Digital Readiness of Pre-Service Chemistry Teachers for Integrating Technology in STEM Education

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Abstract: Although the integration of digital technology in STEM education is growing, empirical evidence on the extent to which pre-service chemistry teachers are digitally prepared in terms of technology, pedagogy, and infrastructure is still limited. This study examines the digital readiness of pre-service chemistry teachers to integrate technology into STEM learning across six dimensions: Technology Acceptance, Technology Competence, Technology Control, Pedagogical Readiness, Infrastructure Readiness, and Utilisation of Digital Learning Resources. An embedded mixed-methods approach was employed in this study, integrating quantitative and qualitative methods to explore pre-service chemistry teachers' digital readiness. Data were collected from 147 pre-service chemistry teachers at a single public University in Yogyakarta, Indonesia, through a validated questionnaire. Quantitative data were analyzed using descriptive statistics. Meanwhile, the qualitative data from open-ended responses were analyzed thematically. The results show that the Technology Acceptance dimension falls into the very good category, reflecting high enthusiasm for adopting digital devices. Conversely, the dimensions of Technological Competence, Technological Control, Pedagogical Readiness, Infrastructure Readiness, and Utilisation of Digital Learning Resources were in the good category, indicating that although pre-service teachers are open to technology, their technical and pedagogical capacities are not yet fully optimal. Furthermore, Augmented Reality, PhET simulations, and Virtual Reality are the most widely used technologies, with limited facilities and a lack of training as the main obstacles. These findings emphasize the importance of structured training, infrastructure improvements, and policy support to strengthen digital pedagogical readiness in STEM education.

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INTRODUCTION

The rapid development of digital technology has fundamentally changed the landscape of education worldwide. One effect of this change is that the integration of digital technology into classroom learning practices is no longer optional but has become an essential requirement for preparing students to compete in the 21st century. This transformation is particularly relevant in STEM (Science, Technology, Engineering, and Mathematics) education, which emphasizes inquiry, problem solving, and innovation (National Research Council, 2012). These aspects can be significantly enhanced through digital technology. In the context of chemistry education, several previous studies have shown that digital technologies such as virtual laboratories, simulations, augmented reality and virtual reality, and artificial intelligence-based learning devices have been proven to improve students' conceptual understanding, engagement, and motivation to learn (Srisawasdi & Panjaburee, 2019; Xie, Zhang, Chen, & Tong, 2022; Rosli & Ishak, 2024; Naaim, M. N. M., & Karpudewan, 2024; Hagos & Lemma, 2025). In the Indonesian context, recent research published also demonstrates that the integration of digital learning materials grounded in pedagogical frameworks such as TPACK can significantly enhance students' creativity and learning outcomes in chemistry education (Dewi et al., 2025). However, the successful integration of digital technology is highly dependent on teachers' readiness, especially pre-service teachers who are still developing their pedagogical and technological identities.

Teachers' readiness to integrate technology extends beyond technical competence to include attitude, confidence, and pedagogical awareness. In 2000, Parasuraman introduced the concept of Technology Readiness (TR). This concept explains how individuals accept and use technological innovations, highlighting three main components (i e., Technology Acceptance, Technology Competence, and Technology Control). These three dimensions collectively reflect how individuals view technology as both an opportunity and a challenge in a professional context. In the field of education, this construct has been widely applied to understand teachers' willingness and capacity to utilize technology in learning. However, readiness in education is not limited to individual characteristics but also encompasses contextual and institutional dimensions, as both can support or hinder technology adoption.

To address this broader perspective, the World Bank (2021) developed the Education and Technology Readiness Index (ETRI). ETRI covers three institutional and pedagogical factors (i e., Pedagogical Readiness, Infrastructure Readiness, and Use of Digital Learning Resources). These dimensions reflect the extent to which education systems, schools, and teacher education programs are positioned to support sustainable digital transformation.

In this study, digital readiness is conceptualised as a multidimensional construct encompassing not only individual attitudes and technical skills toward digital technology, but also pedagogical readiness and institutional support structures that enable the effective integration of technology into learning. Unlike digital competence or digital literacy, which primarily focus on operational skills, digital readiness reflects a broader readiness to adopt, control, and apply digital technology pedagogically in an authentic learning context.

To capture this comprehensive perspective, this study integrates two complementary frameworks. These are the Technology Readiness Index (TRI) proposed by Parasuraman (2000) and the Education and Technology Readiness Index (ETRI) developed by the World Bank (2021). TRI represents individual psychological readiness through the dimensions of Technology Acceptance, Technology Competence, and Technology Control, which describe prospective teachers' motivation, self-efficacy, and confidence in using digital devices. Meanwhile, ETRI represents readiness at the system level through Pedagogical Readiness, Infrastructure Readiness, and Utilisation of Digital Learning Resources, which highlight the institutional and pedagogical conditions that support sustainable digital transformation in education.

In the context of STEM education, digital readiness is a prerequisite for meaningful cross-disciplinary integration. Although frameworks such as Technological Pedagogical Content Knowledge (TPACK) emphasise the domain of teacher knowledge for technology-based learning, digital readiness precedes the application of TPACK by shaping teachers' willingness, confidence, and contextual opportunities to apply this knowledge in practice. A high level of technology acceptance without adequate pedagogical readiness and infrastructure support can lead to superficial technology use rather than authentic STEM learning. Therefore, in this study, digital readiness is positioned as a prerequisite for effective STEM integration, enabling prospective chemistry teachers to design learning experiences that connect science concepts, technological tools, engineering problem-solving, and mathematical reasoning in real-world contexts.

Although digital transformation in learning continues to evolve rapidly, various studies show that pre-service teachers often face challenges, particularly in their enthusiasm for digital technology and their ability to use it effectively in learning (Pozas, Letzel-Alt, & Schneider, 2022). Several studies conducted during the COVID-19 pandemic revealed that many teachers showed a high level of acceptance of technology but experienced difficulties in technical control and pedagogical application due to limited access, inadequate training, and a lack of institutional support (World Bank, 2021). In the Indonesian context, these challenges have become increasingly apparent as teacher education programs have been aligned with the Merdeka Belajar Kampus Merdeka (MBKM) policy and the national push for integrating digital literacy. Chemistry, as a discipline rich in abstract concepts and experimental processes, requires not only conceptual understanding but also visualization. These aspects can be strongly supported by digital technology when effectively integrated into a STEM-based approach.

However, research on the digital readiness of pre-service chemistry teachers, particularly in integrating digital technologies into STEM learning in Indonesia, remains limited. Although several

studies, such as Nugraheni & Srisawasdi (2022, 2025), have examined the development of teachers' TPACK (Technological Pedagogical and Content Knowledge), only a few have examined broader dimensions of readiness, including infrastructural and institutional aspects. Most studies focus on technological competence, while pedagogical readiness and infrastructure barriers, especially in developing countries, have received little attention. This gap limits our understanding of how pre-service chemistry teachers conceptualize and operationalize digital technology in STEM-oriented classrooms.

This study aims to fill this gap by systematically examining the digital readiness of pre-service chemistry teachers at one of Indonesia's leading teacher-training institutions. Adopting a mixed-method design that combines quantitative measurements of readiness and qualitative insights into perceived barriers and needs, this study aims to:

1. Examine the level of digital readiness in six dimensions (Technology Acceptance, Technology Competence, Technology Control, Pedagogical Readiness, Infrastructure Readiness, and Digital Learning Resource Utilization);
2. Identify the technologies most frequently used in STEM learning.
3. Analyze the barriers and needs that influence digital integration in learning practices.

Understanding these aspects not only provides a diagnostic picture of pre-service teachers' readiness but also serves as a basis for developing teacher education curricula, professional development programs, and institutional policies. The results of this study are expected to provide practical recommendations for strengthening the integration of digital technology into STEM education, particularly by increasing pedagogical readiness and infrastructure support at both the individual and institutional levels.

Ultimately, this research aligns with the broader educational agenda of preparing pre-service teachers who are not only technologically literate but also pedagogically adaptable. As the digital learning ecosystem continues to evolve, strengthening the digital readiness of pre-service teachers is key to ensuring equitable, sustainable, and effective STEM education in the digital age.

METHOD

Research Design

An embedded mixed-methods approach was employed in this study, integrating quantitative and qualitative methods to explore pre-service chemistry teachers' digital readiness. The quantitative approach served as the primary method for measuring digital readiness across six dimensions: Technology Acceptance, Technology Competence, Technology Control, Pedagogical Readiness, Infrastructure Readiness, and Use of Digital Learning Resources. Meanwhile, the qualitative aspect provided deeper insights into the pre-service chemistry teachers' perceived challenges and needs. This design is appropriate for this study because it allows for triangulating findings and integrating numeric and narrative data, yielding a comprehensive understanding of the phenomenon (Creswell & Clark, 2018). The study was conducted from April to July 2025 at a single public University in Yogyakarta, Indonesia. As illustrated in Figure 1, the study consisted of three main stages: (1) preparation and instrument development, including literature review and validity testing; (2) data collection through quantitative and qualitative surveys; and (3) data analysis and interpretation involving descriptive statistical analysis, thematic analysis, and data integration.

Participants

The total population consisted of 168 pre-service chemistry teachers enrolled in semesters 6–8. A total of 147 participants (approximately 88 % of the population) met the inclusion criteria and completed the survey. Participants consisted of 87% female and 13% male students, with an average age ranging from 20 to 23 years. The inclusion criteria were as follows:

1. They had completed courses related to technology integration or digital pedagogy;
2. They possessed access to personal digital devices (laptop, tablet, or smartphone);
3. They voluntarily consented to participate in the study.

Demographically, participants included both male and female students with varying levels of teaching experience, from those with no teaching experience to those who had participated in school

internships or microteaching programs. This diversity provided a representative view of digital readiness among future chemistry teachers in Indonesia.
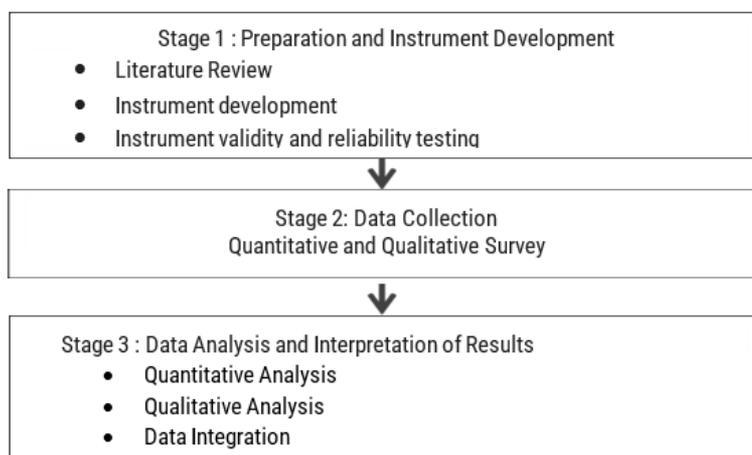
Figure 1. Research Flow Diagram

Research Instrument

Data were collected through a validated questionnaire. The questionnaire was developed through a systematic adaptation process based on two established theoretical frameworks, namely the Technology Readiness Index (TRI) (Parasuraman, 2000) and the Education and Technology Readiness Index (ETRI) (World Bank, 2021). The development process consisted of three stages: (1) construct identification, (2) item development and contextual modification, and (3) expert validation and empirical testing. First, each dimension was theoretically mapped to its original framework. Technology Acceptance, Technology Competence, and Technology Control were derived from the TRI and represent psychological readiness at the individual level. Meanwhile, Pedagogical Readiness, Infrastructure Readiness, and Utilization of Digital Learning Resources are adapted from ETRI and represent readiness at the system and pedagogical levels in the context of teacher education. Second, the original constructs are operationalized into 21 items contextualized for prospective chemistry teachers. The items were adjusted to reflect STEM-oriented learning scenarios and digital tools commonly used in chemistry education (e.g., simulations, virtual laboratories, and AR/VR platforms). Minor linguistic modifications were made to improve clarity and contextual relevance without changing the theoretical meaning of the constructs. Third, content validity was evaluated by three experts in chemistry education, integrated STEM pedagogy, and educational technology. The experts assessed the relevance, clarity, and representativeness of each item using a structured validation rubric. Based on their input, minor revisions were made to improve wording accuracy and eliminate redundancy. All items were retained after revision.

After expert validation, the instrument was empirically validated with 113 prospective chemistry teachers. Reliability testing was conducted using Cronbach's Alpha. The overall reliability coefficient was 0.87, indicating high internal consistency. The reliability coefficients for each dimension are as follows: Technology Acceptance (α = 0.83), Technology Competence (α = 0.81), Technology Control (α = 0.79), Pedagogical Readiness (α = 0.84), Infrastructure Readiness (α = 0.76), and Utilization of Digital Learning Resources (α = 0.74). All values exceed the acceptable threshold of 0.70, indicating adequate internal consistency for research purposes. The instrument comprised six aspects, corresponding to the following dimensions as summarized in the Table 1.

Each item was rated on a five-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The questionnaire also included three open-ended questions that invited participants to describe:
(a) the digital technologies they had used,
(b) the challenges they encountered, and
(c) their perceived needs for enhancing technology integration in teaching.

Table 1. Descriptions of six aspects

Aspect	Description	Number of Items
Technology Acceptance	Measuring motivation and willingness to adopt digital tools	4
Technology Competence	Assessing self-perceived ability to operate educational technologies	4
Technology Control	Capturing confidence in troubleshooting and handling digital problems	4
Pedagogical Readiness	Evaluating capability to design and implement technology-integrated stem learning	4
Infrastructure Readiness	Identifying access to devices, internet stability, and digital facilities	3
Use of Digital Learning Resources	Exploring the frequency and variety of digital platforms used in teaching	2

Data Collection Procedures

The survey was administered online using Google Forms for facilitating accessibility and ensuring efficiency in data management. Participants were briefed about the study's objectives, confidentiality assurance, and voluntary participation principles before completing the questionnaire. Prior to participation, all respondents provided informed consent. Participation was entirely voluntary, and participants had the right to withdraw at any time without consequences. No identifying information was collected, and all responses were treated anonymously to ensure confidentiality. Data collection lasted four weeks, with a response rate of approximately 88%, indicating high engagement among participants.

To enrich quantitative data, qualitative information from open-ended responses was collected concurrently. These narratives provided contextual insights into how pre-service teachers experienced digital learning environments and perceived institutional readiness.

Data Analysis

The quantitative data were analysed using descriptive statistics. Descriptive statistics, i. e., means and standard deviations were computed to categorize readiness levels according to established rubrics. To interpret the readiness level, the average score for each dimension was categorized using interval criteria derived from the ideal maximum and minimum scores. The determination of categories was based on the ideal average score (X_i) and ideal standard deviation (SB_i), with category boundaries set at intervals of $X_i \pm 0.5 SB_i$ and $X_i \pm 1.5 SB_i$. The readiness level is then classified into five categories, namely very good, good, fairly good, poor, and bad. This approach was employed to ensure consistency of interpretation across dimensions, even though the number of indicators differs. As the purpose of this study was to provide a descriptive profile of participants' readiness, no inferential statistical analysis was conducted. Meanwhile, the qualitative data from open-ended responses were analysed thematically following Braun and Clarke's (2019) approach:

1. Data familiarization;
2. Initial coding;
3. Theme identification;
4. Theme refinement; and
5. Interpretation.

Themes were triangulated with quantitative findings to generate comprehensive conclusions about the barriers and enablers of digital readiness. Two researchers independently coded the responses, and discrepancies were discussed until consensus was reached.

RESULT AND DISCUSSION

Overview of Digital Readiness

The results revealed a comprehensive picture of pre-service chemistry teachers' digital readiness. The findings across six key aspects, i.e., Technology Acceptance, Technology Competence, Technology Control, Pedagogical Readiness, Infrastructure Readiness, and Use of Digital Learning Resources, are summarized in Table 2.

Table 2. Mean Scores of Digital Readiness Aspects

Aspect	Mean Score	Category
Technology Acceptance	16.69	Very Good
Technology Competence	15.66	Good
Technology Control	14.74	Good
Pedagogical Readiness	14.64	Good
Infrastructure Readiness	11.50	Good
Use of Digital Learning Resources	7.50	Good

Table 2 shows that the highest average score was in the Technology Acceptance dimension. This reflects the high enthusiasm of pre-service chemistry teachers in adopting digital devices in STEM learning. This finding aligns with Pozas, Letzel-Alt, & Schneider (2022), who found that pre-service teachers tend to view technology positively and consider it an integral part of modern pedagogy. However, the lower average scores in the Pedagogical Readiness and Infrastructure Readiness dimensions indicate that this enthusiasm does not always correlate with effective pedagogical implementation. These findings are in line with a pattern also observed in studies by the World Bank (2021).

Technology Use Patterns

Pre-service chemistry teachers reported using various digital technologies to support STEM learning.

Table 3. Types of Digital Technologies Used

Technology	Frequency (%)	Example Tools
Augmented Reality	57	AR Chemistry App, Merge Cube
PhET Simulations	40	PhET Interactive Simulations
Virtual Reality	26	Labster, VR ChemLab
LMS Platforms	23	Google Classroom, Moodle
Video-based Learning	19	YouTube STEM Channels
AI-Assisted Learning	14	ChatGPT, Quillbot Tutor

Table 3 shows that Augmented Reality (AR) is the most widely used technology (57%), followed by PhET simulations (40%) and Virtual Reality (VR) platforms (26%). Other technologies, such as digital learning management systems (Google Classroom, Moodle), video-based learning, and artificial intelligence-based learning resources such as ChatGPT, were mentioned as additional supports. The dominance of AR and simulation use indicates that pre-service teachers prefer interactive visualizations that simplify abstract chemistry concepts. These findings align with those of Xie et al. (2022), which show that immersive technology can promote deeper conceptual understanding and increase learning motivation. However, limited adoption of artificial intelligence-based devices suggests that this relatively new technology is still not being optimally utilized in teacher education and training.

Barriers to Digital Integration

The qualitative findings identified several barriers to integrating digital technology into STEM learning. These barriers are presented in Table 4.

These findings confirm that although pre-service teachers show a positive attitude towards digital technology, actual implementation in the classroom is still limited by external factors, particularly institutional readiness. These findings align with ETRI (World Bank, 2021), which emphasizes the crucial

roles of policy and infrastructure in supporting the integration of digital technology into learning. Limited digital training is also a significant issue. Although many students have used technology independently, most have not received formal training in STEM-based digital pedagogy. This situation creates an imbalance between technical and pedagogical skills. Many pre-service teachers understand how to use technology, but do not yet understand how to use it to facilitate meaningful chemistry learning.

Table 4. Identified Barriers

Barrier	Percentage (%)	Description
Limited Facilities and Devices	72	Inadequate laboratory computers, unstable internet access
Insufficient Digital Training	43	Lack of systematic workshops on digital pedagogy
Operational Challenges	11	Technical issues in software use and installation
Time Constraints in Courses	9	Limited class time to experiment with digital tools
Low Institutional Support	7	Absence of formal policies or budget allocations

This gap confirms Bybee's (2013) view that true STEM integration must emphasise conceptual connections across disciplines, not simply the use of technology as a visual aid. Thus, the pedagogical readiness of pre-service chemistry teachers must be directed not only to mastering digital media but also to designing learning that integrates science, technology, engineering, and mathematics in real-life contexts.

Discussion and Implications

Overall, this study's results show that pre-service chemistry teachers are enthusiastic and optimistic about integrating digital technology into STEM learning. However, this is not enough. Therefore, stronger support (scaffolding) is needed to optimize digital integration. The "very good" category in the technology acceptance dimension reflects a positive mindset towards innovation, while the moderate scores in the technology competence and control dimensions indicate limited practical experience. These findings align with the phenomenon of readiness without competence identified by Pozas, Letzel-Alt, & Schneider (2022). Their findings show that emotional acceptance of technology precedes technical mastery.

Furthermore, the interaction of the six dimensions of readiness also shows an interdependent relationship. Pedagogical readiness in this case acts as a mediator between technology acceptance and practical implementation, while infrastructure readiness functions as an external moderator. Without institutional support and access to digital devices, even high motivation does not guarantee effective digital technology-based learning.

In this context, the research findings support the need to develop a digital pedagogy framework that is integrated into the teacher education curriculum. The application of structured practical experiences, in which pre-service teachers actively design and implement digital STEM learning using AR, simulations, and virtual laboratories, can strengthen competence and control of technology. In addition, establishing partnerships with educational technology (EdTech) providers can improve access to infrastructure and expand exposure to new technologies.

Finally, mixed-method evidence in this study confirms the importance of policy-driven digital transformation in teacher education. Beyond individual readiness, systemic readiness needs to be built through institutional planning, leadership, and funding support. As emphasized by ETRI (World Bank, 2021), the sustainability of digital innovation in education depends heavily on coordinated action across teacher preparation, curriculum design, and infrastructure investment.

From a teacher education perspective, these findings highlight the need to strengthen pre-service teacher preparation through structured digital pedagogy training embedded within the curriculum. Beyond fostering positive attitudes toward technology, teacher education programs should provide authentic opportunities for pre-service teachers to design, implement, and reflect on STEM-integrated digital lessons through microteaching, practicum experiences, and project-based learning. Institutional support

in the form of infrastructure development and continuous professional mentoring is also essential to ensure sustainable digital integration.

CONCLUSION

This study provides empirical evidence that pre-service chemistry teachers demonstrate strong motivational readiness for integrating digital technology into STEM education, but equivalent levels of pedagogical competence, technological control, and infrastructure support do not fully match this readiness. These findings reveal a persistent acceptance-competence gap, indicating that positive attitudes toward technology alone are insufficient to ensure effective STEM learning through technology.

From a theoretical perspective, this study contributes to prior research by integrating the Technology Readiness Index (TRI) and the Education and Technology Readiness Index (ETRI) into a single analytical framework for assessing teacher digital readiness. The results position pedagogical readiness as a crucial mediating factor between technology acceptance and classroom implementation, thereby expanding on previous research that has focused on technology competence in isolation.

In practice, these findings suggest that teacher education programs need to go beyond building positive attitudes toward technology and prioritise structured pedagogical training, authentic digital STEM learning experiences, and sustained institutional support. Curriculum designers and policymakers are encouraged to systematically integrate technology-based pedagogy into teacher education programs, with adequate infrastructure support and continuous professional development opportunities.

This study has several limitations. Data were collected from a single institution using purposive sampling techniques and self-report measures, which may limit the generalizability of the findings. Furthermore, the descriptive nature of this study does not allow for causal conclusions regarding the relationships between dimensions of readiness.

Therefore, future research is recommended to involve multiple institutions, employ longitudinal or experimental designs, and develop intervention-based studies to examine how targeted digital pedagogy programs influence the development of technological, pedagogical, and professional competencies of pre-service chemistry teachers over time.

Overall, this study confirms that developing digitally fluent pre-service chemistry teachers depends not only on individual readiness but also requires a coherent pedagogical framework and systemic institutional support. Strengthening these interrelated dimensions is key to achieving sustainable and meaningful technology integration in STEM education in the digital age.

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