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Cluster analysis of digital competencies among professors in higher education

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Purpose: This research focuses on the diagnosis and clustering of professor higher education in relation to digital competencies, based on different levels of digital competency development.

Methods: The methodology employed in this study involved an Ordinary Least Squares (OLS) regression analysis and cluster analysis using K-means clustering algorithm, considering the Silhouette score, based on the responses obtained through a questionnaire DigComEdu framework, and adjusted according to the experts who conducted a validity analysis.

Results: The findings indicate that, for the sample professor who answers the questionnaire voluntarily and confidentially, considering margin of error of 5%, a confidence level of 95%, and a response distribution of 50%, corresponding to 314 professors, with a Crombach's alpha of 0.56, there is no relation between the variables of investigation, age, gender, academic degree, academic hierarchy, and years in academy and the level of digital competencies among professors. Regarding the clustering analysis, specifically using the K-means clustering algorithm, four distinct clusters are identified based on the questionnaire scores, aligning with findings from Silhouette score and Quadratic error by number of clusters.

Discussion: This research reveals that professors in higher education span all four levels of competency as defined by the DigComEdu model, primarily falling within the intermediate levels of digital competencies. Clustering analysis further provides insights for the implementation of enhancement and development policies, with the aim of guiding professors toward more complex digital activities, ultimately achieving the highest level of digital competencies. This, in turn, fosters improved teaching practices and, consequently, enhances the teaching experience.

KEYWORDS

digital competencies, TICS, professor, DigComEdu, cluster

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1 Introduction

The use of Information and Communication Technologies (ICT) has grown exponentially in all aspects of human life. In this process of technological advancement and societal transformation, the education sector, especially higher education, cannot remain passive (Muammar et al., 2023). On the contrary, it must take a leading role in contributing to the development of the country.

According to Machado (2021), professors require a process of training and continuous development. This process allows them not only to acquire digital competencies, but also to understand, transform, adapt, customize and use these competencies as tools and resources that improve the teaching and learning processes within their professional practice. Therefore, it is crucial to emphasize the importance of both the initial and continuous training of professors in the use of technology. This is because the quality of education in a country is rooted in the quality of training and continuous learning of its educators.

The inclusion of digital literacy in the educational context is in line with the digital transformation and its integration into the knowledge society. Consequently, it has emerged as one of the key competencies to be acquired by today's individuals. Therefore, it has become a fundamental pillar not only for the European educational system, but also worldwide. Considering the professor as the main person in charge of providing his students with the essential competencies for lifelong learning (Banquez et al., 2021; Dias-Trindade and Santo, 2021).

Due to the global pandemic of COVID-19 (de Obesso et al., 2023), Information and Communication Technologies (ICT) have been urgently integrated into educational systems on a large scale. In this context, it is essential for the professor to possess a range of basic digital literacies and to demonstrate digital leadership in the classroom. Furthermore, it is necessary to consider the relationship between the development of digital literacy and social sustainability, i.e., social and cultural heritage, and to what extent they contribute to improving social cohesion and living conditions within a community, especially in public universities where social sustainability is one of their pillars, i.e., social sustainability (De la Calle et al., 2021)

However, both professors and students must be able to use technology in an educational context in a way that fosters the creation of innovative learning environments. For this to happen, it is imperative that professors and students adapt to the changing times and learn to use digital technologies pedagogically in the educational process. Daily use of technology does not necessarily mean its effective integration, especially since in these new learning scenarios, education transcends physical boundaries. In today's reality, learning also takes place using mobile devices connected to wireless communication networks, sensors and geo-location mechanisms that allow the formation of virtual networks between individuals, objects and situations. Indeed, the use of technology for teaching or learning, extending learning to informal or non-formal settings, requires the possession of skills and digital fluency (Dias-Trindade et al., 2020). Therefore, it is crucial not only to know how to use digital technology, but more importantly, to know how to use it pedagogically to enhance the quality of the teaching and learning process (Ozan and Kesim, 2013). For this to happen, it is imperative not only to change the pedagogical paradigm, but also to establish new policies and training models to facilitate a proper digital transformation. According to Dias-Trindade and Ferreira (2020), the question that arises is not only related to the use of technology and the existence of digital literacy, but, more profoundly, it concerns the understanding of how to effectively use this technology to achieve desired goals. In other words, what it takes to become a truly digitally fluent user. Both professors and students must strive to learn to work in these digital environments. They also need to become proficient in the use of various tools, with professors having additional responsibilities in this process, as they are the architects of these environments.

In these cases, the research results of Dias-Trindade and Ferreira (2020) underline the need for professors to increase their level of digital literacy through targeted training, especially in the pedagogical use of technology. This training should be practical and experiential. Therefore, it should be focused on working with tools, platforms or interfaces, involving both professor and students. In this way, professors will feel confident in using digital technologies not only in collaboration with their colleagues, but especially with their students.

In the current context, course materials are made available to students through digital platforms, handouts have become digital copies, and the traditional blackboard has been replaced by slide presentations or digital whiteboards. In addition to their role as educators, faculty must continue to engage in other related activities, such as collaborative research, conference participation, and various administrative tasks. For all these tasks, a digital skills base is essential, and these skills continue to evolve as technology advances (Cuadrado et al., 2020).

According to Basilotta-Gómez-Pablos et al. (2022), there is a growing interest in understanding the state of digital literacy among university professors. These competencies include the knowledge, skills and attitudes necessary for educators to use technologies effectively.

This research focuses on the diagnosis of the digital competencies of professors in crucial areas within higher education, clarifying whether there are connections between qualitative and quantitative variables related to academic development, and then a process of grouping professors considering the variables and their level of digital competencies will be carried out. Grouping the variables and the level of digital competence of professors will allow institutions to focus their efforts according to the diagnosis made through the questionnaire applied, allowing academics to advance in the development of digital competence, improving their teaching process.

2 Literature review

In the present day, the world is undergoing the Fourth Industrial Revolution. Current advancements are unfolding at an unprecedented pace in historical terms. When compared to previous industrial revolutions, this Fourth Industrial Revolution has evolved at an exponential rate rather than a linear one, affecting a multitude of industries across all countries. The breadth and depth of these changes have consequently led to the transformation of entire systems of production, management, and governance. However, the education sector appears to have remained relatively unaffected by these developments.

Planning amidst uncertainty is the current challenge confronting the field of education. From traditional school education to professional development and lifelong learning, governments and businesses alike need to prepare current and future generations to thrive in the Fourth Industrial Revolution and prepare for the Fifth. However, it is evident that following the traditional path of skill transfer through education no longer proves effective. The skills required for the contemporary workforce are evolving so rapidly that no educational system can keep up with the pace of constantly reinventing how we work and coexist (Gap, 2017).

In this context, as per Torres-Flórez et al. (2022), the World Economic Forum (2020) identifies four interconnected interventions to drive the transformation of education: (i) Implementing new measurement mechanisms for 4.0 education skills. (ii) Integrating technology-enhanced learning experiences for 4.0 education. (iii) Empowering the 4.0 education workforce. (iv) Establishing standards and priorities for 4.0 education.

Nevertheless, the digital revolution has yet to be matched by conventional transformations in educational systems, teaching, and learning. Research from the Massachusetts Institute of Technology suggests that students' brain activity while listening to professors in classroom lectures is lower than when they are asleep. Furthermore, the mixed findings regarding the impact of technology use on student outcomes underscore the need to rethink how educators are utilizing technology to support learning. This underscores the necessity for new teaching that leverage technology to address the challenges of the 21st century, promote peer learning in global educational systems, and catalyze the development of essential cross-cutting competencies: problem-solving, collaboration, and creativity. Such teaching should rely on student-professors learning partnerships, harnessing their intrinsic motivation and integrating knowledge, pedagogy, and system-changing technology (Caena and Redecker, 2019).

The Lisbon European Council proposed the creation of a New European reference framework to define the new basic qualifications that lifelong learning should provide (European Parliament, 2000). This measure is considered essential to respond to the phenomenon of globalization, transforming the socioeconomic landscape with policies based on the knowledge of society. In this line, the Stockholm European Council recommends, as its primary objective, the improvement of basic skills, especially in digital and information technology (Force, 2021). This priority also emphasizes the need to enhance education policies based on the development of lifelong competencies according to Cabero-Almenara et al. (2020) and de Obesso et al. (2023). One of these key competencies is digital competence, understood as the safe, critical, and responsible use of Information Society technologies for work, entertainment, and education (Schola Europaea, 2018). The ability to use technology for living, working, and learning throughout life is considered a fundamental and cross-cutting theme in the development of any educational program. From this perspective, it is crucial to emphasize the importance of comprehensively harnessing and integrating technology in educational institutions (Cabero-Almenara et al., 2020).

The digital society has transformed the way information is accessed, communication occurs, and learning takes place. Therefore, digital competencies are crucial for fostering continuous learning in line with new scenarios (Cabero-Almenara et al., 2021). Students and professors in each field of knowledge should respond to the continually evolving challenges posed by the digital society. Hence, it is a necessary requirement to enhance the development of digital competencies. Digital Competence of Educators (DCE) can be defined as the set of knowledge, skills, and/or abilities related to information and communication technology (ICT) relevant to the teaching profession, which can assist educators in addressing professional and/or pedagogical challenges encountered in the knowledge society (Cabero-Almenara et al., 2021).

The origin of the competency-based teaching and learning approach is the result of social changes in recent decades. However, it has only been in recent years that the rapid expansion of globalization has become evident. Indeed, the constant evolution of Information and Communication Technologies (ICT), the exponential creation of information, the use of various digital resources and media, their unprecedented consumption, the demand for educational platforms enabling distance teaching and learning, and the urgent shift from face-to-face teaching to the recently coined "emergency remote teaching," (Trust and Whalen, 2020), prompted by the COVID-19 health crisis are some of the clearest examples of Basilotta-Gómez-Pablos et al. (2022).

Professors play a key role in the integration of technologies and are crucial in the adoption and implementation of ICT in the classroom. The transformation and improvement of education depend, among other factors, on educational action. This implies that educators must possess effective digital competencies enabling them to integrate and use technologies pedagogically (Basilotta-Gómez-Pablos et al., 2022; Núñez-Canal et al., 2022).

To assess and determine the level of digital competence among university professors, it is necessary to have reference frameworks and theoretical models that identify the dimensions and components of digital competence. An example of this is the research conducted by Bennett (2014), which explores how the digital literacy framework proposed by Sharpe et al. (2010), can be applied to the digital literacy practices of university professors, suggests that there is a relationship between attributes, practices, skills, and access in digital literacy linked to motivation and ownership in developing experiences.

As a result, a revised version of this model is developed and applied to professors. This model is called the Digital Practitioner Framework (DPF) and represents the concept of a digital practitioner proposed by Ecclesfield et al. (2012). The DPF is particularly intended to model the characteristics likely to be found in professors who embrace technology in their teaching and learning practices. The communicative practitioner whose focus has shifted toward initiating, supporting, and facilitating learning, and whose expertise lies in both subject knowledge and the ability to use technology and develop its use in students, opens up the ecology of knowledge and learning. This creates contexts for generating "obuchenie" (teaching and learning at the same time) where learning and teaching can merge in collaboration. There are indicators of this in the data emerging from the study on which Ecclesfield's research is based, showing that many professionals are open to the possibilities afforded by digital technologies in their practice, as well as contributing to the utilization and development of these very technologies (Ecclesfield et al., 2012).

The study by Mirriahi et al. (2015) presents a framework for learning activities, support, and assessment, considering professor' proficiency in these environments. This framework enables the advancement of teaching in higher education. On the other hand, Blayone et al. (2018) have selected the General Technology Competency and Use framework to conceptualize and measure the digital competencies of professors. This model identifies three dimensions of digital competence: epistemological, informational, and social.

However, Dias-Trindade and Ferreira (2020), Balula et al. (2022) present preliminary results of a pilot study that confirm the relevance of the DigCompEdu checking as a self-assessment model to determine the level of digital competence of a professor.

According to Basilotta-Gómez-Pablos et al. (2022), and based on the categories mentioned earlier, the results of empirical studies on the level of digital competencies among professors in higher education have been analyzed. While these studies have been conducted using various tools and strategies, most of them rely on professor' self-perception. In general, the selected sources argue that professors possess moderate levels of digital competence (Guillén-Gámez and Mayorga, 2019; Montoro et al., 2015; Romero-Rodríguez et al., 2019, as cited in Basilotta-Gómez-Pablos et al., 2022). These competencies include the ability to solve problems using ICT, work with a network of contacts, and use 2.0 tools for assessment. Additionally, Blayone et al. (2018) add technical competence (creating and editing documents, managing online accounts, etc.), social competence (communicating via email, sending and receiving messages, participating in social networks, etc.), information competence (finding and using articles, news, and videos, etc.), and epistemological competence (time management, organization, and presentation of complex information, etc.), with the latter being the least well- performed.

According to Santos et al. (2021), the results of their research indicate that characteristics such as being enrolled in a doctoral program, teaching online classes, and being affiliated with polytechnic institutes are associated with higher levels of digital competence.

Furthermore, Guillén-Gámez et al. (2022) suggest that professors with 15 or more years of experience represent the group with the most significant differences in terms of their level of digital competence when comparing the use of three types of ICT resources. These results were consistent across all areas of knowledge.

On a different note, Cabero-Almenara et al. (2021) demonstrate that there are differences in professor' digital competencies based on gender and field of expertise (Morante et al., 2023).

Adicional, the study by Rodríguez Hoyos et al. (2021) suggests that, beyond the technological devices used, the innovative nature of experiences is related to how professors engage in projects designed for innovation and improvement, maximizing their potential for communication and information access.

In relation to the results obtained after evaluating digital competencies, which have gained importance among professors in recent years in the field of educational research, there are differing perspectives. Dzikite et al. (2017) found in their research that professors had limited knowledge and skills in ICT for their teaching practice, and they lacked adequate technological-pedagogical content knowledge essential for teaching in the digital society. Based on the study's results, the document recommends the need for universities to enhance professors' technological-pedagogical content knowledge through continuous professional development in order to implement ICT critically. On the other hand, Rodríguez Hoyos et al. (2021) suggest that university professors have sufficient digital competencies.

These differing findings could be attributed to variations in the sample, context, or methods used in the respective studies, and they highlight the importance of considering various perspectives and conducting further research to gain a comprehensive understanding of professor' digital competencies.

According to Ojeniyi and Adetimirin (2016), they suggest that there is a significant and positive relationship between ICT literacy and the use of electronic resources by professors, indicating that proficiency in ICT can enhance professors' utilization of electronic resources.

However, Cabero-Almenara et al. (2021) point out that there are few studies that comprehensively analyze and compare the digital competencies of professors in each of the knowledge fields attributed to professors. The aim of such studies would be to establish specific training actions that align with the professional context within which professors conduct their academic work. Addressing this training deficit would enable the proper use of technology in teaching and learning scenarios that are appropriate for their educational and research profiles.

These differing viewpoints underscore the need for further research and tailored training approaches to enhance professors' digital competencies across various academic disciplines.

The DigCompEdu model enables educators at all educational levels to synthesize competencies into a consistent model, allowing them to assess and comprehensively develop their pedagogical digital competence. This is illustrated in Figure 1.

3 Materials and methods

3.1 Instrument

The data were collected using a questionnaire instrument, administered via the Qualtrics software, between December 19, 2022, and January 10, 2023 (Supplementary Appendix 1). The questionnaire was developed based on the digital competencies presented in the European Framework for the Digital Competence of Educators (Redecker and Punie, 2017), the model is of use for research on professors' digital competencies (Balula et al., 2022; Barzabal et al., 2022; de Obesso et al., 2023; Muammar et al., 2023; Núñez-Canal et al., 2022; Val and López-Bueno, 2024). It was validated by experts in the educational field, which helped adjust the specificity level of the questionnaire's questions.

The areas comprising the European Framework for the Digital Competence of Educators are as presented in Figure 1.

The six areas of DigCompEdu focus on different aspects of educators' professional activities, according to Table 1.

The questionnaire begins with a consent section for respondents, in which they are informed about the protection of anonymity and confidentiality of the data, then questions are asked to characterize the professors who respond voluntarily, and finally a definition is provided for each of the six modules included in the questionnaire. Each question has the same weight regardless of the module in which it is found, and the answers are ordered in graduation for points, that is, the first answer indicates a low level of digital competencies and the answer 6 the highest level of digital

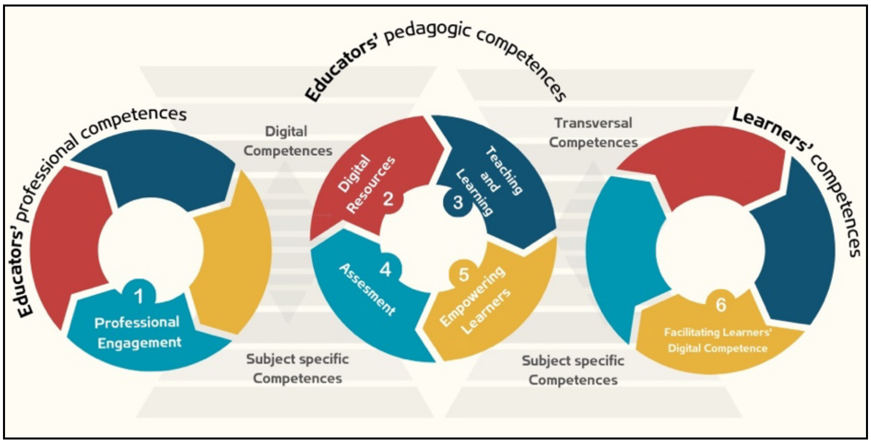

FIGURE 1
DigCompEdu model. Source: Own elaboration based on Redecker and Punie (2017).

TABLE 1 Digital competence areas.

Module	Description	Number of items	Question details
1: Professional engagement.	Using digital technologies for communication, collaboration, and professional development.	4	Organizational communication, Professional collaboration, Reflective practice, Digital Continuing Professional Development (CPD)
2: Digital resources.	Searching, creating, and sharing digital content.	4	Selection, Creation and modification, Management, sharing and protection
3: Teaching and learning.	Managing and organizing the use of digital technologies in teaching and learning.	4	Teaching, Guide, Collaborative learning, Self-directed learning
4: Assessment	Using digital technologies and strategies to enhance assessment.	3	Assessment Strategies, Learning Analytics, Feedback and planning
5: Empowering learners.	Using digital technologies to enhance inclusion, personalization, and active student engagement in their own learning.	3	Accessibility and inclusion, Differentiation and personalization, Active student participation
6: Facilitating Learners' Digital Competence	Training students to creatively and responsibly use digital technologies for information, communication, content creation, well-being, and problem-solving.	5	Information and media literacy, Digital Communication and Collaboration, Creating digital content, Responsible use and well-being, Digital problem solving

Source: Europea Commissión (2022).

TABLE 2 Classifications and point ranges.

Classification	Points
Novice (A1)	Less than 23
Explorer (A2)	23 – 38
Integrator (B1)	39 – 56
Expert (B2)	57 – 74
Leader (C1)	75 – 91
Pioneer (C2)	92 or more

Source: Europea Commissión (2022).

competencies in teaching, assigning as a system score each time the professor has given an answer, so that at the end of answering 100% of the questionnaire, the professor receives his rating according to the levels of his teaching digital competencies.

The questionnaire aimed to assess and diagnose the professor' digital competencies according to the levels defined in the European Framework: Novice (A1), Explorer (A2), Integrator (B1), Expert (B2), Leader (C1), and Pioneer (C2), considering the following points (Table 2).

3.2 Data

The application was carried out at a state public university in Chile, which, according to its public information (Institutional Self-Evaluation Report, 2022), indicates that the permanent professor staff comprises 1135 members, to whom the survey was sent via institutional email. Initially (question 1), the survey informed about data protection and consent. Considering the population of the institution, a representative sample of the population was calculated with a margin of error of 5%, a confidence level of 95%, and a response distribution of 50%. This allowed for identifying a corresponding sample of 288 professors to respond to the instrument. Eventually, a larger number of professors, 314, completed the instrument, thereby obtaining the sample.

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TABLE 3 Information from Academics who responded to the survey.

Academic area		Age					Gender			Academic degree				Academic hierarchy				Years in academy				
	Fre cuency	Less than 30 years	Bet ween 30 and 40 years	Bet ween 40 and 50 years	Bet ween 50 and 60 years	Older than 60 years	Fe-male	Male	Other	Gra-du-ate	Mas-ter	Ph.D.	Post Degree	Hel per	Assis tant	En clouse	Hol der	Less than 5 years	Bet ween 5 and 10 years	Bet ween 10 and 15 years	Bet ween 15 and 20 years	Over 20 years
Health sciences	76	0	21	22	27	6	61	15	0	14	51	10	1	6	22	39	9	10	14	19	17	16
Economic sciences	49	0	9	9	20	11	19	30	0	2	43	4	0	1	7	23	18	3	6	11	5	24
Engineering	45	0	12	17	10	6	12	33	0	2	25	13	5	1	13	21	10	6	9	8	11	11
Social sciences	44	0	6	15	18	5	26	18	0	2	19	21	2	3	8	20	13	3	6	13	13	9
Sciences	18	1	5	7	3	2	5	13	0	2	4	2	10	1	5	4	8	2	6	4	5	1
Mathematics	12	0	3	3	1	5	2	10	0	3	5	3	1	1	4	6	1	2	1	2	1	6
Education	12	0	2	5	3	2	11	0	1	0	7	4	1	0	5	5	2	1	2	2	2	5
Law	11	0	3	1	6	1	5	6	0	2	3	6	0	2	3	4	2	1	2	1	1	6
Dentistry	10	0	2	5	1	2	3	7	0	4	6	0	0	1	2	6	1	2	1	0	3	4
Arts	9	0	2	2	3	2	3	6	0	2	4	2	1	0	1	4	4	1	2	0	1	5
Architecture	8	1	1	0	4	2	2	6	0	4	4	0	0	1	2	1	4	1	1	0	1	5
Humanities	7	0	1	2	2	2	4	3	0	1	2	2	2	0	2	4	1	0	2	2	1	2
Marine sciences	7	0	0	5	1	1	3	4	0	1	1	2	3	0	0	6	1	1	1	3	0	2
Pharmacy	6	0	3	1	2	0	5	1	0	0	3	3	0	0	1	4	1	1	0	2	0	3

It is noteworthy that 498 professors attempted to complete the instrument but did not answer all the questions; however, only those who completed 100% of the questions were considered for the study. Additionally, Crombach's alpha was calculated for the questionnaire, which yielded 0.56. The information characterizing the professor who responded to the questionnaire is presented in Table 3.

3.3 Clusters

Data analysis focused on determining clusters from the responses of the professor who completed the questionnaire. The K-means clustering algorithm from scikit-learn was used to group the data into clusters based on similarities. The k-means methodology is employed in this research due to its relatively rapid processing speed, straightforward methodological comprehension, and extensive practical utilization (Raykov et al., 2016). This facilitates the straightforward implementation of this approach by other practitioners in the context of monitoring and implementing digital competencies. Nevertheless, there are more sophisticated alternatives for cluster implementation, including partition-based clustering, hierarchical clustering, and others, which could be used in place of k-means.

In the K-means clustering algorithm, the distance between a data point and a centroid was calculated using Euclidean distance. The Euclidean distance formula between two points, *P1(x1, y1, ..., zn)*, and *P2(x2, y2, ..., zn)*, in an n-dimensional space is shown in Equation 1:

$$dist\,(P1, P2) = sqrt((x2 - x1)^2 + (y2 - y1)^2 + \ldots + (zn - z1)^2) \qquad (1)$$

In the context of the K-means clustering algorithm, data points are assigned to the nearest centroid based on the calculated distance.

The traditional K-means clustering algorithm indeed uses various distance measures, including the Euclidean metric, city block distance, Pearson correlation, absolute value correlation, absolute non-central correlation, Spearman rank correlation, and Kendall's tau. However, the Euclidean distance is the most employed metric in the traditional K-means clustering algorithm, as noted by Giannella (2021).

The Euclidean metric according to Drusvyatskiy et al. (2017) and Morin et al. (2020), also referred to as Euclidean distance, represents a widely adopted definition of distance that denotes the actual distance between two points within an m-dimensional space or the inherent length of a vector (i.e., the distance from the given point to the origin). In two and three dimensions, Euclidean distance corresponds directly to the physical distance between two points (Lei et al., 2017).

The K-means clustering algorithm, well known in the field of unsupervised learning, serves as an essential tool to solve complex problems in the classification and clustering of unlabeled data (Sinaga and Yang, 2020). This approach, which we refer to as K-means clustering algorithm, involves a meticulous process of categorizing data sets into a predefined number of clusters, each defined by the strategic placement of k centroids. The placement of these centroids plays a critical role, as their variation leads to divergent results.

The effectiveness of the process is magnified when maximizing the separation between different clusters, resulting in greater internal coherence within each grouping. Determining the optimal number of clusters, k, becomes a crucial question, aiming to achieve the maximum distance calculated from the dataset. One of the methodologies employed for this purpose is the elbow method, which seeks to visualize the point at which the benefits of adding more clusters become marginal.

For the precise choice of k, a practical technique suggests comparing the results obtained from multiple runs with different values of k, selecting the one that best fits the predetermined criteria. It is worth noting that a high value of k tends to reduce clustering error; however, it also increases the likelihood of overfitting, a phenomenon in which clusters adapt excessively to the peculiarities of the input dataset.

In conclusion, the K-means clustering algorithm proves to be a powerful resource in exploratory data analysis, enabling the identification of underlying patterns and latent structures. Still, its application requires a judicious selection of parameters to ensure robust and consistent results in line with the nature of the analyzed data.

For a dataset $CLUSTER = \{clus_1, clus_2, \ldots, clus_N\}$, $clus_n \in R_{,,}$ we define K-means clustering algorithm dependents on a set of centroids m1, m2, ..., mM and a subset $C_k \in C$ which contains $clus_i$ as Equation 2:

$$\arg\min_{C} \sum_{i=1}^{N} \sum_{k=1}^{M} I\left(Clus_i \in C_k\right) ||x_i - m_k||^2, \qquad (2)$$

where I(CLUSTER) = 1 if CLUSTER is true and 0 if not. In particular, we will employ a K-means clustering algorithm to determine the number of states present in the experimental data obtained in this research (Likas et al., 2003; Mohamad and Usman, 2013).

The fundamental principle underlying the elbow criterion is rooted in computing the squared distances between the sample points constituting each cluster and the centroid representing that cluster. This computation results in a series of K values. The cumulative sum of squared errors (SSE) is harnessed as a performance metric, providing a quantitative assessment of clustering quality. The iterative procedure involves systematically varying the K-value and subsequently calculating the SSE. Reduced SSE values are indicative of a heightened convergence within individual clusters.

As the count of clusters is incrementally adjusted to approximate the true number of underlying clusters, the SSE exhibits an initial steep descent. Nevertheless, upon surpassing the actual number of clusters, the decline in SSE continues, albeit at a decelerated pace.

The K value can be better determined by plotting the K-SSE curve and by finding the inflection point down. As shown in Figure 2, there is a very obvious inflection point when K = 4.

The Silhouette method was originally introduced by Kaufman and Rousseeuw (2009). This technique harmonizes the dual aspects of cohesion and resolution. Cohesion denotes the degree of similarity between an object and its respective cluster, while the term separation pertains to the dissimilarity between an object and

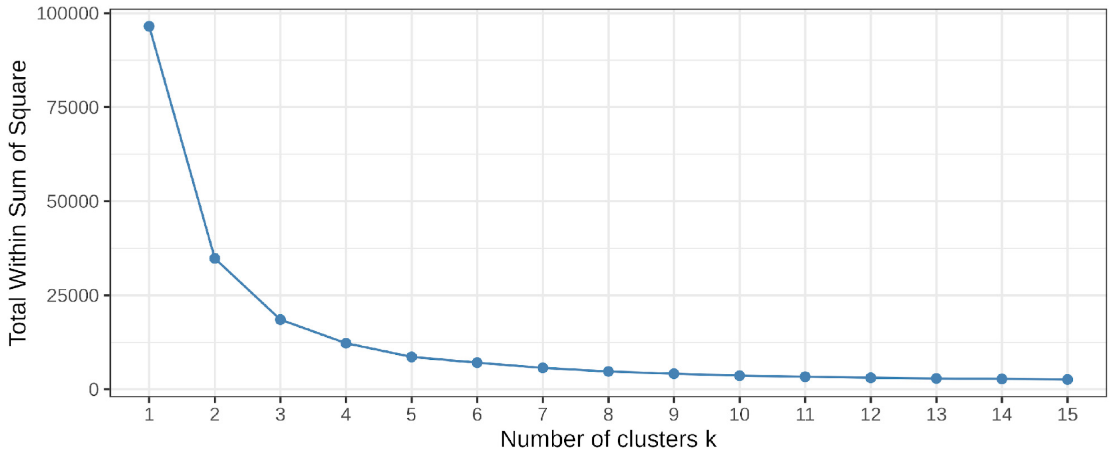

FIGURE 2
Quadratic error by number of clusters.

other clusters. This comparative assessment is facilitated through the Silhouette value, which ranges from -1 to 1. A Silhouette value proximate to 1 signifies a strong association between the object and its assigned cluster. Consequently, when a data cluster within a model yields a notably high Silhouette value, the model is deemed suitable and acceptable.

For a given number of clusters where $clus_i \in C_k$, we have Equations 3–5:

$$a(i) = \frac{1}{|C_k| - 1} \sum_{j \in C_k,\ ij} dist(clus_i,\ clus_j) \tag{3}$$

$$b(i) = \min_{ij} \frac{1}{|C_k|} \sum_{j \in c_k} dist(clus_i,\ clus_j) \tag{4}$$

$$s(i) = \begin{cases} \frac{b(i)-a(i)}{\max(a(i),\ b(i))}, & if\ |C_k| > 1 \\ 0, & if\ |C_k| = 1 \end{cases} \tag{5}$$

Indeed, in the equation you provided, C_k represents the number of elements within cluster k, and dist() corresponds to the distance between two points as defined in Equation 1.

4 Result

4.1 Questionnaire application

The results obtained from the questionnaire administered over a 30-day period through Qualtrics software provide the following description in Table 4:

4.2 Relationship among variables

The variables studied were related using a model that show in Equation 6 corresponding to an Ordinary Least Squares (OLS) regression model, that is equivalent to a further development of the simple correlation analysis, which takes into account variables such as age, gender, degree, university positions, professional years, academic field, faculty affiliation, points obtained in questions related to digital competencies, and classification based on the levels for digital competencies.

$$Point_i = \beta_0 + \beta_1 age_i + \beta_2 Profesionalarea_i + \beta_3 gender_i + \beta_4 topdegree_i + \beta_5 academicarea_i + \beta_6 faculty_i + \epsilon_i \tag{6}$$

The analysis considers three models, based on the grouping of variables specified in the previous paragraph. The first model includes variables such as age, gender, professional years, and degree. The second model adds the academic area as a qualitative variable, which is incorporated as a dummy variable. Finally, the third model includes both the academic area and the faculty to which the professor belongs, with both being incorporated as dummy variables in the analysis. The coefficients for the academic area and faculty are deliberately omitted for better clarity in the results (Table 5).

The variables associated with the three OLS regression models show that there is no statistical evidence to associate academic digital competence scores with any of the variables considered in the analysis. Therefore, it is not possible to associate teaching digital competencies with the characterization of the public university professors studied.

4.3 Clusters

When developing the K-means clustering algorithm, the following graph is presented, based on the mean squared error. Figure 2 illustrates an optimum of four clusters.

To complement the previous process, we can use an alternative technique for identifying the number of clusters based on classification (points) through a silhouette analysis. This analysis helps identify the number of clusters and is illustrated in the scatterplot using t-SNE in Figure 3.

In addition, to confirm the number of clusters, a different visualization was used for the Silhouette metric, which allows

TABLE 4 Frequency table of classifications by area of work.

Area	Novice (A1)	Explorer (A2)	Integrator (B1)	Expert (B2)	Leader (C1)	Pioneer (C2)
Architecture	0	0	1	5	1	1
Arts	0	0	1	4	1	3
Sciences	0	1	7	8	2	0
Economic sciences	0	1	7	13	18	10
Social sciences	0	0	6	21	13	4
Health sciences	0	1	20	36	13	6
Marine sciences	0	0	2	2	3	0
Law	0	1	3	2	3	2
Education	0	0	1	5	5	1
Pharmacy	0	0	1	1	2	2
Humanities	0	0	2	3	1	1
Engineering	0	0	8	21	11	5
Mathematics	0	0	5	5	2	0
Dentistry	0	0	2	4	2	2

TABLE 5 Correlation models.

	(1)	(2)	(3)
	Points	Points	Points
Age	−0.334	−0.220	−0.279
	(−0.25)	(−0.16)	(−0.20)
Profesional years	1.041	0.652	0.736
	(1.01)	(0.63)	(0.70)
2. Gender	−0.227	−1.366	−1.398
	(−0.12)	(−0.62)	(−0.62)
2. Degree	4.407	2.161	1.960
	(1.43)	(0.67)	(0.61)
3. Degree	4.002	2.860	3.225
	(1.15)	(0.77)	(0.86)
4. Degree	−2.108	−0.619	1.362
	(−0.48)	(−0.13)	(0.27)
cons	64.84*** (15.39)	69.16*** (13.40)	67.49*** (12.91)
N	313	313	313

st statistics in parentheses. $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

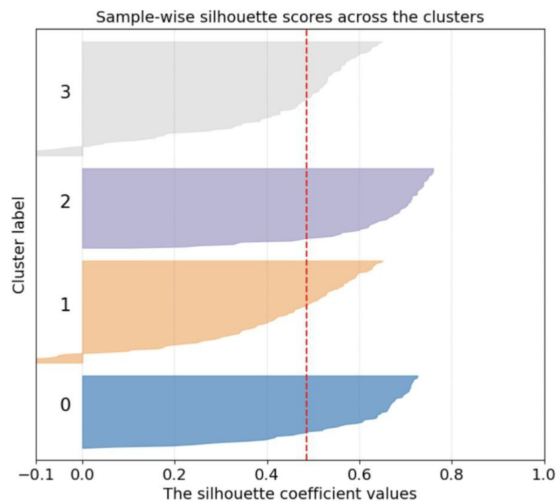

FIGURE 3
Silhouette metric with clusteval.

confirmation through the visualization of the numbers of clusters with Figure 4.

The Silhouette coefficient and its values, as shown in Figures 3, 4, indicate that the optimal number of clusters is 4, which is consistent with the elbow method. Based on the number of clusters, a graphical analysis of cluster identification was performed using HNET—Association ruled based networks using graphical Hypergeometric Networks. The presented graph indicates that the clusters are based on the points related to the academic competencies of the professor, as shown in Figure 5.

According to Figure 5, the clusters are based on the variable associated with the categories determined by the points (classification) obtained from the digital competencies of the professor. The axes correspond to variables that represent the reduction of dimensionality to represent the composition of the clusters in a two-dimensional space. There are four clusters organized according to the points obtained in the questionnaire on the digital competencies of the professor. Additional variables are not correlated with digital competencies based on the accompanying questions.

Identifying four clusters based on the points obtained from the digital competencies of professors, it is possible to classify them in fewer groups than those established by DigComEdu, this classification allows considering that professor can develop digital competencies independently of another characteristic they possess, for example age, gender, area in which they work, faculty to which they belong, hierarchy, or other included in this research.

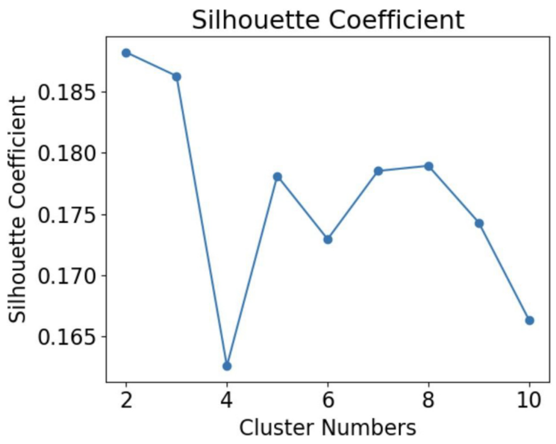

FIGURE 4
Silhouette coefficient with sklearn.

Moreover, the calculated centroids permit the undertaking of qualitative analyses on the behavior of the groups in accordance with the variables of which they are composed. This offers a distinct advantage over the alternative of utilizing information extraction methodologies, such as PCA, since these alternatives preclude the possibility of conducting the qualitative analysis that the approach described in this research does provide. Therefore, this clustering allows concluding that it is possible to advance in supporting the development of digital literacy in an institution independently of other variables, so that efforts can be made at the macro level or at the institutional level. In other words, with appropriate training and support, differentiated activities can be developed for these four identified clusters, based on digital teaching competencies and not on other characterization variables.

5 Discussion and conclusion

5.1 Discussion

The structure of the applied questionnaire, DigCompEdu, allowed the diagnosis to be made according to the research conducted and to define the category in which the professors in the sample were found, which is in line with Dias-Trindade and Ferreira (2020), who confirm the relevance of the DigCompEdu check as a self-assessment model to determine the level of digital competence of a professor.

In the course of the research, progress was made in the digital competencies of the professor, identifying fourth groups or clusters based on the diagnostic level of each professor. These clusters correspond to the means of the last four groups of digital competencies, which means that there are no professors who self-diagnosed themselves in the lower ranges. Therefore, specific clusters for the levels of Novice and Explorer were not generated. This aligns with the findings of previous research that suggests the need for new pedagogies that use technology to address the challenges of the 21st century and that professors have made progress in recent years (Caena and Redecker, 2019; Rodríguez Hoyos et al., 2021).

The constant evolution of Information and Communication Technologies (ICT), the demand for educational platforms that enable distance teaching and learning, and the urgent shift from in-person teaching to the recently termed emergency remote according Trust and Whalen (2020) teaching due to the COVID-19 pandemic are some of the clearest examples of this revolution (Basilotta-Gómez-Pablos et al., 2022). These developments have allowed professors to advance in digital competencies in the

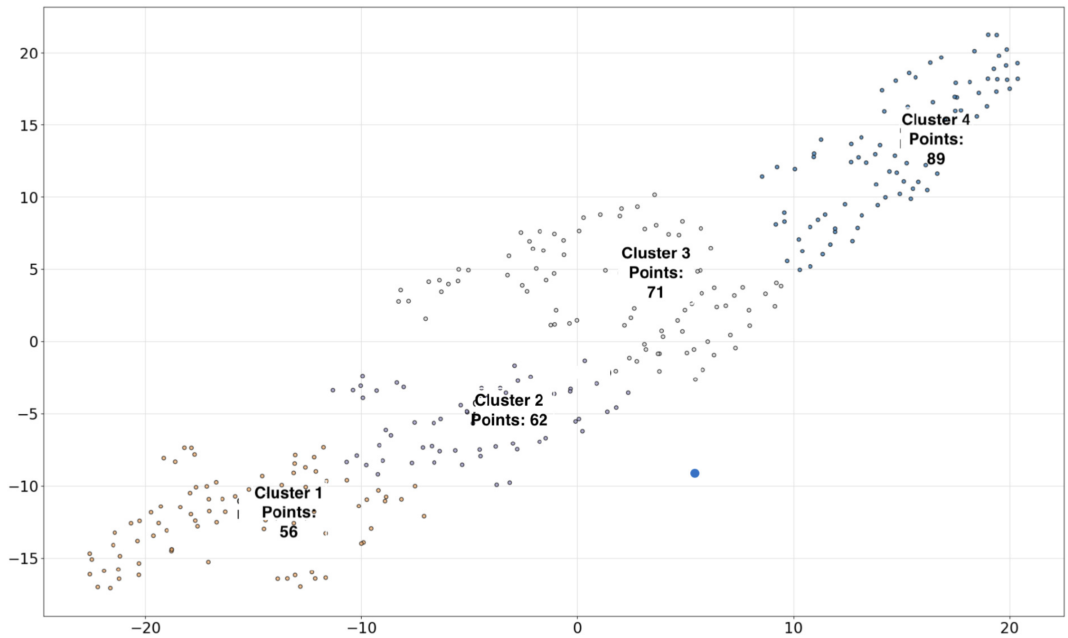

FIGURE 5
K-means clustering. Own elaboration based on clusteval; cluster: agglomerative, metric: euclidean.

processes of teaching and learning, as reflected in the higher categories proposed by DigCompEdu.

The Digital Practitioner Framework (DPF), which represents the concept of a digital practitioner proposed by Ecclesfield et al. (2012), is linked to the development of competencies demonstrated by the professor who responded to the questionnaire. They actively engage in digital competencies, showing motivation through their responses and self-assessment, aiming to continue improving.

In the case of the results presented through the questionnaire responses, it can be observed that there is no relationship between the variables in this context. Therefore, the assertion made by Guillén-Gámez et al. (2022), stating that professors with 15 or more years of experience represent the group with significant differences in their level of digital competence when comparing the use of ICT, is not reflected in this research. Consequently, when improving digital competencies, there is no requirement to make distinctions based on the other variables considered in this study.

On the other hand, Cabero-Almenara et al. (2021) show that there are differences in the digital competencies of professors based on gender and area of performance. However, in this research, there is no distinction or connection with gender or the area of performance. Therefore, the development of improvement is solely based on the level of digital competencies as reflected by the obtained scores.

For comparative purposes with previous research, the progress in the use of technology for teaching purposes is reflected in the research, and especially with the diagnosis that the questionnaire allows by generating a classification of professors according to the responses, and that for the sample the concentration of responses is focused on the middle and high levels, not so in the two initial levels. On the other hand, previous research related variables of age, gender and area of development with the level of digital literacy, this research shows that there is no correlation of these variables with the level of digital literacy of professors.

5.2 Conclusion

The study highlights the confirmation and validity of the proposed classification model. When applying the instrument, the data were naturally grouped into the four levels proposed by DigCompEdu (Integrator, Expert, Leader, Pioneer), which supports the usefulness and applicability of the model in the context of teaching in higher education. This model can provide a reliable classification of digital competence, measuring the professors' skills and technological expertise in the classroom.

Identifying the digital competence of professors allows policy makers to make informed decisions and focus activities and resources based on the analysis obtained. The promotion of professors to higher levels of digital literacy, with the proposed reinforcement activities, is beneficial for future professionals who will generate new knowledge.

A noteworthy aspect of this research is to be able to advance in the development of digital competencies of professors, and by considering in this study that there are no variables that have influenced the classification of a professor in a level of digital competencies, it allows the institution to advance in a macro-teaching way in the development of digital competencies, taking into account the category level to which the professor belongs and the level to be achieved. This can lead to the establishment of clear development goals.

A limitation of the research is the depth of the instrument. To address this, it would be beneficial to include a greater number of questions that allow for a more in-depth analysis of each dimension. This would facilitate a more accurate classification of clusters with more homogeneous elements. However, it is important to consider that increasing the number of questions may also have a detrimental impact on the effectiveness of the instrument in obtaining the required information. This is due to the possibility of a higher number of people who would be unwilling to answer. A further limitation of this research is that for grouping purposes we worked with the variables, without using PCA for modeling.

As a future research opportunity, the study could be validated by means of other classification techniques to observe the robustness of the proposed methodology. Another avenue for future development could be the measurement of the absorption of digital competences, with a particular focus on other stakeholders in the education system, such as students at different levels and in different areas of knowledge, or administrative staff, and their impact on the educational process.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

Author contributions

KCH-J: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. EL-Y: Conceptualization, Data curation, Project administration, Software, Visualization, Writing – review & editing. DG-A: Data curation, Funding acquisition, Methodology, Project administration, Resources, Writing – original draft, Writing – review & editing. ES-A: Conceptualization, Data curation, Investigation, Project administration, Validation, Writing – review & editing. PH-A: Conceptualization, Methodology, Supervision, Validation, Writing – original draft, Writing – review & editing. RR-T: Methodology Software, Validation, Visualization, Writing – review & 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.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2025.1499856/full#supplementary-material

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