Levene's test, confirmed that the data variances were homogeneous (p > 0.05). Consequently, an Independent Samples t-test was employed to examine gender differences, while a One-way ANOVA was used to analyze differences based on the variety of software used.

RESULT AND DISCUSSION

Respondent profile

The respondents in this study consisted of 158 pre-service chemistry teachers from seven State Islamic Universities in Indonesia. The demographic profile of the respondents, including university, gender, GPA, and number of software used, is presented in Table 3.

Table 3. Respondent demographics

University	Frequency (N)	Percentage (%)
UIN Sunan Kalijaga Yogyakarta	26	16.45%
UIN Walisongo	35	22.15%
UIN Syarif Hidayatullah	10	6.33%
UIN Sultan Syarif Kasim	34	21.52%
UIN Sunan Gunung Djati	26	16.45%
UIN Ar-Raniry	13	8.23%
UIN Mahmud Yunus	14	8.87%
Total	158	100%
Gender		
Male	24	15.19%
Female	134	84.81%
Total	158	100%
GPA		
3,51 – 4,00	108	68.35%
3,01 – 3,50	47	29.75%
2,51 – 3,00	3	1.90%
2,01 – 2,50	0	-
Total	158	100%
Software used		
>6 software	44	27.85%
4-6 software	60	37.97%
<4 software	54	34.18%
Total	158	100%

Table 3 shows that most respondents were female and had a GPA between 3.51 and 4.00. Regarding digital technology use, the largest group of respondents reported using 4–6 software applications.

Digital Pedagogy Skills of Pre-Service Chemistry Teachers

The descriptive analysis of digital pedagogy skills across the three dimensions is presented in Table 4.

Table 4. Descriptive Statistics of Digital Pedagogy Skills among Pre-Service Chemistry Teachers

	Min	Max	Mean	Std.Deviation	Category
Pedagogical Orientation	2.0	5.0	3.594	.6034	Good
Pedagogical Practices	2.1	4.9	3.585	.5746	Good
Digital Pedagogical Competencies	1.6	4.8	3.528	.6069	Good

Table 4 indicates that all dimensions of digital pedagogy are in the good category. Pedagogical orientation obtained the highest mean score, followed by pedagogical practices and digital pedagogical competencies. This result shows that pre-service chemistry teachers generally have good digital pedagogy skills, although digital pedagogical competencies still need to be strengthened compared to the other dimensions.

Comparison of Digital Pedagogy Skills by Gender

An independent samples t-test was conducted to examine differences in digital pedagogy skills based on gender. The results are presented in Table 5..

Table 5. Comparison of Digital Pedagogy by Gender

Dimension	Gender	N	Mean	Sig	Conclusion
Pedagogical Orientation	Male	24	3.667	.522	Ho accepted
	Female	134	3.581		
Pedagogical Practices	Male	24	3.696	.308	Ho accepted
	Female	134	3.566		
Digital Pedagogical Competencies	Male	24	3.692	.153	Ho accepted
	Female	134	3.499		

The results show that there are no significant differences in pedagogical orientation, pedagogical practices, and digital pedagogical competencies between male and female pre-service chemistry teachers. This indicates that gender does not significantly differentiate digital pedagogy skills among the respondents.

Comparison of Digital Pedagogy Skills Based on the Number of Software Used

A one-way ANOVA was conducted to examine differences in digital pedagogy skills based on the number of software used. The results are presented in Table 6.

Table 6. Comparison of Digital Pedagogy Based on the Number of Software Used

Dimension	Software Used	N	Mean	Sig	Conclusion
Pedagogical Orientation	<4 sofware	53	3.536	.644	Ho accepted
	4-6 software	61	3.643		
	>6 software	44	3.595		
Pedagogical Practices	<4 sofware	53	3.564	.941	Ho accepted
	4-6 software	61	3.602		
	>6 software	44	3.589		
Digital Pedagogical Competencies	<4 software	53	3.462	.570	Ho accepted
	4-6 software	61	3.541		
	>6 software	44	3.591		

The results indicate that there are no significant differences in the three dimensions of digital pedagogy based on the number of software used. Although respondents who used more software showed slightly higher scores in some dimensions, these differences were not statistically significant.

Discussion

Teachers play an important role in shaping the quality of education and preparing students for future challenges. Therefore, the development of pre-service teachers' competencies, including knowledge, skills, attitudes, and professional experiences, is an important foundation for preparing them to become future chemistry teachers (Singh & Gupta, 2022). In the current digital era, these competencies are not limited to general pedagogical skills, but also include the ability to integrate digital technology into teaching and learning activities meaningfully. The results of this study indicate that the digital pedagogy skills of pre-service chemistry teachers are generally in the good category across the three dimensions: pedagogical orientation, pedagogical practices, and digital pedagogical competencies. The relatively close average scores among the three dimensions show that the respondents have fairly balanced digital pedagogy skills. However, pedagogical orientation obtained the highest average score, while digital pedagogical competencies obtained the lowest score. This finding suggests that although pre-service chemistry teachers already have positive views and practices related to teaching and learning, their ability to critically and pedagogically integrate digital technology still needs further strengthening.

This condition can be linked to the characteristics of Gen Z as digital natives. Gen Z tends to be familiar with digital technology, adaptive to technological change, and exposed to various digital platforms in daily life. These characteristics support their confidence and readiness to use technology in learning contexts (Shofiyyah et al., 2024; Wajdi et al., 2024). Therefore, it is reasonable that pre-service teachers in this study showed good levels of pedagogical orientation and pedagogical practices. However, technological familiarity does not automatically lead to strong digital pedagogical competence. Pongrač et al. (2025) found that Gen Z still faces weaknesses in information navigation and processing, especially in verifying the quality and truth of information. This supports the finding of this study that digital pedagogical competencies are slightly lower than the other dimensions. In other words, being accustomed to technology does not necessarily mean being able to select, evaluate, and integrate technology into learning in a pedagogically meaningful way.

The higher score in pedagogical orientation indicates that pre-service chemistry teachers already have positive perceptions of teaching and learning.

Pedagogical orientation is related to how teachers view learning, how students should be supported, and how classroom interactions should be developed (Väätäjä & Ruokamo, 2021). A positive pedagogical orientation is important because teachers' beliefs and attitudes influence how they design instruction, interact with students, and create learning environments. Russell D'Souza et al. (2021) emphasized that teachers' orientation toward technology integration can influence students' motivation and engagement. In line with this, teachers who show positive, supportive, empathetic, and professional attitudes can encourage students to participate more actively in learning (Hikmah et al., 2024). Thus, the strong pedagogical orientation found in this study reflects an important foundation for developing more effective digital pedagogy among pre-service chemistry teachers.

In terms of pedagogical practices, the findings show that pre-service chemistry teachers are able to apply various teaching strategies and approaches in learning. Pedagogical practices are essential because effective learning requires teachers to provide students with access to knowledge, meaningful activities, and opportunities to develop their skills (Farquhar, 2003). In chemistry learning, this ability is especially important because many chemistry concepts are abstract and require appropriate strategies to help students connect concepts with real-life contexts. The use of digital learning media can support this process when it is aligned with learning models and instructional objectives, as shown in the development of a PjBL-based digital flipbook module on chemical bonding (Simbolon & Panggabean 2025). Therefore, good pedagogical practices among pre-service teachers can support the development of interactive, student-centered, and contextually relevant chemistry learning.

Although pedagogical orientation and pedagogical practices were in the good category, digital pedagogical competencies showed the lowest average score among the three dimensions. This finding highlights an important issue: pre-service teachers may be familiar with digital tools, but still need support in transforming technical ability into pedagogical competence. Digital pedagogical competence is not merely the ability to use digital applications, but also involves the ability to choose appropriate technology, design technology-based learning activities, solve digital learning problems, and evaluate the effectiveness of technology use in learning (Cabanero et al., 2022). In chemistry learning, this competence is particularly important because digital technologies can help visualize abstract concepts and support inquiry-based activities, such as inquiry-based virtual laboratories for acid–base titration (Purwanto et al., 2025) and augmented reality-based chemistry e-modules on hydrocarbon material (Fadhilah & Nasution, 2025).

This finding is also consistent with Fernández-Batanero et al. (2022), who stated that teachers have a dual role in relation to digital competence. On the one hand, teachers must develop their own technological knowledge and skills. On the other hand, they are also responsible for helping students develop digital competencies needed in society. Therefore, digital pedagogical competence requires reflective and critical thinking, not only technical fluency. Hirdinis et al. (2019) explained that the internet can be an important source for teachers to develop teaching materials, methods, and media. However, digital pedagogical competence requires more than searching for information. Teachers need to process digital resources into specific knowledge and learning experiences that are relevant to students' needs.

1. Digital Pedagogy Skills by Gender

The results of this study show that there is no significant difference in digital pedagogy skills between male and female pre-service chemistry teachers. This finding indicates that both groups have relatively similar digital pedagogy abilities across pedagogical orientation, pedagogical practices, and digital pedagogical competencies. In the context of Gen Z, this result is understandable because both male and female students generally have broad access to digital technology and similar exposure to digital learning environments. This finding also suggests that gender differences in digital pedagogy may be less prominent among current pre-service teachers. Although technology-related fields have often been associated with male dominance and lower female representation (Saputri & Prasetiyo, 2023), the results of this study show that gender does not significantly influence digital pedagogy skills in this sample. This may indicate that access to digital tools, learning platforms, and online learning experiences has become more equal among male and female pre-service teachers. This trend of digital democratization is supported by a meta-analysis from Scherer et al. (2021), which found that institutional support and learning environments are far more decisive factors in determining digital literacy than biological gender differences. However, the descriptive results show that male pre-service chemistry teachers obtained slightly higher average scores than female pre-service teachers in several dimensions. This difference was not statistically significant, but it can still be considered as a point for reflection. Hapsari et al. (2022) stated that gender may influence teachers' TPACK-related abilities, particularly through differences in self-efficacy. Similarly, Ramnarain and Schuster (2014) found that teachers' confidence can influence their pedagogical orientation. Therefore, although gender does not significantly differentiate digital pedagogy skills in this study, teacher education programs should continue to provide equal opportunities and support for all pre-service teachers to develop confidence and competence in integrating technology into learning.

2. Digital Pedagogy Skills Based on the Number of Software Used

The results also indicate that there is no significant difference in digital pedagogy skills based on the number of software programs used. This means that pre-service chemistry teachers who used fewer than four software programs, four to six software programs, or more than six software programs showed relatively similar levels of digital pedagogy skills. This finding suggests that the number of software tools used does not automatically determine the quality of digital pedagogical competence. Although the descriptive results show that pre-service teachers who used more than six software programs had slightly higher scores in digital pedagogical competencies, the difference was not statistically significant. This indicates that using more software may provide broader technological exposure, but it does not necessarily ensure better pedagogical integration. Astuti and Andrari (2021) stated that the use of software can support teachers' competence in education, while Diarini and Winangun (2022) also explained that online learning software can help improve teachers' teaching abilities. However, the findings of this study show that the pedagogical quality of technology use is more important than the number of applications used.

The development of learning technology has made various software applications more accessible for educational purposes. Rofiq (2011) stated that learning quality can be developed through internet facilities, learning software, and self-developed learning programs. Subarkah et al. (2021) also showed that training in the use of online learning platforms can support teaching and learning activities. Nevertheless, the present study emphasizes that digital pedagogy is not determined solely by the number of digital tools pre-service teachers can use. This reinforces the principle of "Pedagogical Primacy," where the quality of integration is superior to the quantity of software used. This reinforces the principle that the pedagogical quality of technology integration is more important than the quantity of software used. Moreover, in the era of AI, teachers' roles are shifting from merely searching for information to critically curating and pedagogically integrating AI-supported learning tools. In chemistry education, AI and ML can provide data-driven insights for identifying students' misconceptions and learning gaps, while responsible implementation requires teachers to critically evaluate AI-generated content using their chemistry and pedagogical knowledge (Blonder & Feldman-Maggor, 2024; Iyamuremye et al., 2024). Rather, it depends on how well they can select, adapt, and integrate those tools into chemistry learning based on learning objectives, student characteristics, and instructional needs. This is consistent with studies on chsemistry learning that show that tools such as Wordwall, Macromedia Flash, problem-based virtual laboratories, and educational game-based media are meaningful when integrated into learning activities with clear pedagogical purposes (Pangaribuan & Sutiani, 2025; Sinuhaji & Sutiani, 2025). Overall, the findings of this study indicate that Gen Z pre-service chemistry teachers already have good digital pedagogical skills, but their digital pedagogical competencies still require further development. The absence of significant differences by gender and the number of software used suggests that digital pedagogy development should not only target specific groups but also be strengthened for all pre-service teachers. Teacher education institutions need to provide systematic and sustainable training that focuses not only on technical skills, but also on reflective, analytical, and pedagogically grounded technology integration. This is important to ensure that future chemistry teachers are not only familiar with digital tools but also capable of using them to design meaningful, effective, and contextually relevant chemistry learning.

CONCLUSION

This study confirms that Indonesian Gen Z pre-service chemistry teachers have a good level of digital pedagogy across pedagogical orientation, pedagogical practices, and digital pedagogical competencies. However, the lower score in digital pedagogical competencies indicates an important gap between general technological fluency and the ability to pedagogically select, evaluate, and integrate technology into chemistry instruction. Thus, being a digital native does not automatically ensure meaningful digital pedagogical competence. The absence of significant differences based on gender and the number of software programs used shows that digital pedagogy development should become a shared priority for all pre-service chemistry teachers, regardless of demographic background or the variety of digital tools they use. These findings suggest the need for chemistry teacher education programs to shift from general ICT literacy toward subject-specific digital pedagogy. This includes strengthening pre-service teachers' ability to use digital tools to support chemical representation, diagnose misconceptions, design technology-based assessments, and create meaningful chemistry learning experiences.

For practitioners and policy makers, the findings emphasize that the quality of pedagogical integration is more important than the quantity of software mastered. Therefore, universities should integrate standardized digital pedagogical competencies into chemistry teacher education curricula. This effort is expected to prepare future chemistry teachers who are not only technologically fluent, but also capable of designing effective, reflective, and contextually relevant digital chemistry learning environments.

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