Jurnal Pijar MIPA
https://jurnalfkip.unram.ac.id/index.php/JPM

ISSN 1907-1744 (Print)
ISSN 2460-1500 (Online)

Validation of Instrument to Measure Science Pre-Service Teachers Digital Skills: Confirmatory Factor Analysis

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Received: October 13, 2025. Accepted: November 11, 2025. Published: December 5, 2025

Abstract: Validating instruments that measure digital skills—such as through Confirmatory Factor Analysis (CFA)—is crucial to ensure that pre-service teachers, particularly those from Generation Z, possess accurate, reliable, and pedagogically meaningful digital competencies. Using a quantitative survey design, data were collected from 349 Generation Z pre-service teachers across four science specializations (chemistry, physics, biology, and general science). The instrument used was adapted from previous studies and translated using the back-translation method to ensure its validity. Confirmatory Factor Analysis (CFA) was employed in AMOS 24 to evaluate both first-order and second-order models to analyze the data. The six dimensions assessed—Access to and Management of Digital Content (AMDC), Use of Digital Means (UDM), Communication Skills (CS), Creative Skills (CrS), Digital Safety Skills (DSS), and Digital Empathy (DES)—demonstrated strong loadings onto the higher-order construct of Digital Skills (standardized regression weights = 0.94–0.97). Model fit indices confirmed the robustness of the structure (χ^2 = 865.079, RMSEA = 0.075, TLI = 0.908, CFI = 0.923). Reliability was high, with Cronbach's alpha ranging from 0.674 to 0.966 and Composite Reliability (CR) exceeding 0.70 for most constructs. Correlation analysis revealed strong interrelationships among dimensions (r = 0.779–0.998), underscoring the integrated nature of digital skills. The findings suggest that digital skills among pre-service science teachers can be conceptualized as a unified but multidimensional construct. The validated instrument offers a reliable tool for assessing digital competencies in teacher education. Practically, the results have implications for curriculum development, underscoring the need to integrate digital literacy training into teacher preparation programs. Future research should expand validation to diverse cultural contexts and apply longitudinal approaches to capture changes in digital skill development over time.

Keywords: Confirmatory Factor Analysis; Digital Skill; Instrument; Pre-Service Teachers; Validation.

Introduction

In the 21st century, digital skills have become an indispensable component of teacher professionalism and educational effectiveness. Teachers are no longer confined to traditional pedagogical methods such as lectures or textbook-based instruction but are increasingly expected to integrate digital technologies to support interactive, student-centered learning [1]. The incorporation of digital competence allows teachers not only to access and curate online content but also to evaluate its credibility, adapt it for instructional purposes, and design engaging, multimodal learning materials. Furthermore, digital skills empower teachers to utilize online communication tools, learning management systems, and multimedia platforms to create collaborative environments that extend learning opportunities beyond the physical classroom walls [2]. In addition to enhancing classroom teaching, the rapid growth of online learning platforms, blended learning approaches, and virtual classrooms has underscored the urgency of teachers being proficient in digital pedagogy. Such proficiency enables them to adapt flexibly to disruptions, such as those caused by the COVID-19 pandemic, and to continue providing quality learning experiences in both face-to-face and remote contexts [3-4].

Teachers who are digitally literate are also better positioned to address diverse learning needs, implement differentiated instruction, and foster higher-order thinking skills, including creativity, critical thinking, and problem-solving. Beyond its pedagogical functions, digital competence significantly contributes to administrative efficiency by supporting data management, student assessment, and professional communication [5]. It also facilitates teachers' participation in professional learning networks, enabling them to share best practices, collaborate with peers, and engage in continuous professional development through global online communities [6]. In the context of ongoing global education reforms, digital literacy is increasingly recognized as a core competency that underpins educational equity and prepares students for the digital economy and workforce of the future. Consequently, assessing and strengthening digital skills among pre-service teachers is crucial, as it ensures that future educators enter the profession prepared to integrate technology in effective, ethical, and sustainable ways [7].

Within this context, Generation Z—those born and raised in the digital era—has drawn significant attention. Often described as "digital natives," members of this generation are deeply immersed in technology, with their daily lives shaped by the pervasive use of smartphones,

How to Cite:
D. P. Ningthias and H. Qudratuddarsi, "Validation of Instrument to Measure Science Pre-Service Teachers Digital Skills: Confirmatory Factor Analysis", *J. Pijar.MIPA*, vol. 20, no. 7, pp. 1296–1301, Dec. 2025. https://doi.org/10.29303/jpm.v20i7.10423

social media, and instant access to information [8]. For pre-service teachers from this generation, digital skills are not only advantageous but essential to their professional identity. However, research highlights a critical distinction: while Gen Z students tend to demonstrate strong competence in using digital tools for personal, entertainment, or social purposes, this proficiency does not automatically extend to pedagogical applications. Skills such as designing instructional digital content, managing online safety and privacy, and promoting ethical and empathetic digital practices require explicit development [9-10]. As future educators, these pre-service teachers need to transform their familiarity with technology into meaningful pedagogical strategies that enhance learning outcomes. When effectively applied, digital skills enable them to create interactive and engaging classroom experiences, support differentiated instruction for diverse learners, and guide students in becoming responsible and ethical digital citizens. Preparing Gen Z pre-service teachers with validated and measurable digital competencies ensures their readiness to navigate the complexities of future teaching challenges in an education system increasingly shaped by technological innovation [11-12].

The validation of instruments plays a critical role in educational research, particularly when measuring abstract constructs such as digital skills. Validity and reliability are essential to ensure that instruments accurately capture the intended dimensions of competence [13]. In this regard, Confirmatory Factor Analysis (CFA) offers a powerful statistical method for testing whether observed data fit a hypothesized measurement model. Unlike exploratory methods, CFA provides rigorous evidence of construct validity by examining factor loadings, model fit indices (such as RMSEA, CFI, and TLI), and the relationships among latent variables. This enables researchers to confirm whether items are grouped appropriately into their designated dimensions and whether the hierarchical structure of competencies holds true across samples [14]. By doing so, CFA not only enhances the credibility of the research findings but also minimizes measurement errors, thereby strengthening the reliability of the instrument across diverse educational contexts. For this study, employing CFA to validate the adapted digital skills instrument is particularly essential, as it ensures that the translation and cultural adaptation process did not alter the meaning or measurement accuracy of the original tool. This step guarantees that the instrument measures pre-service teachers' digital competencies consistently and meaningfully within the Indonesian context.

Research Methods

Research Design

This study employed a quantitative survey method, focusing on gathering and analyzing numerical data derived from structured responses provided by participants. As a survey-based investigation, it aimed to evaluate pre-service science teachers' digital skills at a specific point in time, without introducing interventions or manipulating the participant group [15-16]. The researchers employed a cross-sectional design, which enabled them to capture participants' digital skills in a single snapshot, thereby avoiding the typical challenges associated with longitudinal studies, such as participant attrition or changing external factors that may influence perceptions over time. The use of quantitative analysis ensured objectivity and data reliability, enabling statistical exploration of trends and response patterns [17-18].

Subject of the study

A total of 349 Generation Z pre-service science teachers participated in this study. They were selected through convenience sampling, which provided quick and accessible participant recruitment; however, this method may slightly limit the generalizability of the findings [19]. Despite this, the sample was highly relevant due to their use of technology in their daily lives and educational journey. Table 1 presents the demographic distribution of the study participants. A total of 349 pre-service science teachers took part in the research. Based on gender, 28.08% of the participants were male, and 71.92% were female, indicating that the majority of participants were female. In terms of year of study, 32.38% of participants were in their first year, 30.08% in their second year, and 37.53% in their third year. This distribution shows a balanced representation across the different years of study.

Table 1. Sample of the study

Sample	N	Percentage
Gender		
Male	98	28.08%
Female	251	71.92%
Year of study		
First year	113	32.38%
Second year	105	30.08%
Third Year	131	37.53%
Total	349	100 %

Instrument

This instrument is adapted from [20] Fan and Wang (2022) to measure students' digital skills, translated and validated in the Indonesian context using the back-translation method. It consists of seven dimensions: Access to and Management of Digital Content (AMDC), which assesses the ability to search, organize, and evaluate digital information; Use of Digital Means (UDC), which refers to operating devices and applications; Communication of Digital Content (CS), which focuses on sharing and adapting communication styles in digital environments; Creation of Digital Content (CrS), which covers producing and modifying digital materials responsibly; Digital Safety (DSS), which emphasizes cybersecurity and privacy; and Digital Empathy (DES), which reflects respect and ethical behavior in online interactions.

Data Collection

Data collection was conducted through Google Forms, supporting sustainable, paperless research practices while also improving efficiency and minimizing data entry errors. The digital format allowed for real-time access to responses [21]. To further ensure clarity and accurate

understanding of the survey items, the researcher was present during data collection, offering immediate assistance to participants if needed. This presence also helped create a supportive environment that encouraged participants to respond sincerely. Participation in the study was voluntary, with clear assurances that their responses would remain confidential and would not influence their academic evaluation [22]. These ethical safeguards were crucial in maintaining the credibility and integrity of the collected data.

Data Analysis

After data collection, participants' responses were systematically organized using SPSS version 25 to facilitate accurate processing and preparation for further analysis. We applied Confirmatory Factor Analysis (CFA) using the validation sample in AMOS 24 to examine the unidimensional structure of the mathematical modelling test. Model fit was evaluated through several indices, including chi-square (χ^2) with non-significance ($p > 0.05$), the Tucker-Lewis Index (TLI > 0.90), Comparative Fit Index (CFI > 0.90), and the Root Mean-Square Error of Approximation (RMSEA < 0.08). In addition, internal consistency and construct reliability were assessed using Cronbach's alpha ($\alpha > .60$), composite reliability (CR > .60), and average variance extracted (AVE > 0.50), following the recommended guidelines [23-24].

Results and Discussion

Goodness of Fit (first and second order of CFA)

In First-Order Confirmatory Factor Analysis (CFA), observed variables (such as questionnaire items) are directly linked to latent factors, and the analysis tests whether these items accurately measure the intended constructs. Each item loads onto its hypothesized factor, allowing researchers to confirm the measurement model's structure. In Second-Order CFA, the first-order latent factors themselves are treated as indicators of higher-order (second-order) latent factors. This approach is used when multiple related constructs are assumed to be explained by a broader underlying dimension. It provides a hierarchical understanding of relationships among constructs and their overarching conceptual framework [25].

In this study, model fit for both first-order and second-order Confirmatory Factor Analysis (CFA) is evaluated using several goodness-of-fit indices. Chi-square (χ^2) assesses the difference between the observed and expected covariance matrices, with a non-significant value indicating good fit, though it is sensitive to sample size. The Root Mean Square Error of Approximation (RMSEA) measures the model's approximation error in the population; values ≤0.08 indicate acceptable fit, and ≤0.05 indicate good fit. The Comparative Fit Index (CFI) compares the specified model to a null (independence) model, with values of≥0.90 indicating a strong fit. Similarly, the Tucker–Lewis Index (TLI) adjusts for model complexity, with values close to or above 0.90 considered acceptable. Together, these indices provide a comprehensive evaluation of how well the hypothesized measurement models (first-order and second-order) represent the data, ensuring reliability and validity of the constructs being tested [26-27].

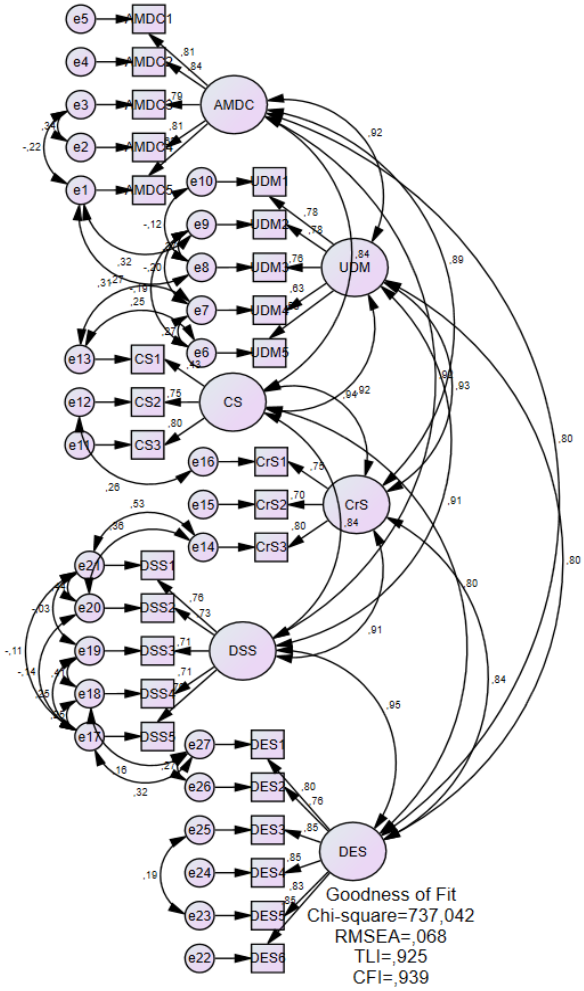

Figure 1. First Order CFA

The goodness-of-fit results from the Confirmatory Factor Analysis indicate that the model used to validate the instrument for measuring science pre-service teachers' digital skills demonstrates an acceptable to good fit (Figure 1). The Chi-square value (χ^2 = 737.042) is significant, as expected, given the test's sensitivity to large sample sizes. Therefore, greater emphasis is placed on alternative indices. The RMSEA value of 0.068 falls below the 0.08 threshold, indicating an acceptable approximation of fit. Similarly, the TLI value of 0.925 exceeds the recommended cutoff of 0.90, indicating that the model accounts for complexity well. The CFI value of 0.939 is also close to the ideal benchmark of 0.95, suggesting a strong comparative fit. Taken together, these indices confirm that the measurement model is robust and valid in representing the digital skills constructs among science pre-service teachers.

The second-order Confirmatory Factor Analysis (CFA) was conducted to validate the instrument measuring science pre-service teachers' digital skills (Figure 2). The model demonstrates that six first-order latent constructs—Access to and Management of Digital Content (AMDC), Use of Digital Media (UDM), Communication Skills (CS), Creative Skills (CrS), Digital Safety Skills (DSS), and Digital Ethical Skills (DES)—are strongly loaded onto a higher-order latent construct, namely Digital Skills. The standardized regression weights from the first-order factors to the second-order factor are high, ranging from .94 to .97,

indicating that each dimension substantially contributes to the overarching construct. The observed indicators for each dimension also show acceptable loadings (mostly above .65), supporting convergent validity. The model fit indices further confirm the adequacy of the structure: Chi-square = 865.079, RMSEA = 0.075, TLI = 0.908, and CFI = 0.923. These values suggest a reasonably good fit, meeting the threshold criteria for construct validation.

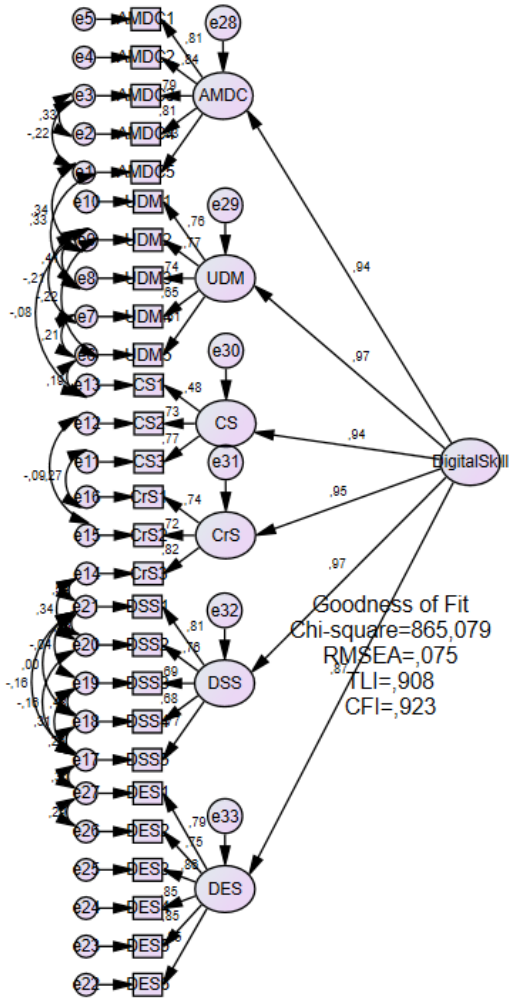

Figure 2. Second Order CFA

Reliability

The reliability results of the Confirmatory Factor Analysis (CFA) provide strong evidence for the internal consistency and construct validity of the instrument designed to measure science pre-service teachers' digital skills [28]. As shown in the table, most dimensions demonstrate acceptable to excellent reliability. Cronbach's alpha values range from 0.674 to 0.966, with five out of seven dimensions exceeding the 0.80 threshold, indicating high internal consistency. The lowest alpha is found in the Communication of Digital Content (0.674), which is still within the minimum acceptable range for exploratory studies; however, it suggests potential refinement of the items. Composite Reliability (CR) values also support the robustness of the constructs, with most dimensions above the recommended 0.70 cutoff, confirming the stability of the measures. Additionally, the Average Variance Extracted (AVE) values are above 0.50 for most constructs, reflecting adequate convergent validity, except for Use of Digital Means (0.514), which is only slightly above the threshold, and Communication of Digital Content, for which AVE was not reported. At the higher-order level, Digital Skill as an overarching construct demonstrates excellent reliability (α = 0.966; CR = 0.980; AVE = 0.650).

Table 2. Reliability Result

No	Dimensions	Cronbach's alpha	CR	AVE
1	Access to and management of digital content (AMDC)	0.879	0.916	0.688
2	Use of digital means (UDC)	0.833	0.838	0.514
3	Communication of digital content (CS)	0.674		
4	Creation of digital content (CrS)	0.803	0.836	0.632
5	Digital Safety (DSS)	0.884	0.892	0.735
6	Digital Empathy (DES)	0.903	0.929	0.688
7	Digital Skill	0.966	0.980	0.650

Correlations among Dimensions

The correlation analysis among the dimensions further supports the Confirmatory Factor Analysis (CFA) results, strengthening the validity of the instrument that measures science pre-service teachers' digital skills. As presented in the table, all dimensions are highly correlated, with correlation coefficients ranging from 0.779 to 0.998. Such strong positive correlations indicate that, while each dimension represents a distinct aspect of digital skills, they are also closely related and collectively contribute to the overarching construct of digital skills. For example, the correlation between Communication of Digital Content and Creation of Digital Content is the highest (r = 0.998), indicating that the ability to communicate digitally is strongly tied to the skill of creating digital materials. Similarly, Digital Safety and Digital Empathy demonstrate a very strong correlation (r = 0.977), highlighting the interconnectedness between safe digital practices and empathetic online behavior. The relatively high correlations across all dimensions also confirm the multidimensional but integrated nature of digital skills. These results are consistent with the second-order CFA model, where the dimensions function as first-order constructs under a broader higher-order construct of digital skills. Therefore, the correlation analysis provides additional empirical support for the structural validity and coherence of the instrument.

Although this study provides valuable insights into the digital skills of pre-service science teachers, several limitations should be noted. First, the use of a cross-sectional survey design limits the ability to capture changes in digital skills development over time. Longitudinal studies would provide a more comprehensive understanding of growth and progression. Second, the sample was obtained through convenience sampling, which may restrict the generalizability of the findings to wider populations of

pre-service teachers. Third, the reliance on self-reported data introduces the possibility of social desirability bias, as participants may overestimate or underestimate their digital competencies. Finally, while the Confirmatory Factor Analysis (CFA) confirmed the validity and reliability of the instrument, additional validation across diverse cultural and institutional contexts is recommended to strengthen external validity.

Table 3. Correlation among dimensions

Dimensions	1	2	3	4	5	6
Access to and management of digital content (AMDC)	1	0.869	0.922	0.868	0.780	0.779
Use of digital means (UDM)		1	0.940	0.888	0.871	0.892
Communication of digital content (CS)			1	0.998	0.796	0.794
Creation of digital content (CrS)				1	0.817	0.813
Digital Safety (DSS)					1	0.977
Digital Empathy (DES)						1

The use of a quantitative cross-sectional survey design and CFA-based instrument validation has direct implications for instructional design, particularly in ensuring that decisions are grounded in empirical evidence rather than assumptions. By identifying which dimensions of digital skills are strongest or weakest among pre-service teachers, instructional designers can tailor learning experiences, resources, and training modules to target specific gaps revealed in the data. For example, if the validated instrument indicates lower competence in digital content creation or communication, instructional designers can integrate more project-based tasks, multimedia assignments, or training in educational technology tools to strengthen those areas. Moreover, the reliability and validity obtained through CFA ensure that the instructional decisions and course designs are based on accurate measurements of learners' actual digital abilities, thus enabling the creation of more relevant, efficient, and responsive learning interventions. Ultimately, these research methods support data-driven instructional design that aligns technology integration strategies with the authentic needs of pre-service teachers.

Conclusion

This study validated an instrument designed to measure the digital skills of pre-service science teachers by employing a cross-sectional survey and Confirmatory Factor Analysis (CFA). The results demonstrated that six first-order dimensions—Access to and Management of Digital Content, Use of Digital Media, Communication Skills, Creative Skills, Digital Safety Skills, and Digital Ethical Skills—are strongly represented within a second-order construct of Digital Skills. Model fit indices, reliability measures, and correlation analyses confirmed that the instrument is both valid and reliable for assessing digital competencies in this population. The validated digital skills instrument enables teacher education programs to diagnose pre-service teachers' strengths and weaknesses, allowing institutions to design targeted training that addresses specific competency gaps. By identifying dimensions such as digital content creation, communication, or digital safety that require improvement, lecturers can integrate technology-rich activities and scaffolded practice into coursework. The findings also encourage the incorporation of authentic, real-world digital tasks—such as designing multimedia learning materials or managing online platforms—to help pre-service teachers translate personal technology use into pedagogical applications. Furthermore, the validated instrument can be embedded into periodic assessments to monitor digital competency development throughout the teacher preparation program.

Author's Contribution

Hilman Qudratuddarsi: Research conceptualization, data analysis, manuscript writing; Author name2: data collection, ethical clearance, manuscript writing

Acknowledgements

The authors extend their deepest appreciation to the respondents and all individuals and institutions that provided support and participation, making this study possible.

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