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Multidimensional assessment and validation of digital competencies in university teacher education: a confirmatory factor analysis

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Introduction: The digital era requires teaching competencies that transcend simple technological competence, promoting innovative and sustainable pedagogical approaches. This research evaluates and models the digital competencies of higher education teachers, highlighting their impact on student learning and the adoption of sustainable pedagogical strategies.

Methods: Data were collected from 166 Ecuadorian teachers using an adapted "DigCompEdu Check-In" questionnaire, which examined six competency domains: Professional Engagement, Digital Resources, Digital Pedagogy, Assessment and Feedback, Student Empowerment, and Facilitating Student Digital Competence. The reliability of the scales was confirmed with internal consistency indicators (Cronbach's α from 0.77 to 0.91). In addition, a Confirmatory Factor Analysis (CFA) was performed to validate the dimensional structure of the competencies.

Results: Descriptive results showed that 29.09% of the participants identified themselves as "Leader" and 56.36% as "Pioneer" in digital competencies. The AFC presented excellent fit indices (CFI = 1.00, TLI = 1.00, RMSEA = 0.00), evidencing a solid structure. The relationship between "Facilitating students' digital competence" and "Empowering students" was high (factor loading of 0.93), highlighting the multidimensional and interdependent nature of digital competencies. Significant covariances were observed, such as between "Professional engagement" and "Facilitating digital competence" (0.76), reflecting the interaction between pedagogy, technology and professional engagement.

Discussion: The findings revealed a strong synergy between advanced digital competencies and sustainable pedagogical practices, reinforcing the importance of frameworks such as DigCompEdu and TPACK for professional development. It is concluded that strengthening these competencies is key to preparing teachers for the challenges of the transforming higher education context.

KEYWORDS

digital competencies, DigCompEdu, higher education, confirmatory factor analysis, pedagogy

1 Introduction

In the 21st century, educational institutions operate within an authentic virtual training environment created not only by the technologies commonly used in schools (such as videos, computers, projectors and the Internet), but also by the variety of new tools introduced by Web 2.0 (Cabero Almenara and del Llorente Cejudo, 2013). Therefore, the digital competencies of teachers play a key role in this process, as they not only facilitate the use of technological tools, but al-so promote innovative pedagogical methods that enrich student learning (Lisperguer Soto et al., 2021; Hailegebreal et al., 2022).

As higher education moves to a digital reality, the digital skills of teachers are essential to their training. According to Tejedor et al. (2020) initial training should focus on the development of technological skills that allow educators to adapt to a constantly changing educational environment. However, challenges such as insufficient continuous training, resistance to change and lack of comprehensive strategies for the incorporation of technology in education persist (Redecker and Punie, 2017). In addition (García-Valcárcel Muñoz-Repiso et al., 2025), they indicate that a considerable number of teachers do not have advanced digital competencies, which restricts their ability to maximize the educational possibilities offered by information and communication technologies (ICT) (Fernández-Cruz and Fernández-Díaz, 2016). This problem occurs mainly in developing countries, where technological disparities and deficiencies in educational infrastructure obstruct access to and effective use of these resources (Urquizo Alcivar and Villamarín Guevara, 2022).

UNESCO (2019) has stressed the importance of developing assessment frame-works for digital competencies that are adapted to local contexts, integrating technical and pedagogical aspects. According to García-Ruiz et al. (2023), an effective assessment should measure not only the mastery of technological tools, but also the ability of teachers to design meaningful activities that integrate ICT. These evaluations are crucial to identify areas for improvement and promote specific training programs (Liesa Orús et al., 2016). In addition, the Horizon Report points out that the growing technological transformation demands from an approach based solely on technical skills to assessing their impact on learning, pedagogical design and digital ethics (Ainley and Carstens, 2018; Brown et al., 2020).

The European Framework of Digital Competences for Educators (DigCompEdu) is positioned as a key framework for training teachers, facilitating not only the development of their digital competencies, but also their ability to effectively integrate them into the teaching-learning process. This aligns with the need for strategies that combine assessment, training and institutional support to ensure a sustainable adoption of digital technologies in education (Harris et al., 2009a). The European Framework of Digital Competences for Educators highlights six key areas for teachers to develop, including professional engagement, digital resources (DR), and facilitating learning through technology (European Commission, 2017).

The objective of this study is to analyze and model the influence of digital competencies of teachers in the Education career, highlighting their impact on the strengthening of sustainable pedagogical practices and the development of digital competencies in students. To this end, the interrelationships between key dimensions such as Professional Engagement, DR, Digital Pedagogy (DP), Assessment and Feed-back, Student Empowerment and Facilitation of Digital Competencies are explored. The validation of these relationships will be carried out using confirmatory factor analysis (CFA), a statistical technique that allows assessing the validity and reliability of a theoretical model by analyzing the relationships between latent variables and their observed indicators (Mohd Sharif et al., 2020). This approach provides a solid basis for validating the proposed dimensions and analyzing their interaction in the educational context, offering valuable information on the factors that promote the effective adoption of digital technologies.

In this way, it contributes to the design of pedagogical strategies that are resilient, inclusive and aligned with the principles of sustainable development.

2 Theoretical framework

2.1 Digital competence of teachers

In the educational context, ICT have posed fundamental challenges to educational researchers and training institutions, demanding changes in what should be learned and how to do it (Voogt et al., 2013). Beardsley et al. (2021) suggests that to ensure the integration of digital technologies in institutions, it is necessary to train and accompany teachers to integrate them in the class-room from the point of view of active citizenship as well as from the point of view of professional development, either in the framework of initial or continuing education.

This period of technological transformation has posed a number of challenges for teachers, requiring rapid adaptation to new pedagogical tools and practices. This transition was hindered mainly in the predominant age range of the teaching workforce, where most of them are over 40 years old, resulting in a slower adaptation process and even resistance to change (Monteiro et al., 2020). In addition, the constant updating of ICT knowledge has led to professional burnout, causing burnout syndrome and, consequently, an in-crease in teacher attrition (Cacciamani et al., 2022). On the other hand, deficiencies in continuous ICT training in some educational institutions limit the ability of teachers to use these technologies effectively. This lack of training restricts the possibility of designing enriching learning experiences aligned with current demands (Spiteri and Chang Rundgren, 2020). As a result, student disinterest and demotivation emerge as collateral effects, negatively affecting their academic and professional training.

Teacher preparation in the use of ICT should not be considered optional, but a strategic priority. The lack of technological competencies in the classroom can generate significant gaps in the training of students, especially in their ability to integrate into an increasingly competitive labor market oriented towards technological innovation (Falloon, 2020). For Falloon (2020), the competencies inherent in the pillars of the framework should not be considered as the exclusive responsibility or within the skill set of one or two teacher educators. For the author, success would lie in faculty adopting a coordinated, interdisciplinary approach to the delivery of teacher education programs, rather than the discipline-based and siloed models currently prevalent.

A recent development that has accentuated this need is the standardization of the use of artificial intelligences (AI) in education. These technologies have the potential to optimize teaching and learning processes, but their implementation without knowing the ethical issues, limitations and risks involved can compromise educational quality by diminishing the human role in pedagogical mediation (Ng et al., 2023). This phenomenon forces a rethinking of curricular frameworks and pedagogical models, allowing rapid adjustments in response to growing technological advances. Among the key competencies expected of teachers in this context are: commitment to the integration of ICT in the educational environment, mastery in the use of DR, implementation of assessment and feedback (AF) strategies adapted to the digital environment, and the ability to motivate students towards a responsible and proactive use of these tools (Cabero-Almenara et al., 2020b).

2.2 The European framework of digital competences for educators

Originally, DigComp was designed as a tool to promote technological literacy among citizens in general; however, it was later adapted to DigCompEdu specifically for educators with the objective of integrating digital competencies into formal education, demanding a broad repertoire of knowledge and skills (European Commission, 2017). Recent research highlights that this initiative fosters the professionalization of educational practice by stimulating critical reflection on the use of DR (Caena and Redecker, 2019). For their part, Carretero et al. (2017) stress the importance of establishing competency profiles that allow a framework of progression and staggered levels of mastery, facilitating a progress in the management of digital tools.

The European Framework of Digital Competences for Educators was presented at the end of 2017 by the joint research center of the European Union (Redecker and Punie, 2017). It aims to establish a comprehensive conceptual framework to guide and assess the development of digital competencies in teachers at all educational levels. This model defines digital competence through six differentiated areas each of which includes several key competencies that teachers must acquire to implement effective, inclusive and innovative learning strategies through the use of digital tools. Its competency areas are:

2.2.1 Professional commitment

Teachers' professional commitment (PC) is fundamental to the incorporation of ICT into their teaching methods by adhering to institutional policies to promote quality education (Husain and Khan, 2020). Redecker and Punie (2017), argue that professional engagement is a fundamental dimension of the DigCompEdu framework, as engaged teachers not only embrace digital technologies to improve teaching, but also collective and continuous innovation in the educational organization. In addition, professional engagement includes active participation in virtual communities, continuous learning, and collaborative network building, which strengthen teacher professional development (UNESCO, 2017). According to Bandura et al. (1999), self-efficacy is a key determinant of human behavior. In the educational context, self-efficacy derived from professional engagement strengthens the teacher's willing-ness to manage DR. In addition, digital training is crucial to promote critical reflection on digitized pedagogical practices and personal learning networks for professional development in virtual environments (Dabbagh and Kitsantas, 2012; Cabero-Almenara et al., 2020a; Kirschner et al., 2022). This comprehensive approach enables teachers to continuously improve their performance and adapt to the demands of education in the digital era.

2.2.2 Digital resources

Digital resources comprise information or media stored or transmitted in digital format, such as documents, images, audio or video files and data sets (Churchill, 2017). According to the TPACK model, the effective integration of technology in teaching requires not only technical knowledge, but also pedagogical and disciplinary knowledge that allows the design of content aligned with educational objectives (Harris et al., 2009a). In this sense, the selection of DR should be guided by clear learning purposes, avoiding the in-discriminate use of technological tools without pedagogical justification (Bower and Laurillard, 2018).

The willingness of teachers to search, select and share DR is directly linked to their level of digital competence (Gil-Flores et al., 2017). However, to ensure effective use of educational platforms, it is essential that educators receive ongoing training to enable them to integrate these resources into their teaching practice (Siddiq et al., 2016). In addition, content curation plays a crucial role in promoting relevant and quality materials, helping to avoid information overload and ensuring that the selected resources respond to learning needs (Kimmons and Irvine, 2023). In this way, DR become strategic tools to enrich teaching and optimize educational processes in digital environments.

2.2.3 Digital pedagogy

Digital pedagogy is the design, planning and implementation of teaching-learning strategies that integrate ICT in a meaningful way. This approach recognizes that learning is built from the interconnection of information networks, where technology acts as a catalyst to foster collaboration (Siemens, 2004). In addition, DP emphasizes the active role of the student in the construction of his or her own knowledge, emphasizing that technological integration must be accompanied by a pedagogical approach that is tailored to the specific needs of the student body and supported by solid disciplinary foundations (Mishra and Koehler, 2006; Fullan, 2013). It also stresses the importance of initial teacher training in digital competencies, ensuring that they can respond effectively to the demands of the contemporary educational environment (Howard, 2013).

2.2.4 Evaluation and feedback

Assessment and Feedback is the implementation of digital tools and strategies de-signed to evaluate and improve teaching and learning processes. Digital assessment should be aligned with pedagogical objectives and disciplinary content, as established by the TPACK model, which integrates technology, pedagogy, and domain knowledge (Harris et al., 2009b). In addition, the SAMR model helps teachers integrate technology in stages, from simply replacing traditional methods to completely transforming educational activities (Puentedura, 2010). The Horizon Report highlights that data analytics tools make it possible to generate personalized, real-time feedback, improving learning effectiveness (McKnight et al., 2016). However, technological acceptance by teachers is essential to ensure the effectiveness of these digital strategies (Scherer et al., 2019). Moreover, formative feedback in digital environments not only facilitates students' continuous adjustment, but also fosters self-regulation, allowing them to take a more active role in their learning process (Wang et al., 2014).

2.2.5 Empowering students

In this study, empowering students (ES) is to promote autonomy and participation in their formative process through digital tools (Avidov-Ungar and Eshet-Alkalai, 2011). For Castañeda and Selwyn (2018), the creation of collaborative spaces and the integration of interactive tools facilitate the construction of knowledge, promoting a more participatory and dynamic learning. Such tools can increase student motivation and sense of competence. The design of activities that promote student self-regulation and responsibility requires teachers trained in pedagogical strategies that enhance these skills (Foulger et al., 2017). Likewise, authentic tasks and problems based on real contexts reinforce student empowerment (Brown et al., 2020). Metacognitive reflection and self-direction strategies are fundamental to consolidate students' autonomy and ability to manage their learning (Ennin, 2023).

2.2.6 Facilitating students' digital competence

This area assesses the teacher's ability to develop skills and knowledge that enable students to make effective and ethical use of ICT (Cabero-Almenara et al., 2020a). Blau and Shamir-Inbal (2017) point out that digital competency training should integrate aspects related to media and information literacy. In this context, UNESCO (2019) promotes the orientation of curricula towards the development of transversal competencies, including critical thinking and collaboration. Similarly, the OECD (2019) stresses the urgency of training students capable of adapting to increasingly digitized work contexts.

3 Materials and methods

3.1 Research design

The objective of the present study is to evaluate the digital competencies of teachers of the Education degree program. The study was planned under an empirical design, with a cross-sectional quantitative approach. This sampling strategy is justified by the ease of access to the teaching population through the institutional platform and by the support of the university's research department, which considered this method as the most appropriate to obtain a first approximation of the current state of digital competencies of the teaching staff.

3.2 Data collection

A total of 166 teachers invited to participate in the analysis were included in the analysis by means of non-probabilistic convenience sampling, with a margin of error of 3.2% and a confidence level of 95%. The population was composed of undergraduate teachers of education in face-to-face, semi-face-to-face and online modalities. Table 1 shows the composition of the sample, detailing the sociodemographic characteristics and the current situation of the teachers.

3.3 Procedure and ethical considerations

This study explored various aspects related to the digital competencies of university teachers. The main objective was to collect a probability sample of teachers in the education career. The questionnaire was administered using Google Forms survey management software (Adelia et al., 2021) and distributed to university staff at a university in Ecuador in late 2024, a method that guaranteed the anonymity of the survey data. Sent electronically to faculty via institutional email. As argued by Mainardes and Carvalho (2019), the research process was always associated with high levels of vigilance and self-reflection regarding ethical issues. Following the guidelines of Winter and Gundur (2024), several ethical considerations were taken into account to ensure the welfare of the participants were informed about privacy, confidentiality and privacy protection. Participation was completely voluntary, with the possibility of withdrawal at any time from the questionnaire, and all participants gave in-formed consent prior to data collection. In addition, in order to obtain more reliable data, participants were provided with a clear explanation of the research objectives and a

TABLE 1 Sample distribution.

Category	Factor	Frequency	Proportion
Gender	Woman	108	65%
	Male	57	35%
Type of employment	Occasional	138	84%
	Owner	27	16%
Workload	Half time	53	32%
	Part-time	4	2%
	Full-time	108	65%
Modality	On-site	55	33%
	Blended	33	20%
	Online	77	47%
Age	25–34 years	28	17%
	35–44 years	61	37%
	45–54 years	50	30%
	More than 55	29	18%
Study level	3 level	2	1%
	4 level	134	81%
	pHD	29	18%

basic conceptual description of the digital competencies framework in education.

3.4 Data collection instrument

The instrument used for data collection was the "DigCompEdu Check-In" questionnaire adapted to prospective teachers, an internationally validated tool for assessing digital competencies (Cabero-Almenara and Palacios-Rodríguez, 2020; Tena et al., 2021). The questionnaire included two main sections: the first consisted of collecting demographic information of the participants, such as gender, work relationship, modality, age, academic degree. The section "2. Theoretical framework" included 22 items structured on a five-point Likert scale, ranging from 1 (Never) to 5 (Al-ways). This questionnaire, in addition, consisted of 22 items distributed in six competency areas defined in DigCompEdu: (PC) professional commitment (4 items), (DR) digital resources (3 items), (DP) teaching and learning (4 items), (EF) assessment (3 items), (ES) student empowerment (3 items) and (FSDC) support for students' digital competence (5 items). Teachers initially self-assessed themselves by classifying them-selves into one of the competency categories (novice, explorer, leader or pioneer), and repeated this process at the end to evaluate.

3.5 Data analysis

After the data collection process, the data were cleaned and coded using SPSS statistical software. To evaluate the digital competence of higher education teachers in Ecuador, three statistical methods were used: the reliability of the questionnaire was evaluated using Cronbach's α coefficient (Santos et al., 2022), and a confirmatory factor analysis (CFA) to confirm that the theoretical means of the model demonstrated good internal consistency using structural equations (Fernández-Batanero et al., 2021). This was followed by a descriptive analysis, which included the calculation of frequencies, measures of central tendency (mean, median, mode) and measures of dispersion (standard deviation). These analyses provided a comprehensive overview of teachers' digital competencies. This methodological approach, which combined the use of SPSS for initial data cleaning and R Studio for advanced and descriptive analyses, ensured the reliability and validity of the findings obtained.

4 Results and discussion

In Figure 1, the results obtained through the "DigCompEdu Check-In" tool show a predominantly high distribution in the higher levels of the scale. Specifically, 6.06% of the surveyed teachers are located at the Integrator level (B1), 8.48% at the Expert level (B2). In addition, the percentage of teachers at the most advanced levels is 29.09% as Leader (C1) and 56.36% as Pioneer (C2). This distribution suggests a consistent dominance in the adoption and integration of digital technologies in educational practice, far exceeding the initial stage of incorporation to consolidate at advanced levels of maturity and technopedagogical proactivity (Redecker and Punie, 2017).

The high presence of teachers with advanced digital competencies in the university environment is an encouraging indicator in terms of the quality of teaching and learning in higher education. For Santos et al. (2022), faculty with high levels of digital competence are better prepared to implement innovative and collaborative methodologies, which has a direct impact on the quality of learning and student participation. This strengthening of digital skills enables the integration of technologies in educational processes, promoting more inclusive and personalized learning experiences (Fernández-Batanero et al., 2021). On the other hand, these competencies allow students to acquire and develop transversal skills, increasingly in demand in the labor market, such as collaboration and digital literacy (Zhao et al., 2021), promoting the consolidation of a training ecosystem in line with the requirements of the 21st century (European Commission, 2017).

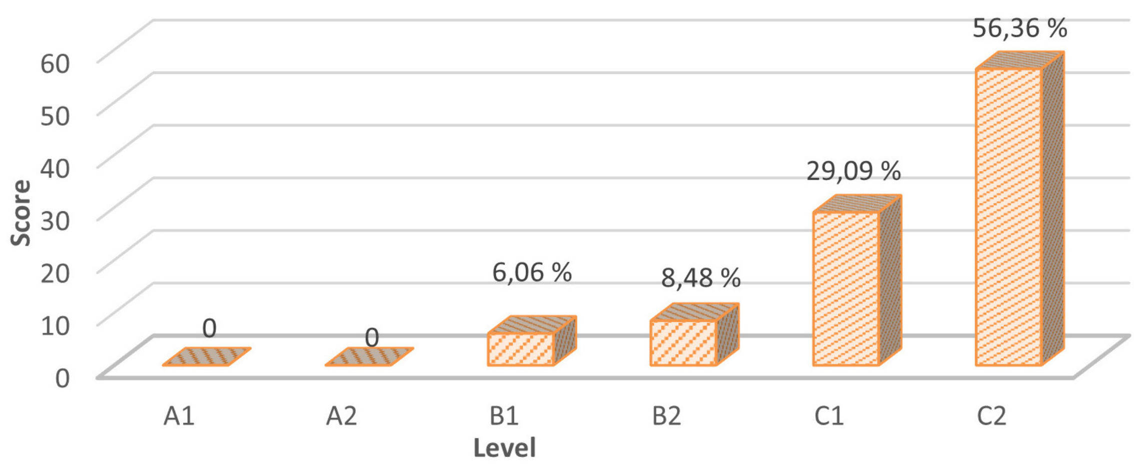

FIGURE 1
Frequency distribution by categories.

4.1 Evaluation and identification of factors

The homogeneity indicators, measured by Cronbach's Alpha coefficient, ranged between 0.77 and 0.91 which indicates adequate internal consistency (Nunnally and Bernstein, 1994) and reinforces the validity of the items used to measure the following factors: Professional Commitment (PC), Digital Resources (DR), Digital Pedagogy (DP), Assessment and Feedback (AF), Empowering Students (ES) and Facilitating Students' Digital Competence (FSDC).

Table 2, shows the descriptive values of the study population, classified on a liker scale of (1 = "Strongly Disagree," 2 = "Disagree," 3 = "Neutral," 4 = "Agree," 5 = "Strongly Agree"), with "f" being the frequency of each response.

In the PC factor, the means were between 3.28 and 3.68, with a Cronbach's alpha of 0.85, demonstrating high internal consistency. This range suggests that teachers have a good level of commitment to the adoption of technologies in their professional practice. However, the absence of responses at the maximum level five could be retributed to the requirement in the advanced stages of DigCompEdu, which emphasize continuous innovation and digital leadership 5. Also, the fast-paced evolution of technologies promotes the perception that goals are constantly shifting, making it difficult to feel a sense of total mastery (Mengual-Andrés et al., 2016).

Digital Resources means ranged from 3.51 to 3.71, with moderate consistency (α = 0.77). Teachers perceive themselves as competent in the selection and use of digital re-sources, although without reaching outstanding levels. According to Redecker and Punie (2017), technical competencies are not enough to effectively integrate these re-sources: pedagogical strategies that respond to teaching and learning needs are also required5. Moreover, for Bandura (1997) self-perception can be influenced by comparison with high standards, leading to underestimation of one's own competence.

As for DP, the means ranged from 3.40 to 3.67, with a coefficient of 0.88 indicating high internal reliability. This result suggests that teachers are applying digital pedagogical practices appropriately. However, the lack of responses at the maximum of scale 5 may be associated with the demands of integrating technology, pedagogy, and content in a balanced way, as described by the TPACK model (Harris et al., 2009a). Achieving an outstanding level in this dimension implies continuous training and a prolonged effort to maintain coherence among the three components.

In AF, scores hovered around 3.47, with a Cronbach's alpha of 0.86, reflecting a satisfactory level of competencies in digital assessment and feedback, although not outstanding. This is initially due to the complexity of personalizing feedback in technological environments, as well as the lack of specific training in digital assessment tools (Instefjord and Munthe, 2017). Such shortcomings may limit teachers' self-confidence and, therefore, their assessment in this aspect.

Finally, ES yielded means of 3.44–3.56 and a Cronbach's alpha of 0.90, reflecting internal consistency. This factor reflects the intention to empower students through technology; however, the absence of scores of 5 could be attributed to the lack of resources or the complexity of customizing instruction to foster autonomy in learning (Mengual-Andrés et al., 2016). Achieving excellence in this area requires not only the appropriation of advanced technological tools, but also a pedagogical rethinking oriented to the participation and integral development of each student.

4.2 Confirmatory factor analysis

4.2.1 Tests of data adequacy

The analysis reflects a robust structural model for the assessment of digital competencies in education. The sample adequacy index KMO = 0.95 and Bartlett's test of sphericity (χ^2 = 3617; *df* = 231; $p < 0.001$) validate the relevance of conducting the confirmatory factor analysis (Tenenhaus and Young, 1985). These values agree with Tabachnick et al. (2013), who propose that a KMO index above 0.90 constitutes an excellent reference for performing CFA.

4.2.2 Model fit indices

Several standardized indices were used to assess the quality of fit of the proposed model. The Comparative Fit Index (CFI) reached a value of 1.00, indicating that the model fits the empirical data well, far outperforming the null model. Similarly, the Tucker-Lewis Index (TLI) and the Non-Normalized Fit Index (NNFI) showed values of 1.00, reflecting a correct model fit without parameter overfitting (Sathyanarayana and Mohanasundaram, 2024).

The Normalized Fit Index (NFI) showed a value of 0.998, indicating that the model fits robustly. Although this value is slightly lower than the Parsimony Normalized Fit Index (PNFI = 0.838), its proximity to 0.90 suggests an acceptable balance between fit and simplicity (Schermelleh-Engel et al., 2003). As for the error measures, the root mean square error of approximation (RMSEA) was 0.00, falling within the acceptable range according to the criteria established in the literature (Hu and Bentler, 1999). Finally, the standardized root mean square error (SRMR) obtained a value of 0.033, indicating that the discrepancies between the observed correlations and those predicted by the model are minimal and that, in general terms, the model fits the data adequately (Lin et al., 2017).

4.2.3 Confirmatory factor model

The structural model graphically represents the relationships between the latent constructs (indicated by circles) and their observed items (represented by squares). The standardized factor loadings mostly exceed 0.7, indicating a strong association between the indicators and the theoretical factors.

As shown in Figure 2, the connection between FSDC and ES, with a factor loading of 0.93, reveals the high interdependence between the two dimensions. According to Brown (2006), high correlations of this magnitude point to the multidimensional nature of digital competencies, indicating that these dimensions are mutually reinforcing and do not operate in isolation (Brown, 2006). This evidence suggests that faculty, in addition to promoting students' autonomy and active participation, focus on the comprehensive development of their digital competencies in order to prepare them to perform effectively in digitized educational and professional scenarios (Instefjord and Munthe, 2017).

Likewise, the covariances between latent factors (represented by dotted arrows) reflect significant associations that are not linked

TABLE 2 Statistical summary of average ratings for emotional descriptors by age group.

Scores		1	2	3	4	5	Mean	Standard deviation	Cronbach's alpha
Factor	COD	f(%)	f(%)	f(%)	f(%)	f(%)			
Professional commitment	PC1	0	10	32	123	0	3.68	0.582	0.85
		(0)	6.1	19.4	74.5	(0)			
	PC2	2	7	35	121	0	3.67	0.618	
		(1.2)	(4.2)	(21.3)	(73.3)	(0)			
	PC3	6	25	51	83	0	3.28	0.852	
		(3.6)	(15.1)	(31)	(50.3)	(0)			
	PC4	1	14	53	97	0	3.49	0.677	
		(0.6)	(8.5)	(32.1)	(58.8)	(0)			
Digital resources	DR1	0	7	36	122	0	3.70	0.546	0.77
		(0)	(4.2)	(21.8)	(74)	(0)			
	DR2	3	17	38	107	0	3.51	0.754	
		(1.8)	(10.3)	(23)	(64.8)	(0)			
	DR3	1	10	25	129	0	3.71	0.605	
		(0.6)	(6)	(15.2)	(78.2)	(0)			
Digital pedagogy	DP1	0	14	27	124	0	3.67	0.628	0.88
		(0)	(8.5)	(16.3)	(75.2)	(0)			
	DP2	2	15	30	118	0	3.60	0.705	
		(1.2)	(9.1)	(18.2)	(71.5)	(0)			
	DP3	0	13	40	112	0	3.60	0.632	
		(0)	(7.9)	(24.2)	(67.9)	(0)			
	DP4	3	16	45	101	0	3.48	0.746	
		(1.8)	(9.7)	(27.3)	(61.2)	(0)			
Assessment and feedback	EF1	2	16	50	97	0	3.47	0.720	0.86
		(1.2)	(9.7)	(30.3)	(58.8)	(0)			
	EF2	1	15	45	104	0	3.53	0.686	
		(0.6)	(9.1)	(27.3)	(63)	(0)			
	EF3	0	19	37	109	0	3.55	0.694	
		(0)	(11.5)	(22.4)	(66.1)	(0)			
Empowering students	ES1	0	16	42	107	0	3.55	0.666	0.90
		(0)	(9.7)	(25.5)	(64.8)	(0)			
	ES2	2	21	44	98	0	3.44	0.760	
		(1.2)	(12.7)	(26.7)	(59.4)	(0)			
	ES3	1	16	38	110	0	3.56	0.693	
		(0.6)	(9.7)	(23)	(66.7)	(0)			
Facilitating students' digital competence	FSDC1	6	21	42	96	0	3.38	0.844	0.91
		(3.6)	(12.7)	(25.5)	(58.2)	(0)			
	FSDC2	2	16	43	104	0	3.51	0.721	
		(1.2)	(9.7)	(26.1)	(63)	(0)			
	FSDC3	1	22	38	104	0	3.48	0.746	

(Continued)

TABLE 2 (Continued)

Scores		1	2	3	4	5	Mean	Standard deviation	Cronbach's alpha
Factor	COD	f(%)	f(%)	f(%)	f(%)	f(%)			
		(0.6)	(13.3)	(23)	(63)	(0)			
	FSDC4	4	12	34	115	0	3.58	0.734	
		(2.4)	(7.3)	(20.6)	(69.7)	(0)			
	FSDC5	2	13	35	115	0	3.59	0.689	
		(1.2)	(7.9)	(21.2)	(69.7)	(0)			

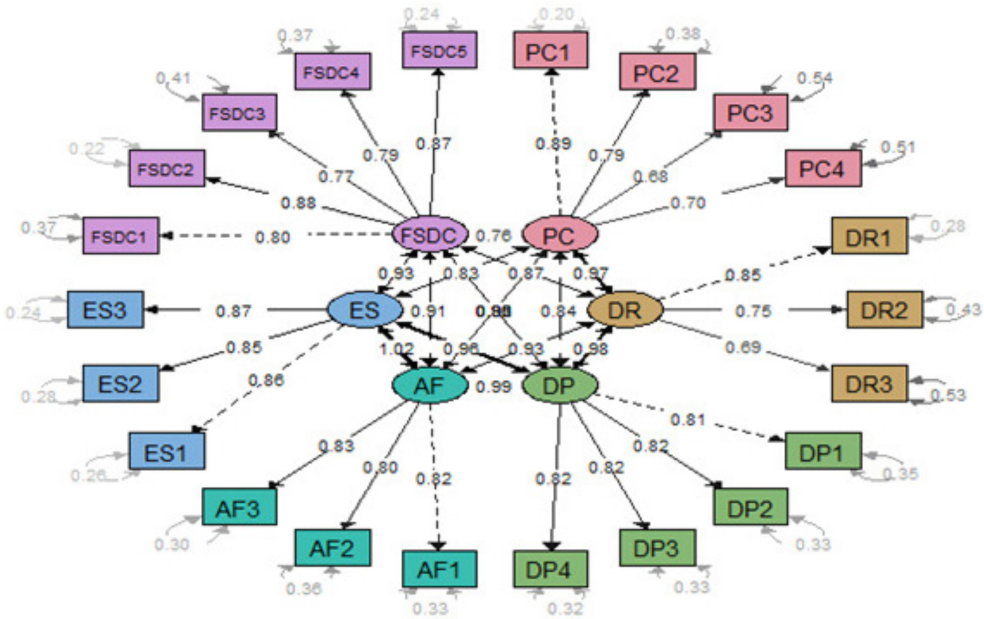

FIGURE 2
CFA model in the latent constructs and their observed indicators.

by direct causal pathways. A noteworthy case is the covariance between PC and FSDC, with a value of 0.76, which is similar to that proposed by the TPACK model, emphasizing the relevance of the convergence between technology, pedagogy and content for teaching in digital environments (Harris et al., 2009a).

The measurement errors associated with the observed variables are small, supporting the reliability of the measurements. Values close to 1 in the coefficients of the loadings suggest that these variables are appropriate to represent the latent constructs and that the committed error is minimal. This coincides with the proposal of Cebrian et al. (2020) who point out the importance of considering both individual and contextual dimensions in the assessment of teachers' digital competencies.

5 Study limitations

This study has certain limitations that should be considered when interpreting the findings. First, a non-probabilistic convenience sample was used, which introduces a risk of selection bias. It is possible that participants with greater interest, familiarity or affinity for digital technologies may have been more motivated to answer the questionnaire, generating an overrepresentation of teachers with higher levels of digital competence. Consequently, there is a possibility of a biased representation towards participants with more developed digital competencies, which could generate an overly optimistic view of the overall picture. This limitation affects the generalizability of the results, as the findings cannot be extrapolated with certainty to the university teaching population as a whole. To address this weakness, it is recommended that future research use probability sampling methods, such as stratified sampling, to adequately represent different teaching profiles in terms of age, experience, area of expertise and level of digital familiarity. Similarly, the combination with qualitative methods can provide a more contextualized and in-depth view of the development of digital competencies in higher education.

Second, the self-administered nature of the questionnaire, based on the adapted "DigCompEdu Check-In" instrument. While this tool is widely recognized for its efficiency in capturing large-scale perceptions, its exclusive use introduces potential biases, especially that of social desirability. This phenomenon occurs when participants tend to provide responses that they consider socially acceptable or valued, rather than accurately reflecting their actual practices (Gower et al., 2022). In addition, self-perceptions may not match observed competencies due to an overestimation or underestimation of one's own abilities, as already pointed out by Bandura (1997) in relation to perceived self-efficacy. This discrepancy may affect the internal validity of the findings, limiting the precision with which the actual levels of digital competence are described. Therefore, it is recommended that future studies integrate complementary validation mechanisms, such as peer review, student feedback or periodic calibration of the instrument, in order to improve the accuracy of the self-assessments and reduce possible biases.

Finally, the absence of objective data on teacher behavior or performance in the use of digital technologies is recognized. By focusing exclusively on self-reported competencies, the study cannot confirm whether these competencies translate effectively into innovative and sustained pedagogical practices. This limitation highlights the need to complement subjective assessments with methodologies that allow direct observation of technology integration in real teaching contexts. Future research could consider the analysis of DR used by teachers, classroom observations or external evaluations of pedagogical performance as strategies to obtain a more comprehensive and validated view of the development of digital competencies.

6 Conclusion

The present study allowed the establishment and verification of a model that describes how the digital competencies of teachers in the Education program affect the adoption of sustainable pedagogical practices and the promotion of digital competencies in students. The results show significant relationships between key constructs, such as FSDC and ES, underscoring the inherent interrelationship of teachers' digital competencies. In this sense, technology is used not only as a technical resource, but also as a means to foster autonomy and collaboration in learning.

The findings support the validity of frameworks such as DigCompEdu and TPACK to guide the assessment and improvement of teachers' digital competence. The importance of considering both PC and DP to ensure educational practices consistent with the demands of an ever-changing digital environment is also evident. This perspective, which addresses the integral development of students, strengthens their capacity to face the technological and educational challenges of the present. Despite the positive aspects identified, the study highlights possible areas for improvement, including multicollinearity between certain constructs, which suggests the need to refine conceptual differentiation. It also highlights the absence of responses at the highest levels.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

Ethical approval was not required for the studies involving humans because ethical approval was not deemed necessary for this study, as it was conducted exclusively online through an anonymous survey platform. Participants were presented with a detailed description of the study's objectives and their rights on the introductory page of the survey. By choosing to complete the survey voluntarily, participants provided implicit consent to take part. Nonetheless, we, as researchers, are fully committed to maintaining the highest ethical standards throughout our work. All data collected is kept strictly confidential and is used solely for the purposes described in the study information provided to participants. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

MC-V: Conceptualization, Formal Analysis, Methodology, Resources, Validation, Visualization, Writing – review and editing. MC-V: Conceptualization, Formal Analysis, Investigation, Methodology, Project administration, Supervision, Writing – review and editing. ES-G: Conceptualization, Investigation, Project administration, Resources, Validation, Visualization, Writing – original draft. FG-V: Conceptualization, Data curation, Formal Analysis, Investigation, Resources, Software, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

The authors declare that no Generative AI was used in the creation of this manuscript.

Publisher's note

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