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Understanding university teachers' digital competencies: a systematic mapping study

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Abstract

Being digitally competent is an imperative requirement for the 21st century university teacher, a fact recognized by both the literature and policymakers. Although this topic has been addressed in different reviews and critical studies recently, none of them have systematically and explicitly addressed the factors that explain, or are explained by, the digital competencies of university teachers. Examples of these factors include, among others, demographic, professional and psychological aspects of university teachers, as well as very specific digital competencies. The present study seeks to close this gap through a systematic mapping of the literature published until 2021 in journals indexed by Scopus and Web of Science (WOS). Based on the selection of 53 primary studies, we characterized the literature and summarized the main results reported so far. The analysis allowed us to conclude the following: 1) there is a growing number of contributions aimed at understanding the acquisition of digital competencies, especially from external factors; 2) European, and more specifically Spanish, university teachers from multiple disciplines are the most studied population; 3) most studies adopted quantitative approaches to explain but not prove causality; 4) there is a great heterogeneity of relationships and results that explain the

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digital competencies of university professors. The implications of these results are discussed with a view to identifying the gaps that provide scope for future research.

Keywords Digital competence · University teacher · Higher education · Systematic mapping study

1 Introduction

Living in a world dominated by technology has important implications for individuals and society in general (Cladis, 2020; Lindgren, 2021). In this context, education has been one of the areas that has benefited the most from technological advances (Guri-Rosenblit, 2010). Today, it is possible to teach and learn in settings and using modalities that are very different than those that existed only 30 years ago (Yen et al., 2018; Spencer & Temple, 2021). Teachers and students interact daily both online and offline using digital technologies, and such interaction has increased particularly during the ongoing pandemic (Cathy & Farah, 2020). This implies that in association with learning and teaching skills, students and teachers must acquire digital competencies that allow them to develop this teaching-learning process effectively in a technological scenario (Ilomäki et al., 2014; Ghavifekr & Rosdy, 2015; Caena & Redecker, 2019).

Although extensive research has been conducted on the acquisition, development, and assessment of digital competence in university students and teachers (Spante et al., 2018; Pettersson, 2018; Zhao et al., 2021), much remains to be understood on this topic. In this context, recent secondary studies have made significant progress in organizing and synthesizing the main existing contributions, primarily in the context of university students (Saltos-Rivas et al., 2021). However, to the best of our knowledge, none of these studies has focused on the factors that explain, or are explained by, the digital competencies of university teachers. We believe that examining these factors is crucial for understanding processes such as the acquisition and development of these competencies in higher education. Joly et al. (2012), Prendes et al. (2018), and Bernate and Vargas Guativa (2020) supported this perception and emphasize the importance of information and communication technologies (ICTs) training for university teachers. Furthermore, Esteve-Mon et al. (2020) drew attention to the fact that learning with digitally competent teachers allows students to develop their digital competencies as well. Guri-Rosenblit (2018) went further and asserted that learning through ICTs can only occur with the help of a digitally competent teacher.

Bearing in mind the aforementioned rationale, our research objective was to fill this gap through a systematic mapping study (Petersen et al., 2015) that aimed to provide an overview of the main trends on the subject, i.e., by selecting, classifying, and analyzing the main contributions reported in the literature. Specifically, we were interested in answering three research questions to find out the following: 1) what is the temporal evolution of the studies and their distribution according to the role of digital competencies; 2) what demographic and methodological characteristics the studies possess; 3) what factors, relationships, and results have been reported so far.

By answering these questions, we sought to provide researchers and policymakers with a detailed summary of the main progresses in the field. The implications of the results obtained are discussed in depth, with a critical look at the current state of the subject and the issues that remain to be answered.

The remainder of this article is organized as follows. In Section 2 we delve into the background of the digital competencies of university teachers, i.e., with the aim of identifying the possible roles that these competencies may have within explanatory relationships. In this section we also include a critical review of secondary studies related to our research, i.e., with the aim of finding out how much progress has been made and what limitations they have. The methodology adopted by our research is described in Section 3, while the results are presented in Section 4. We discuss the main implications of these results in Section 5, and further, in Section 6 we highlight limitations and future work.

2 Background and related works

In this section, we discuss what digital competencies in higher education involve and, in particular, what it means to be a digitally competent university teacher. Subsequently, we delve into related work and what findings have been summarized so far in regard to the factors that explain, and are explained by, the digital competencies of university teachers.

2.1 Digital competence and higher education teachers

In recent years, there has been growing interest in defining what digital competence is and what it means in the field of higher education (Spante et al., 2018). Although several authors speak of *digital literacy* instead of *digital competence*, in this paper, we assumed that both concepts represent the same thing. Our position aligned with that of Spante et al. (2018), who found that the major difference between the two terms lies in the context and demographic characteristics of the publication. While the former is more common in the scientific literature of Asia, the United States, and the United Kingdom, the latter is more frequently used in the scientific and policy literature of Northern Europe and South America (Spante et al., 2018).

From a general perspective, the definition of Ferrari (2012) within EU policies is one of the most comprehensive and widely accepted in academic literature (Spante et al., 2018). Specifically, Ferrari (2012) defined digital competence as a "*set of knowledge, skills, attitudes, strategies, and awareness, which are required when ICT and digital media are used to perform tasks, resolve problems, communicate, manage information, collaborate, create and share content, and build knowledge in an effective, efficient, and adequate way, in a critical, [a] creative, [an] autonomous, [a] flexible, [an] ethical, and a sensible form for work, entertainment, participation, learning, socialization, consumption, and empowerment*" (p. 3).

In the specific case of university teachers, there is a tendency to differentiate between generic digital competencies and teaching competencies. For example, Starkey (2019) distinguished three types of digital competencies for teachers:

generic, teaching-related, and professional. While the former is focused on aspects such as those in Ferrari's aforementioned definition and on what is called *technological knowledge* by the Technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006), the latter takes into account the integration of technologies into the teaching practice. Specifically, digital teaching competence comprises three dimensions: "the ability to teach using digital technology, to critically evaluate teaching decisions, and to teach students who are using digital technology" (Starkey, 2019, p.12). Finally, professional digital competence corresponds to a more advanced level of integration of technologies within the daily work of the university professor. Specifically, it is defined as "the ability of the teacher to work in the context of a digitized school and education system. This includes mastering a range of teacher competencies such as being able to teach in a digitally infused context, manage digital learning environments, and carry out the broader professional work of being a teacher" (Starkey, 2019, p.13).

From a policy perspective, it is common to define teachers' digital competencies (TDCs) through frameworks. This is the case of *DigCompEdu*, which was proposed by the European Commission (Redecker, 2017). This framework defines 22 competencies organized in six areas: *Professional Engagement*, *Digital Resources*, *Teaching and Learning*, *Assessment*, *Empowering Learners*, and *Facilit. Learners' Digital Competence*. DigCompEdu also establishes a system to evaluate each individual's competence according to six proficiency levels (e.g., A1, A2, B1, B2, C1, and C2), which is very similar to the one used by the Common European Framework of Reference for Languages (CEFR) (Caena & Redecker, 2019).

Regardless of the heterogeneity of the aforementioned definitions and positions, it is clear that the digital competence of the university professor can be seen as the combination of generic and professional digital competencies (including the so-called digital teaching competence). While the former is acquired as a citizen of an increasingly digitized society, the latter is acquired during professional practice, i.e., as a teacher, researcher, or academic manager. Whatever the case may be, the acquisition of the skills, knowledge, and attitudes that make up these competencies occurs as a product of teachers' self-learning and the training they receive from others (Roy et al., 2020; Mahapatra, 2020). Like other types of competencies (Witorski, 2012), the acquisition of digital competencies is conditioned by individual factors related to the teacher themself as well as their environment. Consistent with this view, authors such as Pettersson (2018) have attempted to explain the acquisition and development of digital competencies through factors such as infrastructure, policies, strategic leadership, and teaching practice, while other authors such Guillén-Gámez and Mayorga-Fernández (2020) have done so through individual teacher characteristics (e.g., age, gender, and educational level).

Conversely, the digital competencies of university teachers can also explain others factors. Seen as a form of literacy, it is clear that the higher the level of such a literacy, the more prepared and predisposed the teacher will be to carry out activities involving digital technologies and knowledge. As discussed later in the results section of our research, there are authors such as Lohr et al. (2021) who have confirmed this and other interesting hypotheses.

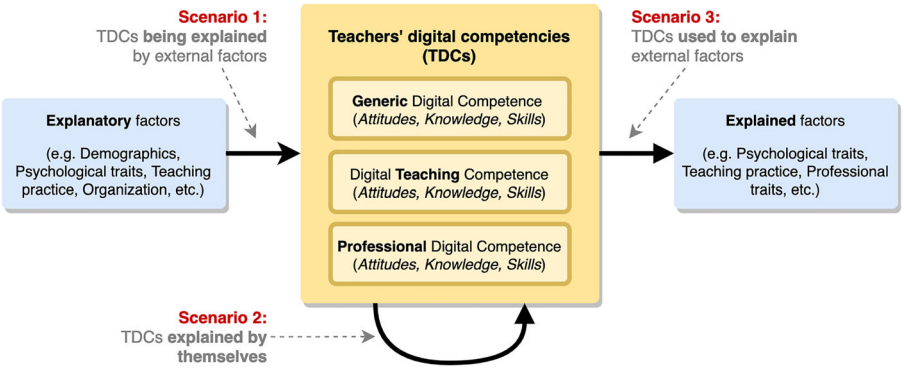

Fig. 1 Digital competencies of university teachers (TDCs) and their roles in explanatory relationships. The arrows do not necessarily imply causality

As a summary of this part, the diagram in Fig. 1 illustrates our view of the factors that explain or are explained by the TDCs. As shown, we conceived of TDCs as the combination of three types of competencies (Starkey, 2019): *generic*, *teaching*, and *professional*. Furthermore, each of these competency types has a dual role in the sense that it can be explained by, or explain, other factors of interest. In this context, we identified three scenarios as described in Fig. 1. In the first scenario, TDCs are explained exclusively by external factors such as demographics (e.g., age and gender). In the second scenario, we grouped relationships that seek to explain TDCs based on factors that are precisely related to TDCs. An example of this type of relationship could be the level of basic digital skills as a predictor of the level of TDCs (Nikou & Aavakare, 2021). The third scenario includes the relationships that use TDCs to explain exclusively external factors (such as factors that are not related to TDCs). Examples of these external factors are positive emotions (Portillo et al., 2020) or the perceived effort in using ICTs in the classroom (Nikou & Aavakare, 2021). A similar investigation in the case of students was developed by Liu et al. (2019), in which the evolution of emotions was analyzed through an unsupervised model.

Although we used arrows in Fig. 1 to illustrate these explanatory relationships, they do not necessarily imply causality (Pearl, 2009). In other words, for the purposes of this study, we considered *explanatory relationship* as an umbrella term that includes not only causal relationships but also other forms of relationships between quantitative variables (e.g., correlation and regression). In addition, we included within this definition the relationships identified through qualitative research approaches, which establish links between subjects' features. In this last scenario, it is also common to find terms such as *facilitator*, *enabler*, or *barrier* being used to refer to explanatory factors (Leigh-Hunt et al., 2015).

Regardless of whether the explanatory relationship includes quantitative or qualitative variables, we referred to these as *explanatory factors* (when they are used to explain) or *explained factors* (when they are explained by other factors). We opted for this general but imprecise definition to group together different types of variables

and characteristics of the teachers and their environment that have been considered by researchers to establish explanatory (not necessarily causal) relationships in the context of university TDCs.

It is important to note that other terms could have been used instead of *explanatory factor* or *explained factor*. For example, in statistical and experimental scenarios, it is more common to use the term *variable* to refer to measurable magnitudes or characteristics that can be included in models to explain other variables (Devore et al., 2021). However, given that we also included the findings reported by qualitative research, we considered that using the term variable, instead of factor, to refer to those features or concepts that researchers use when formulating explanatory relationships would have been inappropriate, especially because these studies are based mainly on the observation of the characteristics of the subjects that are difficult or impossible to be made to correspond to properly quantitative variables. In our opinion, specifying that the factor is *explanatory* (i.e., it serves to explain) or is *explained* (i.e., it has been explained by other factors) is sufficient for the purposes of this study.

Another issue associated with this definition is the granularity of the factor, i.e., the degree of detail with which it is measured when deciding that it is a *factor* and not a *level* (also known as category or attribute) or a *group of factors*. For example, gender and age can be considered as factors composed of different levels and be included in the group of *demographic* factors. However, this distinction is not always clear-cut. An example is *generic digital competence*, which can be seen as either a factor (e.g., when it is measured as such by the researcher) or a group involving those factors measured individually (e.g., in the form of knowledge, attitudes, or skills). Since this level of detail is dependent on the objectives pursued by the research in question, we assumed the granularity of the factor as it appeared in the studies that were the subject of the systematic mapping.

2.2 Secondary studies on the digital competence of university teachers

As noted above, the literature on digital competencies in higher education is very prolific. In relation to our study, there are important secondary studies that began by highlighting the importance of digital skills training for university professors. This was the case of Savin-Baden et al. (2010), who, based on a broad review of the literature, explored the arguments in favor of the inclusion of virtual worlds in education and their impact on university teachers. The main conclusion was that certain forms of digital literacy as well as pedagogically informed models could offer advantages in solving problems that arise during the use of virtual worlds for learning. Similar objectives motivated Sandi Delgado and Veronica Sanz (2020), who explored the role of *serious games* in the development of TDCs. Based on a review of the literature published between 2009 and 2019, the authors found that serious games do indeed facilitate changes in teachers' attitudes and behavior toward ICTs, teaching innovation, and digital competencies.

The essay by Lea (2013) focused on the implications of the term *digital literacies* in higher education. The author highlighted the need for both theoretical and conceptual frameworks for integrating the benefits of digital technologies into teaching practice. Motta and De Lima (2014) also agreed with this idea through a review of the

digital teaching culture. In particular, they stressed the urgency of ensuring adequate training for teachers in order to improve their digital literacy.

In (De Wet, 2014), trends in *digital pedagogies* were reviewed in conjunction with the benefits of ICT in higher education (HE) and the implications of these for South African universities. The author identified several factors that undermine the implementation of hybrid online courses. Among the factors related to teachers are apathy and lack of digital literacy. Similarly, based on a theoretical analysis, Gómez Galán (2016) highlighted the importance of scientifically addressing the use of ICTs to motivate students, new pedagogical models, and the need for media education. These actions are necessary to understand and improve teacher training in the context of what the authors called *Education 3.0*. This term is used to refer to a type of education involving ICTs to train citizens and achieve a better society. Biel and Ramos (2019) used a similar term: *Teacher 3.0*. In particular, these authors identified that there is a gap between teachers' expectations about their digital competencies and their actual training.

The review conducted by Valverde-Berrocoso and Burgos (2017) based on research published between 2010 and 2015 aimed to analyze the impact of the use of b-learning (Ashraf et al., 2021) in digital teacher education. They concluded that b-learning is indeed an effective modality for the development of digital competencies in university teachers. In particular, they pointed out that formal ICT training is not sufficient for the development of such competencies. There is a need for continuous digital training, i.e., integrating digital competencies into teachers' lifelong learning. This view shared by Ryabova and Yelnykova (2020) as evident from a more recent theoretical analysis.

Other authors see digital competencies as a necessity for university faculty in the 21st century. This is the case for (Joly et al., 2012; Prendes et al., 2018; Reyes Perez et al., 2018), where in three non-systematic reviews of the literature, it was concluded that using digital technologies is not enough to achieve digital competencies (Joly et al., 2012) and in order to have digitally competent teachers, (Spanish) universities must redefine their strategic plans (Prendes et al., 2018) and provide continuous training for the teachers (Reyes Perez et al., 2018). Ocana-Fernandez et al. (2020) agreed with this position in a more recent theoretical analysis. Along the same lines, Fernández and Pérez (2018) focused on teacher professionalization by analyzing models for integrating digital competencies. Bernate and Vargas Guativa (2020) also found, under the lens of the fourth industrial revolution, that digital competencies are relevant for the 21st century teacher. This study was based on a systematic review that included 12 studies published in the period 2005–2020.

Other authors invested their efforts in revealing what digital competence is in the context of higher education. The systematic review conducted by Spante et al. (2018) based on 107 papers published in the period 1997–2017 revealed that the concepts of digital competence and digital literacy are used interchangeably in the literature, with great heterogeneity in their definitions. Moreover, the focus of these definitions has been on the development of digital competencies of the student. Similar research was subsequently conducted by Palacios Hidalgo et al. (2020) in the case of English as a Foreign Language (EFL) teachers. In the latter study, 68 studies published in the period 2009–2018 were scrutinized. The authors provided a series of suggestions

to enhance the development of digital competencies in both teachers and students. These included the following: inclusion of digital competencies in subject syllabus; simplification and better definitions of the concepts of digital competencies; a better model for developing TDCs; frequent evaluation of teachers; raising awareness about the role of ICTs during pre-service teacher education. Similar suggestions were made for English teachers in Malaysia (Had & Rashid, 2019) and in a more general context (Bendriyanti et al., 2019).

With a similar motivation, Pettersson (2018) analyzed how digital competence was being addressed in the educational context. The author conducted a systematic review of 41 studies published in the period 2007–2017 while considering four dimensions: policies, infrastructure, strategic leadership, and teaching practice. The author detected that most of the research had focused on very specific competencies, i.e., it had ignored the fact that there are other competencies that are also demanded by educational settings. Specifically, it was possible to reveal the important role of these four dimensions in the development of TDCs as well as in educational change at all levels.

Guri-Rosenblit (2018) viewed e-teaching as a prerequisite of e-learning, i.e., he claimed that university students are unable to learn effectively without the help of an expert teacher. The author also addressed the reasons why academic staffs do not take advantage of the potential of online teaching. Specifically, he identified four main reasons: disengagement from professional responsibility; work overload and burnout; lack of ongoing support systems; concerns about intellectual property.

In the field of medical and health education, some studies have also approached the subject of digital competence in higher education. One such example focused on teachers was provided by Díaz (2018), who characterized social networks and the Internet of Things in the context of the digital competencies of teachers, researchers, and educational institutions. The author highlighted the need for teacher training and the development of strategies for the implementation of ICTs in health institutions.

Unlike other secondary works, the meta-analysis conducted by (Rivas et al., 2019) was focused on estimating the proportion of digital competence in Latin American higher education. From 12 primary studies, the authors concluded that the estimated proportion was 0.64 (with 95% confidence interval of [0.61, 0.68]). However, these results involved both students and teachers, so it is difficult to determine to what extent teachers were digitally competent.

Although focused more on initial teacher education, the review conducted by Starkey (2019) also included teacher educators. This study covered 48 papers published from 2008 to 2018, which were organized according to three broad categories: generic digital competencies, digital teaching competencies, and professional digital competencies. As an additional contribution, the author proposed a model that provides insight into the latter category.

More recently, some authors have addressed digital competencies in the context of the COVID-19 health crisis. This is the case of Cabero-Almenara and Llorente-Cejudo (2020); in a theoretical reflection, the authors focused on the effects of the pandemic on the digitization of higher education. The authors emphasized that the lack of technological resources and connectivity are factors that have led to an increase in the social gap. They also called attention to the importance of ensuring the

quality of distance teaching, a predominant modality in several universities during the health crisis.

Digital teaching competence was the focus of the systematic review conducted by Esteve-Mon et al. (2020). Based on 43 studies published up to 2019, the authors confirmed that being digitally competent is indispensable to meeting the challenges of today's society and facilitates not only teaching activities but also the development of digital competencies in students. The authors also noted that although the levels of TDCs are reported in the literature as adequate, the effective use of technologies in their teaching activities is not.

Recently, the systematic review conducted by Zhao et al. (2021) covered the literature published between 2015 and 2021. The focus was digital competence in higher education, and the study considering several aspects: definitions of digital competence, dimensions to assess it, purposes of the studies, methodologies, results, and limitations. Based on 33 studies, it was concluded (consistent with (Spante et al., 2018)) that definitions of digital competence in HE come from both research and EU policy. Furthermore, it was found that teachers possess basic levels of digital competencies.

Finally, Saltos-Rivas et al. (2021) focused on reviewing the quality of quantitative instruments used to measure digital competence in higher education. A total of 73 primary studies published from 2010 to 2020 were considered through a systematic mapping. The authors showed that there are serious problems with the quality reported by more than 50% of the studies, i.e., issues in relation to the evidence they should have provided on the reliability and validity of the administered instruments.

In summary,

- most of the studies were focused on defining what digital competencies are or emphasizing the importance of digital competencies in the current educational context along with the need for teachers to receive adequate training;
- only a few studies included aspects related to the factors or variables that were studied as explanatory for, or explained by, digital competencies in teaching. For a better understanding, we have summarized these papers and their main findings on this topic in Table 1. As can be seen, there were studies focused on very specific technologies or methodologies as enablers of (or enhanced by) digital competence (Savin-Baden et al., 2010; De Wet, 2014; Valverde-Berrocoso & Burgos, 2017; Guri-Rosenblit, 2018), while others (Pettersson, 2018; Zhao et al., 2021) focused on a more general scope. In the case of Pettersson (2018), the results were from a generic perspective, while the more recent study of Zhao et al. (2021) found other factors more specific to teachers. It is important to note, however, that in the case of the latter study, the findings included in Table 1 corresponded to only one primary study: (Guillén-Gámez & Mayorga-Fernández, 2020). Another aspect to note is that not all the studies were systematic reviews of the literature, so both the theoretical validity and *generalizability* of the results may have been affected.

It is clear from the studies analyzed above that the factors explaining, and explained by, digital competencies have not been addressed in sufficient depth. Consequently, our study sought to close this gap through a systematic mapping study.

Table 1 Related work that has addressed factors or variables that explain, or are explained by, the digital competencies of university teachers

Study	Systematic review	Covered period	Number of studies	Findings
(Savin-Baden et al., 2010)	No	<2010	n.e.s*	Digital literacy as a facilitator of teaching with immersive virtual worlds.
(De Wet, 2014)	No	<2014	n.e.s	Digital literacy as a facilitator of hybrid online courses.
(Valverde-Berrocoso & Burgos, 2017)	No	2010-2015	n.e.s	B-learning as enabler of digital competence.
(Pettersson, 2018)	Yes	2007-2017	41	Policies, infrastructure, strategic leadership and teaching practice as enablers of digital competence development.
(Guri-Rosenblit, 2018)	No	<2018	n.e.s	Digital teaching as a requirement for students' digital learning.
(Sandi Delgado & Veronica Sanz, 2020)	No	2009-2019	n.e.s.	Serious games facilitate changes in TDCs.
(Zhao et al., 2021)	Yes	2015-2021	33	The number of participating research and educational projects correlates positively with digital competence; teaching experience correlates negatively with digital competence; working with video learning objects as a facilitator of achieving digital competence.

*Not explicitly stated by the authors of the study

3 Methodology

In order to achieve the objective of this research, we adopted the methodology proposed by Petersen et al. (2015) for conducting systematic mapping studies (SMS). These are defined as studies "designed to give an overview of a research area through classification and counting contributions in relation to the categories of that classification" (Petersen et al., 2015, p.1).

Although other methodologies for developing secondary studies could have been adopted instead of SMS (Grant & Booth, 2009), we considered the latter to be sufficient for our purposes. The main reason for that was we were interested in providing a general overview of the subject through a quantitative summary of the reported results and the characteristics of the studies where they appear so that researchers

or policymakers can quickly acquire an overview of the current state of the subject. In addition, we considered that SMS as well as the so-called *scoping reviews* (Grant & Booth, 2009) are a first approach to issues that emerge in fields still under development.

The guide suggested by Petersen et al. (2015) indicates that the mapping is achieved through three fundamental steps: planning, development, and reporting. In the subsequent sections, we discuss how the first two steps were carried out, while the third step was completed with the writing of this article.

3.1 Research questions

The objective of the present research was to provide an overview of the literature that addressed the factors that explain, or are explained by, the digital competencies of university teachers. Accordingly, we defined the following research questions:

1. *What is the temporal evolution of the studies and their distribution according to the role of the TDCs? (RQ1).* In answering this question we seek not only to know how interest in this topic has evolved in terms of scientific production, but also on what specific aspects most of the current contributions have focused. On the first question, the evidence from the review made in Section 2.2 allows us to infer that we will find a growing trend towards the most recent years. However, on the second question, there is uncertainty as to which roles of TDCs have been most studied.
2. *What are the demographic and methodological characteristics of the studies? (RQ2).* Similar to the previous question, with this question we hope to identify the main trends in the demographic characteristics present in the studies, as well as their most relevant methodological aspects. The results of previous reviews, such as those developed by Saltos-Rivas et al. (2021) and Saltos-Rivas et al. (2022), allow us to infer some of these general trends. For example, it is quite possible that we will find a large number of studies that adopt cross-sectional quantitative approaches to analyzing the TDCs in Spanish teachers. However, given that we are focusing on a very specific topic of TDCs, it is also possible that the patterns identified by these previous studies may not hold up.
3. *What factors, relationships, and results have been reported so far? (RQ3).* Finally, with this question we intend to contribute to a better understanding of TDCs. Specifically, by organizing the factors into categories and identifying the relationships considered by the studies, we hope to provide for the first time a general overview of this topic. To our knowledge, there are no previous studies that allow us to infer any trend in the literature on this issue. Thus, we do not know the current status of the subject, much less what aspects have been further developed or have yet to be addressed.

3.2 Search

While designing the search formula that was used to find the relevant primary studies, we proceeded as follows: First, the *Population, Intervention, Comparison*

and Outcomes (PICO) tool (Higgins et al., 2019) was used with the aim of identifying relevant terms according to the target population, intervention method, comparison group, and outcomes. As a complement, literature reviews that addressed digital competencies in higher education were taken into account (Spante et al., 2018; Saltos-Rivas et al., 2022). Consequently, the following search formula was defined:

((staff OR instructor* OR lecturer* OR professor* OR teacher* OR facult*) AND ("higher education" OR college OR "tertiary education" OR university) AND ("digital compet*" OR "digital litera*" OR "digital skill*"))*

This formula was used on two databases with large coverage of the scientific literature on the subject: Scopus (https://www.scopus.com/) and Web of Science (WOS) (https://www.webofscience.com/). It is important to mention that our decision aligned with other reviews (Pettersson, 2018; Spante et al., 2018; Saltos-Rivas et al., 2021; 2022; Murillo et al., 2021; García-Murillo et al., 2020) that have also relied on these sources. As a result of the searches developed, a total of 1,595 studies were obtained, as summarized in Table 2. It is worth mentioning that the searches were conducted in January 2022.

3.3 Selection

During study selection, several steps were followed, as shown in Fig. 2. In particular, the following inclusion and exclusion criteria were considered.

Inclusion criteria:

- articles published until 2021;
- articles published in journals;
- primary studies;
- studies addressing the digital competencies of university teachers;
- studies addressing the factors explaining, or explained by, digital competencies of university teachers.

Exclusion criteria:

- papers presented at congresses, book chapters, or editorials;
- not *early access* or *in-press* articles;

Table 2 Records obtained from the search performed on Scopus and Web of Science databases

Database	Search fields	Number of records
Scopus	*TITLE-ABS-KEY((staff* OR instructor* OR lecturer* OR professor* OR teacher* OR facult*) AND ("higher education" OR college OR "tertiary education" OR university) AND ("digital compet*" OR "digital litera*" OR "digital skill*"))*	967
Web of Science	*TS=((staff* OR instructor* OR lecturer* OR professor* OR teacher* OR facult*) AND ("higher education" OR college OR "tertiary education" OR university) AND ("digital compet*" OR "digital litera*" OR "digital skill*"))*	628
Total		1595

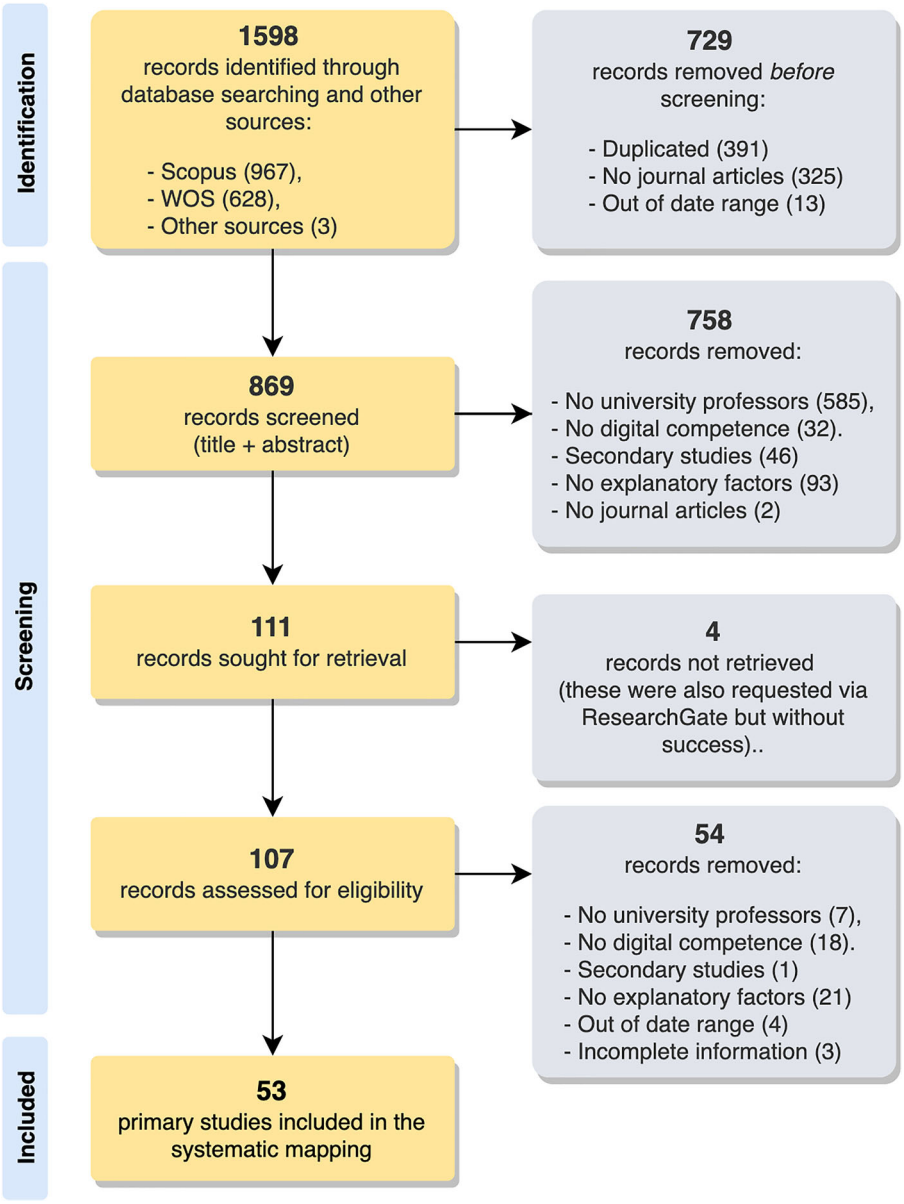

Fig. 2 Study selection process

- not peer-reviewed papers;
- secondary studies;
- studies based on participants other than in-service university teachers;
- studies that do not address the digital competencies of university teachers;
- studies that do not include determinants and/or effects;
- not accessible papers

It should be noted that in Fig. 2, we included 3 additional studies from sources other than the Scopus and WOS databases. These studies were identified by our previous reviews (Saltos-Rivas et al., 2021; 2022), and it was confirmed that they were also indexed by Scopus or WOS. It is also noteworthy that as a result of the systematic screening process performed, we obtained 53 primary studies that served as the basis for the systematic mapping, as depicted in Fig. 2.

Before proceeding to data extraction, the quality of these 53 studies was assessed by adopting a quantitative approach. Specifically, each study was assessed for compliance with the following aspects formulated in the form of a question:

- Is the research objective clearly defined?
- Is the literature that serves as background to the research properly discussed?
- Is the methodology appropriate and well described in the paper?
- Do the measurements performed have psychometric quality (reliability and validity)?
- Are the results clearly explained?
- Are the results obtained and their implications discussed?

The authors responsible for this process were able to issue their evaluations according to the following scoring scheme: 1=*Yes*, 0.5=*Partially*, 0=*No*. Based on a consensus among the authors, it was decided to exclude those studies with a total score (i.e. obtained as the sum of the individual scores for each question) lower than 3.0. However, given that the range of overall scores was [3.5, 6.0], none of the 53 studies were excluded. Overall, the mean of these overall scores was 5.1 with a standard deviation of 0.8. Therefore, we can affirm that this sample of studies has an acceptable level of quality.

3.4 Data extraction

Data were extracted from the relevant studies selected in the previous step in order to answer the questions formulated in Sec. 3.1. Specifically, Table 3 shows the features of the studies that were extracted as well as the research questions to which they contributed.

3.5 Analysis and classification

The data extracted in the previous step were subjected to descriptive statistical analysis, which allowed us to classify the selected studies as shown in *Supplementary information*.

An important issue when answering research question 3 was how to synthesize the different results that could arise for each relationship between factors. If we excluded those relationships formed by factors whose levels are not easily ordered, then the possible types of relationships would have been the following: positive, negative, or non-existent. The question was how to aggregate that information in a way that would provide an overall idea of what the strength and direction of the relationship is. Since we were considering both quantitative and qualitative research results, relying on traditional analysis techniques such as meta-analysis was not appropriate (Page et al.,

Table 3 Data extraction template

Data category	Extracted data	Research question
Temporal evolution of the studies and distribution by scenario	Full study reference: *Year of publication*, *Authors*, *Title*, etc.	R1-RQ3
	Scenario according to the role of teachers' digital competence (TDC): *Scenario 1: TDCs explained by external factors*, *Scenario 2: TDCs explained by themselves*, *Scenario 3: TDCs used to explain external factors*.	
Demographics and methodological characteristics of the studies	*Country* of study participants	RQ2
	Continent of study participants	
	Discipline of study participants	
	Research design	
	Instrument or framework employed to measure digital competence	
	Data collection methods	
	Data analysis techniques	
	Sample size	
Factors' relationships and results	*Factors* reported as explanatory of, or explained by, university teachers' digital competencies.	RQ3
	Result reported on the relationship: *Positive relationship*, *Negative relationship*, *No relationship*, *Significant difference*.	
	Factor category: *Demographic*, *Psychological*, *Teaching practice*, *Professional traits*, *Organizational*, *Generic digital competence*, *Teaching digital competence*, *Professional digital competence*.	

2021). From a descriptive perspective, we chose to rely on the following indicator to characterize the strength S of a given relationship i:

$$S_i = \frac{P_i - N_i}{P_i + N_i + O_i} \tag{1}$$

where P_i, N_i, and O_i are the results corresponding to relationship i and indicating that it is positive, negative, or non-existent, respectively. It should be noted that this indicator is defined in the range of $[-1, 1]$ with the following meanings for the extreme values: -1 =*negative*, 0 =*no relationship*, and $+1$ =*positive*. Any other value would have a meaning depending on its closeness to the extreme values. To be more specific, we divided the interval $[-1, 1]$ into three sub-intervals to represent these cases. Thus, a value of S within $[-1, -0.33)$ means that the relationship is *predominantly negative*, while a value between $(0.33, 1]$ indicates that it is

predominantly positive. Finally, a value of S between $[-0.33, 0.33]$ corresponds to relationships whose reported results point to it being *predominantly non-existent*.

To make the synthesis fairer, we decided that only relationships with two or more reported outcomes should be eligible for evaluation through expression 1. In this way, we gave greater weight to relationships that have been assessed by more than one study, and therefore, the synthesized results will have greater confirmatory power than those reported by a single study.

3.6 Validity assessment

As suggested by Petersen et al. (2015), it is important to assess the validity of the systematic mapping using five types of validity criteria. The first has to do with the *descriptive validity* of the study. In this case, given that our study extracted quantitative information in a structured manner, we considered that the threat of relying on non-objective or imprecise information was controlled.

Theoretical validity was evaluated by taking into account the study selection bias and the analysis of the data extracted from the studies. In the first case, we believed that the threat was controlled since we followed a systematic search and selection protocol, supported by the parallel work of two of the authors of the study. In addition, to minimize the possibility of leaving out relevant studies, we performed snowball sampling on the secondary studies reviewed as related work. In relation to data extraction, the threat of biased or inadequate data extraction was also minimized by two of the authors performing this task in parallel and the supervision of the third author.

Regarding the *generalizability* of the results, our research ensured that the findings have an adequate level of internal generalizability, i.e., the conclusions and implications derived from them are applicable to university teachers in general. However, we are unable to guarantee that they are also applicable to other groups in higher education, such as undergraduate students or pre-service teachers. The *interpretive validity* of our study may also have been compromised by the fact that the authors have collaborated on similar research in the past. Thus, there may have been some bias as to how they viewed the phenomenon under study. However, the diverse backgrounds of the authors provided different perspectives that complemented the interpretation of the results. Finally, the *reproducibility* of the results is guaranteed because a systematic protocol was followed, where the details necessary to achieve this task were made explicit.

4 Results

In this section, we present the results synthesized from the systematic mapping. The presentation has been organized in the same order in which the research questions were formulated.

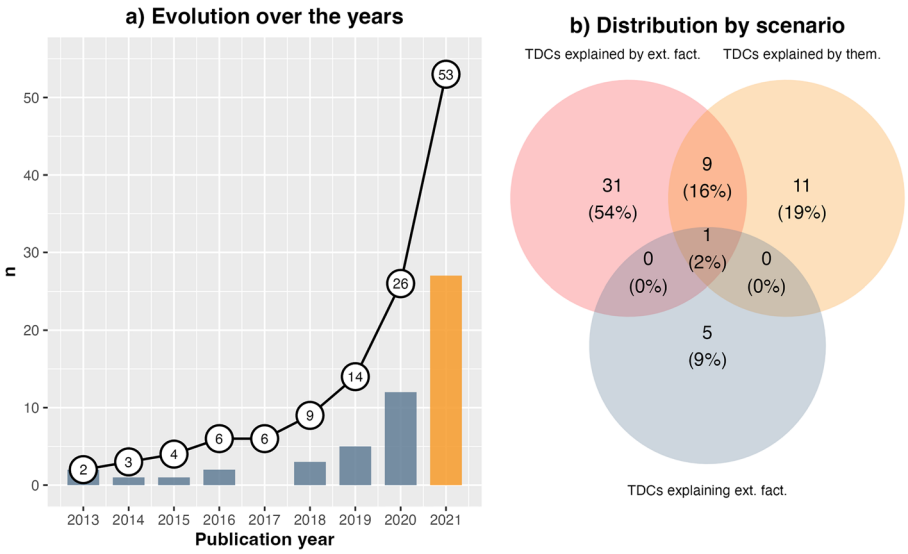

Fig. 3 Evolution of the number of studies over the years (a), and their distribution across the scenarios (b)

4.1 Temporal evolution and distribution by scenario (RQ1)

In response to the first research question, Fig. 3 shows how the number of studies has evolved over the years and how they are distributed across the scenarios related to the role of TDCs. From Fig. 3a, it can be seen that the number of studies has been growing since 2013 with the seminal works by Alarcia and Del Arco Bravo (2013) and Buchanan et al. (2013) being published. In the last year, there has been a substantial increase, and more than half ($n = 27$) of the studies were published. Regarding the distribution of the studies by scenario (role of the TDCs), the Venn diagram in Fig. 3b shows that most of the studies ($n = 41$) belong to scenario 1, where TDCs are explained by external factors. Scenario 2 ranks second in terms of the number of studies with 21 contributions, while scenario 3 ranks third with six contributions. The diagram also shows that 10 contributions that have considered TDCs in the role of being explained by both external factors and themselves at the same time. They were (Bennett, 2014; Arango et al., 2020; Armstrong, 2019; Cabero-Almenara et al., 2021b; Cabero-Almenara et al., 2021; Fernández-Márquez et al., 2017; Mirete et al., 2020; Naim & Razak, 2020; Padilla-Hernández et al., 2020; Sarango-Lapo et al., 2020). Among them, Arango et al. (2020) was the only one exploring TDCs in all three roles.

4.2 Demographics and methodological characteristics (RQ2)

The methodological characteristics of the research carried out by the studies are summarized in Figs. 4 and 5. From Fig. 4a, it can be seen that the tendency is to involve Spanish teachers (32%) as participants. More generally, they come from Europe

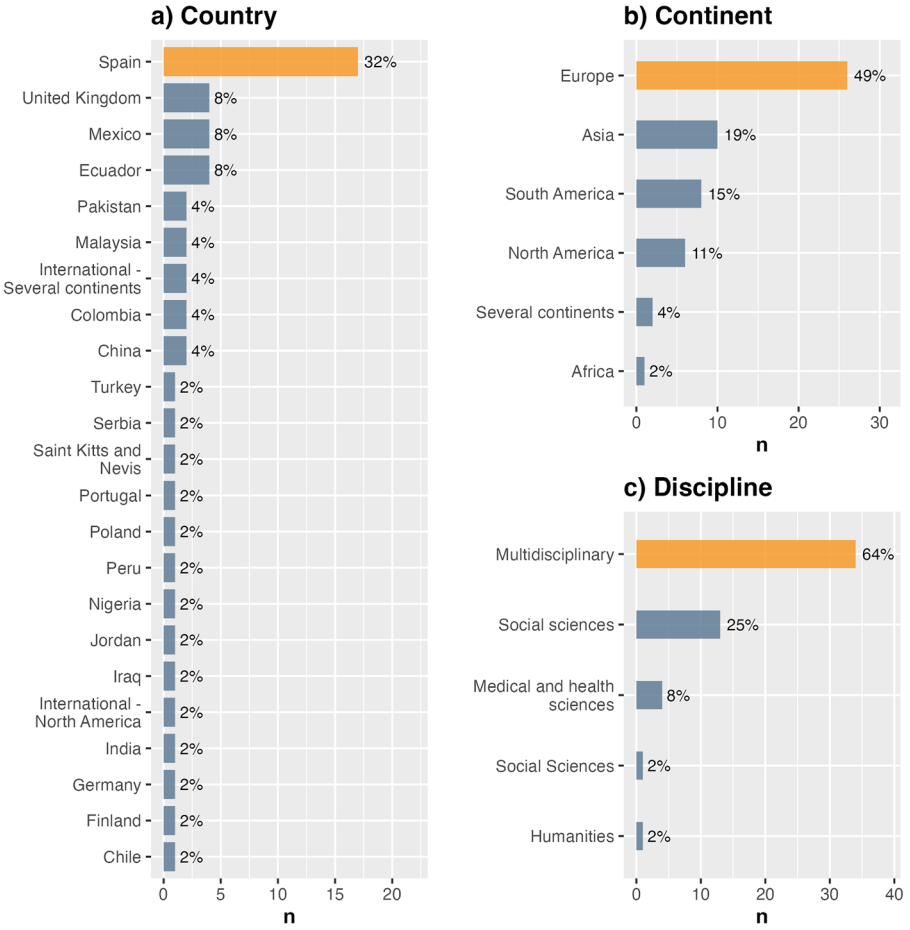

Fig. 4 Demographic information of the study participants ($n = 53$)

(49%) as shown in Fig. 4b. Finally, Fig. 4c shows that most of the studies relied on samples of participants from several disciplines (64%).

From the perspective of research methodology, the plots in Fig. 5 show that most of the studies adopted quantitative approaches, i.e., they applied non-experimental, cross-sectional, and correlation designs (83%). In contrast, only five studies followed qualitative designs (10%): Padilla-Hernández et al. (2020) used a narrative research, and Bennett (2014), Radovanović et al. (2015), Sales et al. (2020), and Zou et al. (2021) used phenomenological studies. Four other studies employed mixed methods approaches (8%): Almpanis (2016) and Sarango-Lapo et al. (2021) used explanatory sequential designs, while Armstrong (2019) and Delgado and Hernández-Gress (2021) used sequential exploratory designs.

The results shown in Fig. 5b are consistent with the aforementioned findings. For example, it can be seen that the questionnaire is the most employed data collection technique (81%), which is typical of non-experimental cross-sectional designs

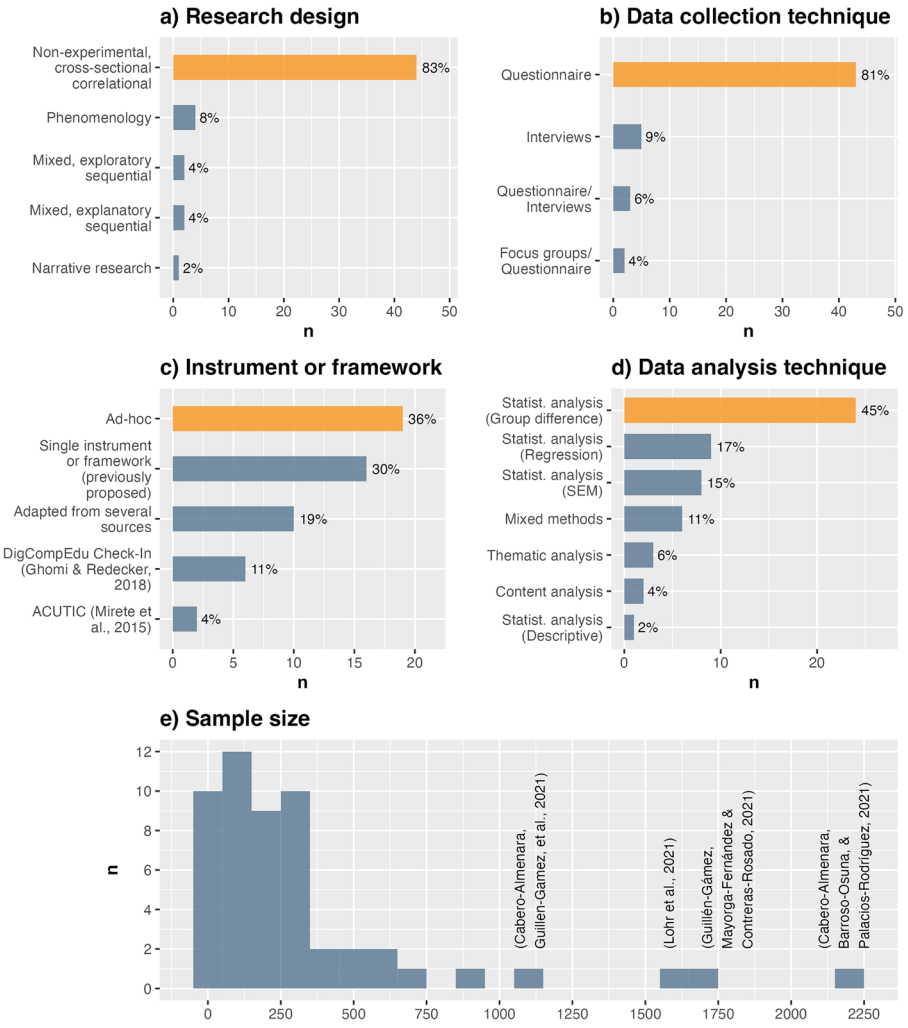

Fig. 5 Methodological features of the studies ($n = 53$)

(Creswell & Creswell, 2018). In addition, all three qualitative studies employed interviews as the data collection technique, while the mixed methods studies relied on a combination of questionnaire with focus groups (Armstrong, 2019; Delgado & Hernández-Gress, 2021) and interviews (Almpanis, 2016).

A great diversity of instruments and frameworks is shown in Fig. 5c. It should be noted that most of the studies applied *ad hoc* instruments (36%) or single instruments previously proposed in the literature (30%). It is important to note that instruments in the latter category were different from each other. Therefore, for the purposes of this analysis, they could also be considered ad hoc. Something similar occurred with the category of instruments *adapted from different sources*, which grouped together very specific instruments that were different from each other. This category involved 19% of the studies. In contrast, only two instruments were applied by two or more

studies. This was the case of *DigCompEdu Check-In* (Ghomi & Redecker, 2019) and ACUTIC (Mirete Ruiz et al., 2015). While the first one was considered by Cabero-Almenara et al. (2021), Cabero-Almenara et al. (2021a), Cabero-Almenara et al. (2021b), Cabero-Almenara et al. (2021), Barragán Sánchez et al. (2021), and Santos et al. (2021), ACUTIC was considered by Mirete Ruiz (2016) and Mirete et al. (2020).

Regarding the data analysis technique, Fig. 5d shows that statistical techniques are predominant ($n = 42$). Within this group, most studies relied on tests for group comparison (45%) and to a lesser extent on regression (17%), structural equation modeling (15%), and descriptive statistics (2%). This last case corresponded to the research carried out by Márquez et al. (2018).

With respect to the sample size (number of participants considered in the study), Fig. 4c shows that regardless of the focus of the study, the tendency is to use samples larger than 100 individuals. However, there are atypical studies (Cabero-Almenara et al., 2021a; Guillén-Gámez et al., 2021; Cabero-Almenara et al., 2021; Lohr et al., 2021) that relied on more than 1000 respondents.

4.3 Reported factors, relationships, and results (RQ3)

Before delving into the relationships and the specific results of the studies, we considered it important to summarize the main statistics of the classification process followed in this section. In general, we identified nine factor categories, which served to organize 150 unique factors. Of these, 74 were *explanatory*, while 88 were *explained* factors. It implied that 12 factors participated in relationships as explanatory or as explained factors. The number of unique relationships between factors that were explored by the studies was 265, and these relationships were associated with 312 results reported by the studies. This indicated that on average, fewer than two results were reported for each relationship.

Although other interesting statistics could have been drawn from these data, for reasons of space, we focused on two aspects that we considered relevant: the number of factors and results. Both are organized by category in Figs. 6 and 7. In the first case, Fig. 6a shows that the most diverse category of explanatory factors was *Generic digital competence*, which accounted for 23% of the factors. In contrast, *Digital teaching competence* grouped 38% of the explained factors, as shown in Fig. 6b.

To summarize the volume of results associated between relationships, we relied on a *Sankey* flow chart (Fig. 7). The links between the categories on the left and right indicate that at least one relationship between factors in these categories has been reported by a study, while the thickness of each link is proportional to the volume of the results associated with these relationships. It should be noted that the number of results represented by the link thickness is independent of the type of result, i.e., whether the relationship was relevant or not. As can be seen in the left-hand side of the graph, demographic factors are the group that has been used most often to explain the TDCs (41%), specifically *generic digital competencies* and *digital teaching competencies*. It is followed by factors related to *teaching practice* (20%) and *generic digital competence* (14%). If we look at the right-hand side of the graph, we can see that *digital teaching competence* was the category most frequently used to explain

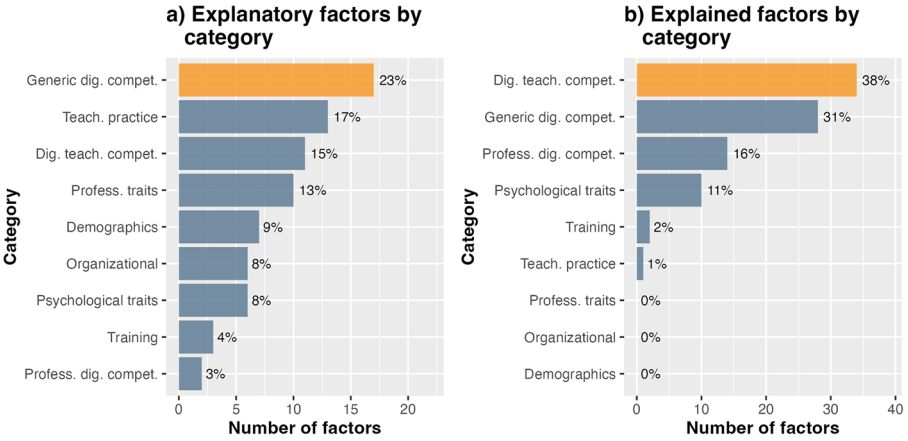

Fig. 6 Distribution of the number of explanatory (a) and explained (b) factors per category

other factors (54%), followed by *Generic digital competence* (34%) and *Professional digital competence* (7%).

The patterns shown in Fig. 7 may seem contradictory compared to those shown in Fig. 6; however, it should be noted that although both show information grouped by factor categories, they have different meanings. For example, Fig. 6 might suggest that *Generic digital competence* is the most studied explanatory category of all (as it groups the largest number of different factors and is, therefore, involved in a larger number of relationships). However, these characteristics only make it the most diverse since, as Fig. 7 shows, *Demographics* is the category with the largest number of results ($n = 125$). This means that the few factors belonging to *Demographics* were included in relationships associated with a larger number of results than those belonging to *Generic digital competence*.

In the following sections, we provide specific details about the factors and relationships that have been investigated within each category summarized in Fig. 7. We organized our exposition by following the scenarios depicted in Section 2.1. First, we focus on external factors that explain TDCs (*Scenario 1*) and then on TDCs being explained by themselves (*Scenario 2*). Last, we focus on TDCs used to explain external factors (*Scenario 3*). We have summarized in Appendices A, B and C, the specific relationships and associated results in tables containing direct references to the supporting studies. Each relationship is represented by an explanatory factor, explained factor, and arrow going from the first to the second.

4.3.1 Scenario 1: Teachers' digital competencies explained by external factors

The relationships between factors and their corresponding results for this first scenario are summarized in Table 4. First, it can be seen that an attempt has been made to explain generic digital competencies by demographic factors of the participants, such as *age*, *country*, *education*, *gender*, and *location*. The general pattern observed here was the large number of results supporting the absence of relationships between the involved factors. The most paradigmatic case here was *Gender*. It should be noted

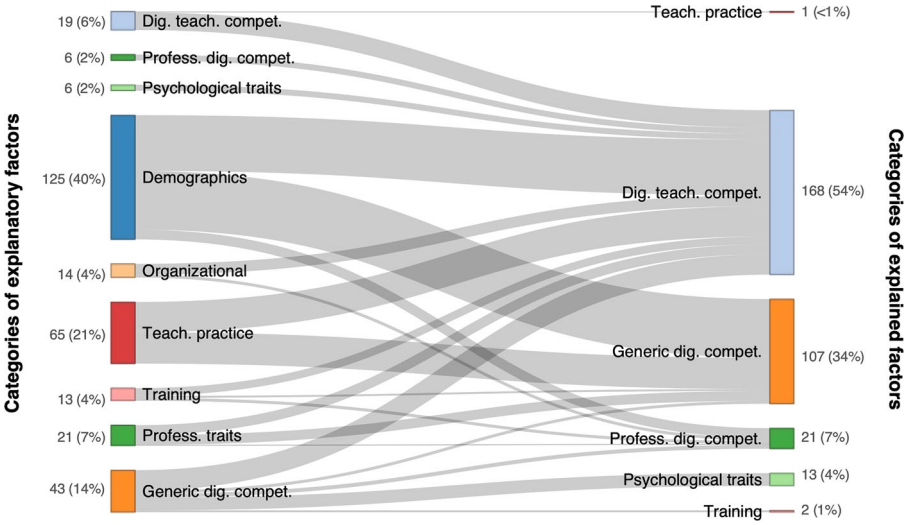

Fig. 7 Summary of the 312 results reported by the literature organized by relationships between factor categories. Factors grouped into the categories on the left were considered to explain those on the right. The thickness of the links between categories is proportional to the number of reported results between categories

that while Araiza and Pedraza (2019), Liesa-Orús et al. (2020), Basantes-Andrade et al. (2020), Zhao et al. (2021), Calderón-Garrido et al. (2021), and Bandrés et al. (2021) have reported 15 specific results (e.g., 7 positive or 8 negative), other authors, such as Basantes-Andrade et al. (2020), Jarad and Shaalan (2020), Torres-Flórez and Diaz-Betancour (2021), Sánchez Trujillo and Rodríguez Flores (2021), and Quiñonez Pech et al. (2021), have reported 11 results about no effects. Something similar was observed in the case of *age*, where only six results out of 19 corresponded to positive or negative relationships.

In the specific case of *Country*, De los Santos Lorenzo and Martínez Abad (2021) used it to compare the five generic digital competencies. Overall, they found that teachers from Spain, Argentina, and Chile have significant higher levels of competence than those from Colombia, the Dominican Republic, and Mexico. Similarly, a nationwide study Torres-Flórez and Diaz-Betancour (2021) found that the location (a geographic region in Colombia in this case) of teachers has a significant effect on information literacy but not on their communication and collaboration skills. Specifically, teachers from a more developed region have higher levels of information literacy than those from a less developed region.

Table 1 also shows that demographics have been employed as explanatory factors for *Digital teaching competence*. Here, *Age* and *Gender* were the most employed explanatory factors with mixed results. For instance, several studies agreed that the relationship between *Age* and *Digital teaching competence* is negative (Radovanović et al., 2015; de Ovando Calderón & Jara, 2019; Alvarez-Flores, 2021; Cabero-Almenara et al., 2021b; Cabero-Almenara et al., 2021; Jorge-Vázquez et al., 2021; Calderón-Garrido et al., 2021), while others reported that it is positive (Mirete et al.,

2020) or non-existent (Quiñonez Pech et al., 2021; Torres-Flórez & Diaz-Betancour, 2021; Sánchez Trujillo & Rodríguez Flores, 2021; Guillén-Gámez & Mayorga-Fernández, 2020; Santos et al., 2021; Liesa-Orús et al., 2020). We observed a similar trend in the cases of *Gender*, *Education*, and *Location*.

An atypical study within this group of results was developed by Cabero-Almenara et al. (2021a), who explored the interaction of demographic factors such as *Age* and *Gender* with teachers' *Discipline* to explain specific digital teaching competencies. As a result, the following was concluded: 1) male professors in the areas of engineering-architecture and social sciences-legal have higher levels of competencies than the rest; 2) within these two disciplines, teachers over 40 years of age have higher levels of digital competence than those aged 40 years or younger; 3) only female teachers showed significant differences according to age and discipline.

Professional digital competencies have been explained by *Age*, *Gender*, and the interaction between these factors. For example, Guillén-Gámez et al. (2021) reported that the interaction of *Age* and *Gender* allows the identification of differences in the levels of competencies related to ICT-assisted research. Specifically, they reported that for teachers up to 40 years of age, there are no differences in any of the competencies considered, i.e., there are no differences regardless of gender. As for the group over 40 years of age, differences were observed only in five competencies, as shown in Table A1. In all cases, slightly higher levels of competencies were observed in male teachers.

Regarding *psychological* factors, Bennett (2014) and Armstrong (2019) explored the teachers' characteristics associated with the adoption of technology-enhanced learning (TEL). In this context, Bennett (2014) took into account a set of attitudes grouped into a category defined as *Attributes*, while Armstrong (2019) analyzed in more detail aspects such as *confidence*, the *ability to take risks*, and *feeling inspired*. In all cases, the relationships found between these factors and the adoption of TEL when teaching were positive. Similarly, Fernández-Márquez et al. (2017) reported two positive relationships for explaining the use of ICTs in the classroom, i.e., with respect to teachers' *interest* and *ability to adapt to technologies*.

From Table 1, we can notice that there has been a tendency to explain TDCs based on factors related to the *teaching practice*. Here, the fundamental explanatory factor for both teaching and generic digital competencies was clearly *teaching experience*. It appeared in 41 results. However, only 19 corresponded to positive or negative relationships. The rest ($n = 22$) corresponded to results indicating no relationship at all. In the case of *generic digital competencies*, positive relationships were reported by (De los Santos Lorenzo & Martínez Abad, 2021; Zhao et al., 2021), while negative relationships were reported by (Liesa-Orús et al., 2020). In contrast, authors such as Calderón-Garrido et al. (2021), Naim and Razak (2020), Sánchez Trujillo and Rodríguez Flores (2021), and De los Santos Lorenzo and Martínez Abad (2021) reported that *Teaching experience* does not explain certain competencies.

Regarding *digital teaching competence*, there was a greater number of results confirming positive and negative relationships involving *Teaching Experience*. In the group of positive relationships, the results supported by Akram et al. (2021) and Zhao et al. (2021) appeared, while the negative relationships were supported by Cabero-Almenara et al. (2021b), Cabero-Almenara et al. (2021), Guillén-Gámez and

Mayorga-Fernández (2020), Liesa-Orús et al. (2020), de Ovando Calderón and Jara (2019), and Sarango-Lapo et al. (2020). The results of no relationship came from the studies developed by Alarcia and Del Arco Bravo (2013), Calderón-Garrido et al. (2021), Sánchez Trujillo and Rodríguez Flores (2021), and Santos et al. (2021).

Other factors were explored to a lesser extent than *teaching experience* to explain digital teaching competencies. For example, Calderón-Garrido et al. (2021) considered *teaching mode* as a predictor of attitudes toward the use of ICT for teaching. Specifically, they found that teachers who teach using the blended learning mode have a more favorable attitude. Similarly, in the same study, it was found that greater *knowledge* about the use of ICTs in teaching is associated with greater actual *use*.

The effects of ICT *training* on TDCs have been considered by a smaller number of studies compared to *Teaching practice*. As shown in Table 1, there were 11 relationships with an equal number of results, most of which ($n = 8$) corresponded to positive relationships (Arango et al., 2020; Fernández-Márquez et al., 2017; Jorge-Vázquez et al., 2021; Naim & Razak, 2020; Pozos Pérez & Tejada Fernández, 2018; Sarango-Lapo et al., 2020). Only Arango et al. (2020) and Pozos Pérez and Tejada Fernández (2018) found that ICT training does not explain some generic or professional digital competencies.

A total of 35 relationships corresponded to *organizational* and *professional traits* as explanatory categories. As evident, a wide range of organizational factors have been studied to explain both digital teaching competencies and professional digital competencies. In the first group, Bennett (2014), Jorge-Vázquez et al. (2021), Fernández-Márquez et al. (2017), Santos et al. (2021), Armstrong (2019), Pozos Pérez and Tejada Fernández (2018), and Sales et al. (2020) reported that factors like *access* (to ICTs), *infrastructure*, *institutional category*, *support from colleagues*, *type of university*, or *university culture* have positive effects on certain digital teaching competences. In contrast, Pozos Pérez and Tejada Fernández (2018) and Santos et al. (2021) reported no relationships. Similarly, Pozos Pérez and Tejada Fernández (2018) found no relationship between organizational factors and digital professional competencies.

Professional traits have also been considered as factors that explain TDCs. For example, Delgado and Hernández-Gress (2021) found that *being a researcher* is positively associated with having high levels of *digital competence*. However, Naim and Razak (2020) found no relationship between the *position* held by teachers and their levels of *digital competence*. In the case of digital teaching competencies, all the results reported in the literature corresponded to positive relationships, with the exception of Guillén-Gámez and Mayorga-Fernández (2020). Finally, in the context of professional digital competencies, Arshad and Ameen (2021) found that teachers' *discipline* is a significant factor that explain their levels of *digital information literacy*. Teachers in the area of natural sciences showed higher levels of proficiency than their peers in social sciences and humanities.

By summarizing the large number of relationships and results in Table 4 using the indicator proposed in Section 3.5, we obtained the graphs presented in Fig. 8. In these graphs, the relationships that were considered by two or more studies appear on the y-axis, while the x-axis shows the value of the strength of the relationship. It should be noted that the size of the arrow indicates its magnitude, while the head indicates

the direction. Vertical dashed lines define both the extreme values and the regions that characterize the relationships, i.e., as predominantly negative, predominantly positive, or predominantly non-existent.

As shown in Fig. 1, only 22 relationships have been considered by two or more studies. Particularly, these relationships involved only two categories of TDCs: *generic digital competencies* and *digital teaching competencies*. In the first group, we found that gender has a predominantly positive association with digital security competence. The strength of this relationship was supported by more than four studies (as indicated by the color scale in the legend). Similarly, *Teaching experience* was found to be positively associated with teachers' digital information literacy and level

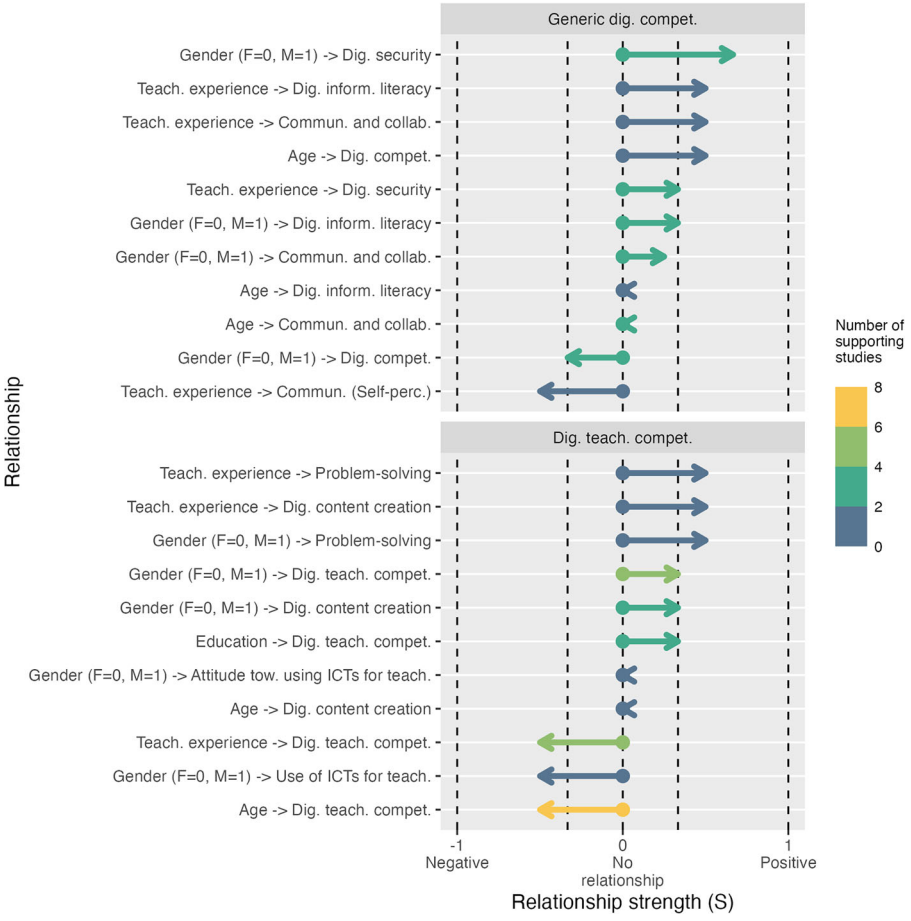

Fig. 8 Summary of the strength of relationships from *Scenario 1*

of digital communication and collaboration. *Age* was also found to have a predominantly positive relationship with teachers' overall digital competence level. However, these three relationships were only supported by two studies. With the exception of the negative relationship between teaching experience and the communication ability, the rest of the relationships could be categorized as predominantly non-existent.

In the case of teaching digital competencies, in Fig. 8, the graph at the bottom shows that teaching experience was positively associated with the ability to solve problems and the creation of digital content. However, it was negatively associated with overall digital teaching competence. While the strength of the first two relationships has been confirmed by two studies, the latter has been confirmed by more than four. *Gender* was positively associated with problem solving ability (e.g., in favor of male teachers) and, at the same time, negatively associated with the use of ICT tools (e.g., in favor of female teachers). In the case of the rest of the relationships, *Gender* participated in predominantly non-existent relationships. This same pattern appeared in the relationships involving *education* and *age* to explain *digital content creation*. *Age* also appeared to be negatively associated with the general level of *digital teaching competence*. This result was supported by more than six studies.

4.3.2 Scenario 2: Teachers' digital competencies explained by themselves

This scenario revealed a smaller number of relationships and results compared to the previous one. As shown in Table 5, there were 51 relationships and 52 results. It should be noted that most of these involved generic digital competencies explaining digital teaching competencies. Regardless of the factor category, it can be seen that with the exception of (Arango et al., 2020), all the results corresponded to positive relationships between factors. However, since these results were supported by single studies, it was not possible to analyze them according to the indicator proposed in Sec. 3.5. The only exception here was the relationship involving *time using the Internet* as an explanatory factor of *digital teaching competence*. Since it had two results claiming a positive relationship, it was easy to show that the corresponding strength was 1, i.e., predominantly positive.

4.3.3 Scenario 3: Teachers' digital competencies used to explain external factors

Table 6 presents the relationships and results corresponding to the Scenario 3. As expected, the number of relationships here was much lower than in the previous scenarios. Specifically, Table 6 shows only 16 relationships and the same number of results. This implies that behind each relationship, there was only one study supporting the result in question. As a general pattern, it can be seen that most of the relationships involved generic digital competencies and that the results were heterogeneous. On the one hand, we found studies such as that of Saad et al. (2021), who reported different results for the moderating effects of *basic digital skills* and *mobile digital competence* on different relationships between psychological factors.

Similarly, Nikou and Aavakare (2021) and Portillo et al. (2020) explored *digital competence* as an explanatory factor for the psychological traits of teachers with mixed results. On the other hand, Soyemi et al. (2018) and Arango et al. (2020) found positive relationships between generic competencies and teacher training, while Yurtseven et al. (2021) reported that digital teaching competence is positively associated with teachers' perception of online learning. Finally, it is important to note that due to the null confirmation of the relationships included in this scenario, it was not possible to analyze them using the indicator proposed in Sec. 3.5.

5 Discussion and conclusion

It is imperative for today's university educators to be digitally competent. Part of the success in achieving this complex undertaking lies in understanding the factors that explain the acquisition and development of such competencies. Likewise, it is important to identify to what extent being digitally competent, or not, can explain other factors associated with the university teacher. This research provided, as its main contribution, an overview of this important topic through a systematic mapping of the literature. Our findings allowed us to conclude the following:

1. *There is a growing number of contributions aimed at understanding the acquisition of digital skills, especially from external factors.*. Based also on the results provided by Spante et al. (2018) and Saltos-Rivas et al. (2021), we noted that the field of digital competencies is evolving to involve issues that go beyond simply defining *what* digital competence is and *how* to measure it. Now, it is also starting to be interested in the reasons behind, and the *implications* of, being digitally competent. This, together with the significant scientific production on this topic (Zhao et al., 2021), allowed us to conclude that this field is beginning to mature. This is an excellent sign from both the scientific and academic (including policy-making) points of view. The reason is that progress is being made in understanding this phenomenon from various perspectives. However, this does not mean that everything is solved or answered. As explained in the following points, there are also important gaps that demand future research and attention. Although to a lesser extent, we have also found an important group of contributions that have used digital competencies to explain other competencies in the same category or other external factors. To the best of our knowledge, no previous research has reported on this.
2. *European, and more specifically Spanish, university professors from multiple disciplines are the most studied population*. This result was partially consistent with previous research (Saltos-Rivas et al., 2021). However, Saltos-Rivas et al. (2021) found that participants from the social sciences were more frequently considered by the studies. One possible reason for this difference is that Saltos-Rivas et al. (2021) included both undergraduate students and teachers. Thus, there is a possibility that this mix of participant types masked the predominant

discipline of the teachers. In any case, the fact that little research exists in the rest of the world (especially in less developed continents) is an important gap that can be utilized for further research. An argument in favor of studying this issue has been provided by De los Santos Lorenzo and Martínez Abad (2021), who found that the country of the participants is a factor that explains both perceived and observed digital competencies. Although there are other comparative studies involving university teachers (Tejedor et al., 2020), these have focused on issues unrelated to digital competencies. The predominance of studies based on participants from different disciplines is a strength of the field, as it increases the degree of generalizability of the findings.

3. *Most studies adopted quantitative approaches to explain but not prove causality*. More specifically, most of the studies adopted non-experimental designs based on cross-sectional measurements from questionnaires. As a consequence of these decisions, the results of the studies were only correlation-based or predictive in scope (Dannels, 2019). There seems to be a perception that the causes of the acquisition or development of digital competencies lie in the teacher's opportunities for training and having scenarios to apply these attitudes, knowledge, and skills. However, the few studies with mixed methods (Almpanis, 2016; Armstrong, 2019; Delgado & Hernández-Gress, 2021) or qualitative approaches (Bennett, 2014; Radovanović et al., 2015; Padilla-Hernández et al., 2020) have shown that at the subject level, there are also psychological and organizational factors that condition such processes. Nevertheless, it is difficult to claim causality based on non-experimental cross-sectional studies, much less those of a qualitative nature. Thus, the field lacks more in-depth research that can confirm not only the available theoretical models of competence acquisition/development (Adeniji et al., 2019) but also the findings reported by the aforementioned qualitative studies. A starting point is to follow a systematic approach as proposed in Pearl (2009) and involving three hierarchically organized layers: *association*, *intervention* and *counterfactuals*. Based on our results, it is clear that so far most contributions have warranted the first two conditions. However, the third is much more difficult to demonstrate due to the inherent challenges of experimentation in the Social Sciences. Unless a probabilistic approach is adopted (Pearl, 2009), we recommend conducting longitudinal and random sample-based studies as a way to ensure causality in the relationships addressed. Of course, our recommendation goes mainly for those relationships involving variables that could be under the experimenter's control. For example, the positive effect of basic digital competencies on the development of more advanced digital competencies (e.g. of a teaching or professional nature). A relationship that seems intuitively valid, but has not been addressed from a causality perspective so far. However, it should be noted that it is increasingly clear to policymakers that it is important to address these issues. From the research perspective, Guri-Rosenblit (2018) supported this position by pointing out that digital education is a prerequisite for effective digital learning, while from the international policy perspective,

the 17 well-known UN Sustainable Development Goals (SDGs, 2019) recognized ICTs as catalysts for achieving such goals (United Nations, 2016). More recently, UNESCO (Montoya & Barbosa, 2020) has acknowledged the need to monitor and improve the use of ICTs in post-confinement education. Specifically, it has highlighted the importance of the digital preparation of teachers for achieving this goal as a way of closing the current ICT skill gap.

4. *There is a great heterogeneity of relationships and results that explain the digital competencies of university professors.* The mapping showed that there is a great variety of relationships, especially those focused on explaining digital teaching competencies based on generic digital competencies. However, most of them involve very specific factors that make it difficult to reach conclusions that can be generalized beyond the populations considered by the studies. In our opinion, the main cause of this phenomenon is the wide variety of instruments and models used by the studies, which measure digital competencies in different ways (Saltos-Rivas et al., 2021; 2022). Only in the cases of demographic and teaching practice-based factors is it possible to identify relationships with certain levels of confirmation. However, these confirmations are also inconclusive, as they show different directions for the relationships. For example, age, which intuitively has been seen as a factor that would be negatively related to digital competencies (e.g., the younger the teacher, the more competent they would be), has been confirmed as a positive factor at times and, at others, as a factor that is simply without effect. The same is true for gender, teaching experience, and educational level. However, it does not seem to be a phenomenon unique to this field of research. Scherer and Teo (2019) reported a similar problem in the context of the technological acceptance of e-learning systems.

So, for the question of how to understand digital competencies, there is no well-defined set of answers. We can conclude that the attempts reported in the literature, although quantitative in most cases, have little confirmatory power in relation to the results. More research should be conducted in the future to address other factors and determinants of the acquisition of these important competencies. In this regard, we would like to call attention not only to base future measurements on existing instruments or frameworks but also to the need of perform deeper analyses to avoid the influence of common phenomena on explanatory models, such as confounding factors. Nevertheless, our results suggested that basic digital competencies and some teacher characteristics can appropriately explain certain more complex digital competencies, such as teaching and professional competencies. Future research in this important field should consider these findings and also take into account that it is a multidimensional phenomenon.

Our results also have important implications for policy makers. On the one hand, the large heterogeneity of results involving demographic factors indicates that there may be risks of digital divides among teachers. This is an aspect that should be taken into account in the design of training programs. On the other hand, there is evidence

that basic digital competencies help explain other more advanced digital competencies. Thus, one way to contribute to the development of the latter could be the training of more basic skills. Finally, having digitally competent teachers should not be considered as an end, but as a necessary requirement for the improvement of the teaching-professional activity of university teachers. Although scarce, the evidence supporting this last point shows that digitally competent teachers are more likely to have positive attitudes towards the use of ICTs in teaching, ICT training, and online learning modalities.

6 Limitations and future work

Although the validity of the research was assessed in Sec. 3.6, in this section, we highlight some of its most important limitations. In our opinion, the main limitation of our work lies in the process of classifying the factors. Given that this process was performed based on the authors' experience in the subject of digital competencies, it is possible that this process was not entirely accurate. This implies that some relationships cataloged as unique are, in essence, similar to other existing ones. As recognized above, we believe that the main cause of this problem is the variety of the definitions of digital competencies that currently exist. However, our objective has been to provide a general overview of the subject and not to establish a standard classification. We are aware that other classifications are possible, which would result in findings different from those obtained here. Secondly, it is possible that certain relevant studies were left out of our selection since we conducted the search oriented, in general terms, to the digital competencies of university teachers. These missing studies would be mainly those that used TDCs to explain external factors. Finally, it is important to note that our research focused on in-service teachers, leaving pre-service teachers aside. Although these were two different populations for us, it is clear that a more comprehensive review would have also considered future teachers.

In addition to the gaps identified in the discussion of our findings, we believe that this research can serve as a starting point for future work. Specifically, it would be useful for this field to have a more formal synthesis of both the effects of certain factors on the levels of digital competence and of digital competencies on other variables related to the teaching and professional work of university professors. The fact that scientific production on the subject has experienced significant growth in recent years augurs well for obtaining relevant evidence in the future that can be synthesized through techniques such as meta-analysis. In this context, there are important questions to be answered that can help both teachers and policymakers to anticipate scenarios that require adequate levels of digital competencies. We live at a time when it is crucial to conduct research on these issues, as different generations of teachers who have interacted differently with ICTs coexist in our faculties. This opportunity must be seized to the maximum since in a few years, most higher education teachers will have been born or grown up in a society permeated by ICTs.

Appendix A: Scenario 1: Teachers' digital competencies explained by external factors

Table 4 Teachers' digital competence being explained by demographics and psychological traits

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Demographics ⇒ Generic digital competence			
Age → Character			(Liesa-Orús et al., 2020)
Age → Citizenship			(Liesa-Orús et al., 2020)
Age → Collaboration			(Liesa-Orús et al., 2020)
Age → Commun. (Self-perc.)			(Liesa-Orús et al., 2020)
Age → Commun. and collab.			(Quiñonez Pech et al., 2021) (Sánchez Trujillo & Rodríguez Flores, 2021) (Torres-Flórez & Diaz-Betancour, 2021)
Age → Creativity			(Liesa-Orús et al., 2020)
Age → Critical thinking			(Liesa-Orús et al., 2020)
Age → Dig. compet.	(Jarad & Shaalan, 2020)		(Quiñonez Pech et al., 2021)
Age → Dig. inform. literacy			(Sánchez Trujillo & Rodríguez Flores, 2021) (Torres-Flórez & Diaz-Betancour, 2021)
Age → Dig. security			(Sánchez Trujillo & Rodríguez Flores, 2021)
Age → Knowl. cloud storage		(Basantes-Andrade et al., 2020)	
Age → Knowl. creat. online presentations		(Basantes-Andrade et al., 2020)	
Age → Knowl. office 365		(Basantes-Andrade et al., 2020)	
Age → Knowl. social networks		(Basantes-Andrade et al., 2020)	
Age → Knowl. technic. troubleshooting		(Basantes-Andrade et al., 2020)	
Country → Commun. (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)*
Country → Commun. (Self-perc.)	(De los Santos Lorenzo & Martínez Abad, 2021)*		
Country → Inform. assessment (Obs.)	(De los Santos Lorenzo & Martínez Abad, 2021)*		
Country → Inform. assessment (Self-perc.)	(De los Santos Lorenzo & Martínez Abad, 2021)*		
Country → Inform. literacy (Obs.)	(De los Santos Lorenzo & Martínez Abad, 2021)*		
Country → Inform. literacy (Self-perc.)			(De los Santos Lorenzo & Martínez Abad, 2021)*
Country → Inform. processing (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)*
Country → Inform. processing (Self-perc.)	(De los Santos Lorenzo & Martínez Abad, 2021)*		

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Country → Inform. search (Obs.)	(De los Santos Lorenzo & Martínez Abad, 2021)*		
Education → Commun. and collab.			(Torres-Flórez & Diaz-Betancour, 2021)
Education → Dig. compet.			(Naim & Razak, 2020)
Education → Dig. inform. literacy	(Torres-Flórez & Diaz-Betancour, 2021)		
Gender (F=0, M=1) → Attitude tow. ICT use		(Araiza & Pedraza, 2019)	
Gender (F=0, M=1) → Character		(Liesa-Orús et al., 2020)	
Gender (F=0, M=1) → Citizenship		(Liesa-Orús et al., 2020)	
Gender (F=0, M=1) → Collaboration		(Liesa-Orús et al., 2020)	
Gender (F=0, M=1) → Commun. (Self-perc.)		(Liesa-Orús et al., 2020)	
Gender (F=0, M=1) → Commun. and collab.	(Zhao et al., 2021)		(Quiñonez Pech et al., 2021) (Sánchez Trujillo & Rodríguez Flores, 2021) (Torres-Flórez & Diaz-Betancour, 2021)
Gender (F=0, M=1) → Creativity		(Liesa-Orús et al., 2020)	
Gender (F=0, M=1) → Critical thinking		(Liesa-Orús et al., 2020)	
Gender (F=0, M=1) → Dig. compet.		(Bandrés et al., 2021)	(Jarad & Shaalan, 2020) (Quiñonez Pech et al., 2021)
Gender (F=0, M=1) → Dig. inform. literacy	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021) (Torres-Flórez & Diaz-Betancour, 2021)
Gender (F=0, M=1) → Dig. security	(Calderón-Garrido et al., 2021) (Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021)
Gender (F=0, M=1) → Hardware mastery	(Calderón-Garrido et al., 2021)		
Gender (F=0, M=1) → Knowl. cloud storage	(Basantes-Andrade et al., 2020)		
Gender (F=0, M=1) → Knowl. creat. online presentations			(Basantes-Andrade et al., 2020)
Gender (F=0, M=1) → Knowl. office 365			(Basantes-Andrade et al., 2020)
Gender (F=0, M=1) → Knowl. social networks	(Basantes-Andrade et al., 2020)		
Gender (F=0, M=1) → Knowl. technic. troubleshooting			(Basantes-Andrade et al., 2020)
Location → Commun. and collab.			(Torres-Flórez & Diaz-Betancour, 2021)*
Location → Dig. inform. literacy	(Torres-Flórez & Diaz-Betancour, 2021)*		

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Demographics ⇒ Digital teaching competence			
Age → Critical use of ICT in teach.		(Alvarez-Flores, 2021)	
Age → Didactics with ICTs			(Quiñonez Pech et al., 2021)
Age → Dig. content creation			(Sánchez Trujillo & Rodríguez Flores, 2021) (Torres-Flórez & Diaz-Betancour, 2021)
Age → Dig. teach. compet.	(Mirete Ruiz, 2016)	(Cabero-Almenara et al., 2021b) (Cabero-Almenara et al., 2021) (Jorge-Vázquez et al., 2021) (de Ovando Calderón & Jara, 2019) (Radovanović et al., 2015)	(Guillén-Gámez & Mayorga-Fernández, 2020) (Santos et al., 2021)
Age → Problem-solving			(Sánchez Trujillo & Rodríguez Flores, 2021)
Age → Use of ICTs for teach.			(Torres-Flórez & Diaz-Betancour, 2021)
Age → Use of open educ. res. in teach.		(Calderón-Garrido et al., 2021)	
Education → Critical use of ICT in teach.	(Alvarez-Flores, 2021)		
Education → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)		
Education → Dig. content creation			(Torres-Flórez & Diaz-Betancour, 2021)
Education → Dig. teach. compet.	(Santos et al., 2021)		(Guillén-Gámez & Mayorga-Fernández, 2020) (de Ovando Calderón & Jara, 2019)
Education → Use of ICTs for teach.			(Torres-Flórez & Diaz-Betancour, 2021)
Gender (F=0, M=1) → Attitude tow. using ICTs for teach.	(Calderón-Garrido et al., 2021)	(Bandrés et al., 2021)	
Gender (F=0, M=1) → Behavior in using ICT to support learn.		(Bandrés et al., 2021)	
Gender (F=0, M=1) → Development of learn. exper.			(Pozos Pérez & Tejada Fernández, 2018)
Gender (F=0, M=1) → Didactics with ICTs			(Quiñonez Pech et al., 2021)
Gender (F=0, M=1) → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)		
Gender (F=0, M=1) → Dig. content creation	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021) (Torres-Flórez & Diaz-Betancour, 2021)

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Gender (F=0, M=1) → Dig. teach. compet.	(Akram et al., 2021) (de Ovando Calderón & Jara, 2019)		(Cabero-Almenara et al., 2021) (Guillén-Gámez & Mayorga-Fernández, 2020) (Jorge-Vázquez et al., 2021) (Santos et al., 2021)
Gender (F=0, M=1) → Effectiveness of ICT on learn.		(Bandrés et al., 2021)	
Gender (F=0, M=1) → Knowl. construction in students			(Pozos Pérez & Tejada Fernández, 2018)
Gender (F=0, M=1) → Planning of learn. exper.			(Pozos Pérez & Tejada Fernández, 2018)
Gender (F=0, M=1) → Problem-solving	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021)
Gender (F=0, M=1) → Research and Innov. in ICTs for learn.			(Pozos Pérez & Tejada Fernández, 2018)
Gender (F=0, M=1) → Use of dig. educ. res.			(Alarcia & Del Arco Bravo, 2013)
Gender (F=0, M=1) → Use of ICTs for teach.		(Bandrés et al., 2021)	(Torres-Flórez & Diaz-Betancour, 2021)
Gender × Age × Discipline → Adapting ICT to student learn.	(Cabero-Almenara et al., 2021a)*		
Gender × Age × Discipline → Creation and distrib. of dig. res.	(Cabero-Almenara et al., 2021a)*		
Gender × Age × Discipline → Dig. pedagogy	(Cabero-Almenara et al., 2021a)*		
Gender × Age × Discipline → Dig. teach. compet.	(Cabero-Almenara et al., 2021a)*		
Gender × Age × Discipline → Facilitating the dig. compet. of students	(Cabero-Almenara et al., 2021a)*		
Gender × Age × Discipline → Use of ICT res. for student evaluation	(Cabero-Almenara et al., 2021a)*		
Location → Dig. content creation	(Torres-Flórez & Diaz-Betancour, 2021)*		
Location → Dig. teach. compet.			(Santos et al., 2021)*
Location → Use of ICTs for teach.			(Torres-Flórez & Diaz-Betancour, 2021)*

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Demographics ⇒ DProfessional digital competence			
Age × Gender → Dig. compet. for research	(Guillén-Gámez et al., 2021)*		
Age × Gender → Dig. ethics in research			(Guillén-Gámez et al., 2021)*
Age × Gender → Dig. flow in research (attitude)	(Guillén-Gámez et al., 2021)*		
Age × Gender → Dig. skills in research	(Guillén-Gámez et al., 2021)*		
Age × Gender → Integration of ICT res. for research	(Guillén-Gámez et al., 2021)*		
Age × Gender → Quality of research-related ICT res. (infrastructure)	(Guillén-Gámez et al., 2021)*		
Gender (F=0, M=1) → Appropriate use of ICTs		(Pozos Pérez & Tejada Fernández, 2018)	
Gender (F=0, M=1) → Dig. ethics in the teach. profession			(Pozos Pérez & Tejada Fernández, 2018)
Gender (F=0, M=1) → Profess. growth management			(Pozos Pérez & Tejada Fernández, 2018)
Gender × Age × Discipline → Profess. commitment to use ICT	(Cabero-Almenara et al., 2021a)*		
Psychological traits ⇒ Digital teaching competence			
Adapt. to the change betw. techn. → Use of ICTs in the classroom	(Fernández-Márquez et al., 2017)		
Attributes → Adopting TEL in teach.	(Bennett, 2014)		
Feeling confident → Adopting TEL in teach.	(Armstrong, 2019)		
Feeling able to take risks → Adopting TEL in teach.	(Armstrong, 2019)		
Feeling inspired → Adopting TEL in teach.	(Armstrong, 2019)		
Interest → Use of ICTs in the classroom	(Fernández-Márquez et al., 2017)		
Teaching practice ⇒ Generic digital competence			
Course in which more hours are taught → Character			(Liesa-Orús et al., 2020)

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Course in which more hours are taught → Citizenship			(Liesa-Orús et al., 2020)
Course in which more hours are taught → Collaboration			(Liesa-Orús et al., 2020)
Course in which more hours are taught → Commun. (Self-perc.)			(Liesa-Orús et al., 2020)
Course in which more hours are taught → Creativity			(Liesa-Orús et al., 2020)
Course in which more hours are taught → Critical thinking			(Liesa-Orús et al., 2020)
Teach. experience → Character		(Liesa-Orús et al., 2020)	
Teach. experience → Citizenship		(Liesa-Orús et al., 2020)	
Teach. experience → Collaboration		(Liesa-Orús et al., 2020)	
Teach. experience → Commun. (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Commun. (Self-perc.)		(Liesa-Orús et al., 2020)	(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Commun. and collab.	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021)
Teach. experience → Creativity		(Liesa-Orús et al., 2020)	
Teach. experience → Critical thinking		(Liesa-Orús et al., 2020)	
Teach. experience → Dig. compet.			(Naim & Razak, 2020)
Teach. experience → Dig. inform. literacy	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021)
Teach. experience → Dig. security	(Zhao et al., 2021)		(Calderón-Garrido et al., 2021) (Sánchez Trujillo & Rodríguez Flores, 2021)
Teach. experience → Hardware mastery			(Calderón-Garrido et al., 2021)
Teach. experience → Inform. assessment (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Inform. assessment (Self-perc.)			(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Inform. literacy (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Inform. literacy (Self-perc.)			(De los Santos Lorenzo & Martínez Abad, 2021)

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Teach. experience → Inform. processing (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Inform. processing (Self-perc.)	(De los Santos Lorenzo & Martínez Abad, 2021)		
Teach. experience → Inform. search (Obs.)			(De los Santos Lorenzo & Martínez Abad, 2021)
Teach. experience → Inform. search (Self-perc.)	(De los Santos Lorenzo & Martínez Abad, 2021)		
Teach. mode (face-to-face=0, blended learn.=1) → Hardware mastery	(Calderón-Garrido et al., 2021)		
Teaching practice ⇒ Digital teaching competence			
Basic use of learn. res. → Dig. teach. compet.	(Padilla-Hernández et al., 2020)		
Commun. hours with students → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)		
Knowl. building approach → Attitude tow. using ICTs for teach.	(Mirete et al., 2020)		
Knowl. building approach → Knowl. on the use of ICTs for teach.	(Mirete et al., 2020)		
Knowl. building approach → Use of ICTs for teach.			(Mirete et al., 2020)
Knowl. on the use of ICTs for teach. → Use of ICTs for teach.	(Calderón-Garrido et al., 2021)		
Knowl. transmission approach → Attitude tow. using ICTs for teach.			(Mirete et al., 2020)
Knowl. transmission approach → Knowl. on the use of ICTs for teach.			(Mirete et al., 2020)

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Knowl. transmission approach → Use of ICTs for teach.		(Mirete et al., 2020)	
Number of pedagogical innovation initiatives → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)		
Pedagogical approach for the creation of knowledge → Dig. teach. compet.	(Mirete Ruiz, 2016)		
Pedagogical approach to the transmission of inform. → Dig. teach. compet.			(Mirete Ruiz, 2016)
Selection and creation of learn. res. → Dig. teach. compet.	(Padilla-Hernández et al., 2020)		
Teach. experience → Attitude tow. using ICTs for teach.			(Calderón-Garrido et al., 2021)
Teach. experience → Dig. compet. and use of open educ. res.		(Sarango-Lapo et al., 2020)	
Teach. experience → Dig. content creation	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021)
Teach. experience → Dig. teach. compet.	(Akram et al., 2021)	(Cabero-Almenara et al., 2021b) (Cabero-Almenara et al., 2021) (Guillén-Gámez & Mayorga-Fernández, 2020) (de Ovando Calderón & Jara, 2019)	(Santos et al., 2021)
Teach. experience → Facilitating the dig. compet. of students			(Calderón-Garrido et al., 2021)
Teach. experience → Problem-solving	(Zhao et al., 2021)		(Sánchez Trujillo & Rodríguez Flores, 2021)
Teach. experience → Use of dig. educ. res.			(Alarcia & Del Arco Bravo, 2013)
Teach. experience → Use of ICTs for teach.			(Calderón-Garrido et al., 2021)
Teach. experience → Use of open educ. res. in teach.			(Calderón-Garrido et al., 2021)
Teach. level → Dig. teach. compet.	(Santos et al., 2021)		
Teach. mode (face-to-face=0, blended learn.=1) → Dig. teach. compet.	(Santos et al., 2021)		
Teach. mode (face-to-face=0, blended learn.=1) → Facilitating the dig. compet. of students	(Calderón-Garrido et al., 2021)		

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative No relation.
Teach. mode (face-to-face=0, blended learn.=1) → Use of dig. educ. res.	(Alarcia & Del Arco Bravo, 2013)	
Training ⇒ Generic dig. compet.		
Continuous ICT training → Dig. compet.	(Naim & Razak, 2020)	
ICT Training → Attitude tow. ICTs		(Arango et al., 2020)
Training ⇒ Dig. teach. compet.		
ICT Training → Development of learn. exper.	(Pozos Pérez & Tejada Fernández, 2018)	
ICT Training → Dig. teach. compet.	(Jorge-Vázquez et al., 2021)	
ICT Training → ICT teach. methodology	(Arango et al., 2020)	
ICT Training → Knowl. construction in students	(Pozos Pérez & Tejada Fernández, 2018)	
ICT Training → Planning of learn. exper.	(Pozos Pérez & Tejada Fernández, 2018)	
ICT Training → Research and Innov. in ICTs for learn.	(Pozos Pérez & Tejada Fernández, 2018)	
ICT Training → Use of ICTs in the classroom	(Fernández-Márquez et al., 2017)	
Number of courses received on open educ. res. → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)	
Training ⇒ Profess. dig. compet.		
ICT Training → Appropriate use of ICTs		(Pozos Pérez & Tejada Fernández, 2018)
ICT Training → Dig. ethics in the teach. profession		(Pozos Pérez & Tejada Fernández, 2018)
ICT Training → Profess. growth management	(Pozos Pérez & Tejada Fernández, 2018)	
Organizational ⇒ Dig. teach. compet.		
Access → Adopting TEL in teach.	(Bennett, 2014)	
Infrastructure → Dig. teach. compet.	(Jorge-Vázquez et al., 2021)	
Infrastructure → Use of ICTs in the classroom	(Fernández-Márquez et al., 2017)	
Institutional category (university=0, polytechnics=1) → Dig. teach. compet.	(Santos et al., 2021)	
Support from colleagues → Adopting TEL in teach.	(Armstrong, 2019)	
Type of university (public=0, private=1) → Development of learn. exper.		(Pozos Pérez & Tejada Fernández, 2018)

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Type of university (public=0, private=1) → Dig. teach. compet.			(Santos et al., 2021)
Type of university (public=0, private=1) → Knowl. construction in students	(Pozos Pérez & Tejada Fernández, 2018)		
Type of university (public=0, private=1) → Planning of learn. exper.			(Pozos Pérez & Tejada Fernández, 2018)
Type of university (public=0, private=1) → Research and Innov. in ICTs for learn.			(Pozos Pérez & Tejada Fernández, 2018)
University culture → Facilitating the dig. compet. of students	(Sales et al., 2020)		
Organizational ⇒ Profess. dig. compet.			
Type of university (public=0, private=1) → Appropriate use of ICTs			(Pozos Pérez & Tejada Fernández, 2018)
Type of university (public=0, private=1) → Dig. ethics in the teach. profession			(Pozos Pérez & Tejada Fernández, 2018)
Type of university (public=0, private=1) → Profess. growth management			(Pozos Pérez & Tejada Fernández, 2018)
Profess. traits ⇒ Generic dig. compet.			
Being a researcher → Dig. compet.	(Delgado & Hernández-Gress, 2021)		
Contract term (adjunct=0, non-official=1, permanent=2) → Character		(Liesa-Orús et al., 2020)	
Contract term (adjunct=0, non-official=1, permanent=2) → Citizenship		(Liesa-Orús et al., 2020)	
Contract term (adjunct=0, non-official=1, permanent=2) → Collaboration		(Liesa-Orús et al., 2020)	
Contract term (adjunct=0, non-official=1, permanent=2) → Commun. (Self-perc.)		(Liesa-Orús et al., 2020)	
Contract term (adjunct=0, non-official=1, permanent=2) → Commun. and collab.			(Torres-Flórez & Diaz-Betancour, 2021)
Contract term (adjunct=0, non-official=1, permanent=2) → Creativity		(Liesa-Orús et al., 2020)	
Contract term (adjunct=0, non-official=1, permanent=2) → Critical thinking		(Liesa-Orús et al., 2020)	

Table 4 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Contract term (adjunct=0, non-official=1, permanent=2) → Dig. inform. literacy			(Torres-Flórez & Diaz-Betancour, 2021)
Position → Dig. compet.			(Naim & Razak, 2020)
Profess. traits ⇒ Dig. teach. compet.			
Contract term (adjunct=0, non-official=1, permanent=2) → Dig. content creation			(Torres-Flórez & Diaz-Betancour, 2021)
Contract term (adjunct=0, non-official=1, permanent=2) → Use of ICTs for teach.			(Torres-Flórez & Diaz-Betancour, 2021)
Development of ICT projects and initiatives → Dig. teach. compet.	(Padilla-Hernández et al., 2020)		
Discipline → Critical use of ICT in teach.	(Alvarez-Flores, 2021)* (Barragán Sánchez et al., 2021)*		
Number of international stays → Dig. teach. compet.	(Guillén-Gámez & Mayorga-Fernández, 2020)		
Number of master's degrees → Dig. teach. compet.	(Guillén-Gámez & Mayorga-Fernández, 2020)		
Number of projects awarded → Dig. teach. compet.	(Guillén-Gámez & Mayorga-Fernández, 2020)		
Scientific productivity → Dig. teach. compet.			(Guillén-Gámez & Mayorga-Fernández, 2020)
Time available → Use of ICTs in the classroom	(Fernández-Márquez et al., 2017)		
Profess. traits ⇒ Profess. dig. compet.			
Discipline → Dig. inform. literacy	(Arshad & Ameen, 2021)*		

Appendix B: Scenario 2: Teachers' digital competencies explained by themselves

Table 5 Teachers' digital competence used to explain other factors

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Generic dig. compet. ⇒ Generic dig. compet.			
Dig. inform. literacy → Dig. compet.	(Deja et al., 2021)		
Formal ICT Education → Dig. compet.	(Naim & Razak, 2020)		
Literacy and use of ICTs → Attitude tow. ICTs			(Arango et al., 2020)
Generic dig. compet. ⇒ Dig. teach. compet.			
Attitude tow. ICTs → ICT teach. methodology	(Arango et al., 2020)		
Basic dig. skills → Didactics with ICTs	(George Reyes & Avello Martinez, 2021)		
Basic dig. skills → Dig. teach. compet.	(Cabero-Almenara et al., 2021b)		
Basic dig. skills → Effective implementation of TELs	(Almpanis, 2016)		
Basic dig. skills → Level of dig. learn. activities initiated	(Lohr et al., 2021)		
Dig. compet. → Engagement with online formative assessment	(Zou et al., 2021)		
Dig. compet. → Perceiv. ease of use with LMS	(Feriady et al., 2020)		
Dig. compet. → Perceiv. usefulness with LMS	(Feriady et al., 2020)		
Having technical skills → Adopting TEL in teach.	(Armstrong, 2019)		
Hours using Internet → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)		
Internet Self-efficacy → Use of online learn. techn.	(Buchanan et al., 2013)		
Knowl. about big data → Browse search and filter	(López-Belmonte et al., 2019)		
Knowl. about big data → Evaluation	(López-Belmonte et al., 2019)		
Knowl. about big data → Storage and recovery	(López-Belmonte et al., 2019)		
Literacy and use → ICT teach. methodology	(Arango et al., 2020)		
Number of dig. skills → Dig. compet. and use of open educ. res.	(Sarango-Lapo et al., 2020)		
Previous experience with ICT → Dig. teach. compet.	(Padilla-Hernández et al., 2020)		
Skills → Adopting TEL in teach.	(Bennett, 2014)		
Technological expertise → Dig. teach. compet.	(Cabero-Almenara et al., 2021)		

Table 5 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Time spent using ICTs → Dig. teach. compet.	(Cabero-Almenara et al., 2021b) (Cabero-Almenara et al., 2021)		
Generic dig. compet. ⇒ Profess. dig. compet.			
Attitude tow. ICTs → Profess. use of ICTs	(Jwaifell et al., 2019)		
Dig. compet. → Inform. empowerment	(Deja et al., 2021)		
Dig. compet. → Profess. use of ICTs	(Jwaifell et al., 2019)		
Dig. inform. literacy → Evidence-based educ. innovation	(Sarango-Lapo et al., 2021)		
Dig. teach. compet. ⇒ Dig. teach. compet.			
Adapting ICT to student learn. → Facilitating the dig. compet. of students	(Cabero-Almenara et al., 2021)		
Attitude tow. using ICTs for teach. → Didactics with ICTs	(George Reyes & Avello Martinez, 2021)		
Attitude tow. using ICTs for teach. → Knowl. on the use of ICTs for teach.	(Mirete et al., 2020)		
Attitude tow. using ICTs for teach. → Use of ICTs for teach.	(Mirete et al., 2020)		
Creation and distrib. of dig. res. → Adapting ICT to student learn.	(Cabero-Almenara et al., 2021)		
Creation and distrib. of dig. res. → Dig. pedagogy	(Cabero-Almenara et al., 2021)		
Creation and distrib. of dig. res. → Facilitating the dig. compet. of students	(Cabero-Almenara et al., 2021)		
Creation and distrib. of dig. res. → Use of ICT res. for student evaluation	(Cabero-Almenara et al., 2021)		
Dig. pedagogy → Adapting ICT to student learn.	(Cabero-Almenara et al., 2021)		
Dig. pedagogy → Facilitating the dig. compet. of students	(Cabero-Almenara et al., 2021)		
Dig. pedagogy → Use of ICT res. for student evaluation	(Cabero-Almenara et al., 2021)		
Importance of ICTs in learn. → Use of ICTs in the classroom	(Fernández-Márquez et al., 2017)		
Knowl. on the use of ICTs for teach. → Use of ICTs for teach.	(Mirete et al., 2020)		
Practice → Adopting TEL in teach.	(Bennett, 2014)		
Techn. making courses easier/more fun → Adopting TEL in teach.	(Armstrong, 2019)		
Techn. making teach. more effective → Adopting TEL in teach.	(Armstrong, 2019)		
Use of ICT res. for student evaluation → Adapting ICT to student learn.	(Cabero-Almenara et al., 2021)		
Use of ICT res. for student evaluation → Facilitating the dig. compet. of students	(Cabero-Almenara et al., 2021)		

Table 5 (continued)

Relationship	Positive (or Sig. diff.*)	Negative	No relation.
Profess. dig. compet. ⇒ Dig. teach. compet.			
Profess. commitment to use ICT → Adapting ICT to student learn.	(Cabero-Almenara et al., 2021)		
Profess. commitment to use ICT → Creation and distrib. of dig. res.	(Cabero-Almenara et al., 2021)		
Profess. commitment to use ICT → Dig. pedagogy	(Cabero-Almenara et al., 2021)		
Profess. commitment to use ICT → Facilitating the dig. compet. of students	(Cabero-Almenara et al., 2021)		
Profess. commitment to use ICT → Use of ICT res. for student evaluation	(Cabero-Almenara et al., 2021)		
Using techn. as part of a team → Adopting TEL in teach.	(Armstrong, 2019)		

Appendix C: Scenario 3: Teachers' digital competencies used to explain external factors

Table 6 Teachers' digital competence used to explain external factors

Relationship	Positive (or Sig. diff.*)	Negative	No relationship
Generic dig. compet. ⇒ Psychological traits			
Basic dig. skills → Effect of facilitating conditions on behav. intent. tow. M-Learn.		(Saad et al., 2021)	
Basic dig. skills → Effect of learn. expectancy on behav. intent. tow. M-Learn.	(Saad et al., 2021)		
Basic dig. skills → Effect of perceiv. ease of use on behav. intent. tow. M-Learn.			(Saad et al., 2021)
Basic dig. skills → Effect of perceiv. usefulness on behav. intent. tow. M-Learn.			(Saad et al., 2021)
Dig. compet. → Effort expectancy	(Nikou & Aavakare, 2021)		
Dig. compet. → Intention to use ICT		(Nikou & Aavakare, 2021)	
Dig. compet. → Negative emotions		(Portillo et al., 2020)	
Dig. compet. → Performance expectancy	(Nikou & Aavakare, 2021)		
Dig. compet. → Positive emotions	(Portillo et al., 2020)		
Mobile dig. skills → Effect of facilitating condit. on behav. intent. tow. M-Learn.	(Saad et al., 2021)		
Mobile dig. skills → Effect of learn. expectancy on behav. intent. tow. M-Learn.			(Saad et al., 2021)
Mobile dig. skills → Effect of perceiv. ease of use on behav. intent. tow. M-Learn.			(Saad et al., 2021)
Mobile dig. skills → Effect of perceiv. usefulness on behav. intent. tow. M-Learn.			(Saad et al., 2021)
Generic dig. compet. ⇒ Training			
Dig. compet. → Participation in massive open online courses	(Soyemi et al., 2018)		
Literacy and use → ICT Training	(Arango et al., 2020)		
Dig. teach. compet. ⇒ Teach. practice			
Dig. teach. compet. → Percep. about distance learn.	(Yurtseven et al., 2021)		

Supplementary information The datasets generated during and/or analyzed during the current study are available in the OSF repository, https://doi.org/10.17605/OSF.IO/4KQVT.

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