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Bibliometric analysis and systematic review of digital competence in education

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The ubiquity of digital technologies has profoundly transformed communication and education in the 21st century, making the development of digital competence essential for both teachers and students to be prepared for the digital age. However, existing reviews predominantly focus on the teachers' perspective with a limited scope and methodology. This literature review combines bibliometric analysis and systematic literature review to provide a comprehensive analysis of existing research. Bibliometric analysis evaluates performance and science mapping to identify influential journals, countries, and authors while visualizing trends in the field. Content analysis identifies five major themes: (1) digital competence levels, (2) factors and variables, (3) digital competence and teacher education, (4) students' digital competence, and (5) digital competence and academic performance. The study also outlines seven future research directions: (1) integrating digital competence into curricula, (2) initial training in digital competence for future professions, (3) subject-specific development, (4) expanding research samples to include younger students, (5) addressing limitations of self-assessment, (6) understanding the needs of teachers and students, and (7) strengthening administrative support. Overall, the review highlights challenges in measuring digital competence and underscores the need for its integration into education systems, offering insights into opportunities for future research.

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Introduction

Digital competence can be broadly defined as "the confident, critical and creative use of ICT to achieve goals related to work, employability, learning, leisure, inclusion and/or participation in society" (Ferrari et al. 2013). Recognized as one of the eight key competences for lifelong learning by the European Union (European Commission, 2018), digital competence is regarded as fundamental for all nations and regions to equip citizens with the necessary skills to effectively use digital technologies (Díaz-Burgos et al. 2024; Redecker, 2017).

The digital revolution has transformed how citizens work, access information, communicate, and learn, initiating discussions on the essential competencies required for success in a technology-driven future (Caena and Redecker, 2019; Eltiana and Saputra, 2024; Pratama et al. 2024). In the field of education, educators and students must be equipped to leverage technologies efficiently and meaningfully. Traditional approaches to developing digital capabilities have predominantly focused on promoting digital literacy, defined as "the capacity to effectively utilize, assess, and integrate digital tools, resources, and services into lifelong learning" (Gilster, 1997). As the research field has evolved, the term "digital literacy" has been increasingly criticized and replaced due to its limited focus on specific skills. Recent research has advocated for a broader conceptual framework, adopting digital competence models that address diverse forms of knowledge across different contexts (Masoumi and Noroozi, 2023; Li et al. 2023; Falloon, 2020).

Teachers are required to continuously update their competence profiles to effectively empower 21st-century learners (Rahimi and Mosalli, 2024; Caena and Redecker, 2019). In educational contexts, the term "professional digital competence" (TPDC) is used to define the specific attributes of teachers' digital competence. While TPDC lacks a precise workplace definition, it stems from the broader concept of digital competence, highlighted in key European policy documents (e.g., European Commission, 2018; UNESCO, 2018) as essential for meaningful participation in a digitalized society. The state of digital competence among teachers across various fields and educational stages, as well as its development, has garnered significant attention from researchers. Several conceptual frameworks have been developed to describe the characteristics of teachers' digital competence, such as the UNESCO Information and Communication Technology Competency Framework for Teachers (UNESCO, 2018), the Technological Pedagogical Content Knowledge (TPACK) model (Mishra and Koehler, 2006), and the European Digital Competence Framework for Educators (DigCompEdu) (Caena and Redecker, 2019). Additionally, these frameworks have been designed to measure and enhance the digital competence required for teachers. Studies indicate that although most teachers hold positive attitudes toward ICT, the digital tools they use in their teaching practices remain limited, and their levels of digital competence remain low (Fernández-Cruz and Fernández-Díaz, 2016). Furthermore, many teachers report that insufficient training in digital competence is a major challenge they face (Gudmundsdottir and Hatlevik, 2017). Research indicates that while teachers are generally aware of the need to develop their digital competence and recognize the potential benefits of ICT in education, their actual competence levels remain low (Gudmundsdottir and Hatlevik, 2017). Challenges identified include insufficient training, inadequate management and resources, lack of state training policies, scarcity of specialized programs, and insufficient resources in academia. Teachers also express a desire for simplicity and free access to ICT resources (Cabero-Almenara et al. 2021). Moreover, teachers exhibit contradictory attitudes toward digital competence: they initially demand more training but often do not pursue continuous professional development (Liesa-Orús et al. 2023). Marín-Díaz et al. (2020) suggested that lecturers found the digital competence training they received did not align with their specific needs.

Digital competence in education also aims to develop students' digital competence; the younger generation is claimed as "digital native" as they are "greatly exposure to digital technology since a very young age" (Prensky, 2001). However, Gallardo-Echenique et al. (2015) suggest that students' digital competence may be significantly lower than those of their teachers, despite they demonstrate high digital confidence. Researchers have also demonstrated the benefits of digital competence, including an increase in students' digital informal learning (He and Zhu, 2017), academic engagement (Mehrvarz et al. 2021), autonomy, efficiency, responsibility, flexibility, critical, and reflective thinking (Díaz-Burgos et al. 2024). Therefore, it is essential for future researchers to have a comprehensive review of existing studies to inform further research from different perspectives with a clearer focus.

As the field continues to evolve, an increasing number of publications are emerging in the field of digital competence in education; thus, there is a growing need for a comprehensive and detailed review to present its evolution, research trends, future directions, and multiple perspectives. However, existing reviews have primarily employed qualitative approaches (Pettersson, 2017; Zhao et al. 2021; Sillat et al. 2021; Godaert et al. 2022; Peters et al. 2022; Heine et al. 2022; Torres-Hernández and Gallego-Arrufat, 2022; Masoumi and Noroozi, 2023; Li et al. 2023; Garcia-Ruiz et al. 2023; Su and Yang, 2023), which are limited by subjectivity, potential biases, and a lack of quantitative insights to capture diverse perspectives on the research topic (Molina-García et al. 2022). Additionally, existing reviews on this topic predominantly focus on empirical studies conducted in specific regions or educational stages, with an emphasis on teachers, often overlooking the development of digital competence at a broader scale. To address these gaps, this study adopts a quantitative approach, recognized as particularly effective for analyzing extensive research landscapes. Nonetheless, it recognizes the limitation of excluding qualitative insights (Donthu et al. 2021). Consequently, the study seeks to overcome these limitations by presenting the intellectual structure, trends, and an in-depth evaluation of research on digital competence in education through a combination of bibliometric analysis and systematic literature review.

The review primarily focused on addressing the following research questions:

1. How have paper publications on digital competence in education been distributed over time?
2. What are the trending topics on digital competence in education, and how has interest in those topics evolved over time?
3. What are the most influential and productive agents (sources, countries, authors, affiliations, and documents) in the field of digital competence in education?
4. what are the major research streams of digital competence in education?
5. What are the emerging future directions in digital competence research in education?

Literature review

As digitalization progresses and technological devices become more prevalent and widely utilized in educational settings, the importance of educators and students possessing corresponding digital competence has become more pronounced. To date, the Web of Science has indexed 14 literature reviews on digital

Table 1 Previous literature reviews.

Authors	Analytical approach	Included studies	Date range of included studies	Review focus
Pettersson (2017)	Systematic review	41	2007–2017	Pedagogical aspects of digital competence in educational contexts
Fernández-Batanero et al. (2020)	Systematic review and meta-analysis	21	2008–2018	Digital competences for teacher professional development
Zhao et al. (2021)	Systematic review	33	2015–2021	Digital competence in higher education
Sillat et al. (2021)	Systematic review	40	2000–2018	Existing proposals and conceptions of digital competence assessment in higher education
Godaert et al. (2022)	Systematic review	14	2014–2020	Empirical research on the assessment of primary school students' digital competence
Peters et al. (2022)	Systematic review	13	2000–2021	Teacher digital competence in higher education
Heine et al. (2022)	Systematic review	23	2006–2021	Empirical research on teachers' professional digital competence
Aydin and Yildirim (2022)	Bibliometric analysis	406	2001–2021	Teachers' digital competence
Torres-Hernández and Gallego-Arrufat (2022)	Systematic review	31	2010–2021	Digital competence in security in initial teacher education
Liesa-Orús et al. (2023)	Meta-analysis	9	2015–2021	Self-perceived digital competence of university lectures
Masoumi and Noroozi (2023)	Systematic review	25	2000–2021	Early career teachers' professional digital competence
Li et al. (2023)	Systematic review	50	2010–2023	Digital competence of K-12 pre-serve and in-service teachers in China
Garcia-Ruiz et al. (2023)	Systematic review	66	2017–2022	Assessment of digital teaching competence
Su and Yang (2023)	Systematic review	23	2012–2022	Digital competence in early childhood education

competence within educational contexts, with 12 of them being systematic reviews (Table 1).

Analysis of existing literature reviews reveals that over sixty percent focus on various types of teachers (early childhood, primary education, university lecturers, pre-service teachers, early career teachers) and their digital competence. This includes their perceptions of ICT, challenges, influencing factors, digital competence levels, and digital competence in security (Fernández-Batanero et al. 2020; Peters et al. 2022; Heine et al. 2022; Aydin and Yildirim, 2022; Torres-Hernández and Gallego-Arrufat, 2022; Liesa-Orús et al. 2023; Masoumi and Noroozi, 2023; Li et al. 2023; Su and Yang, 2023). According to the reviews, existing research is predominantly quantitative, primarily relying on questionnaires, with a scarcity of mixed-method, qualitative, and experimental studies (Li et al. 2023). These reviews primarily emphasize empirical research, assessment tools, and conceptual frameworks related to the development of digital competence in teachers or education across different stages and regions, often conducting small sample scale, critical systematic reviews. However, the systematic reviews exhibit methodological limitations, including narrow scopes and small sample sizes ranging from 13 to 66 papers, making them prone to potential bias and subjectivity. The current study, by contrast, included 1054 papers for bibliometric analysis and 50 papers for systematic review, addressing the limitations of prior studies.

Additionally, the only bibliometric analysis with a relatively large sample size covered studies from 2001 to 2021, underscoring the need for updated investigations. Furthermore, previous research has primarily focused on teachers' digital competence, with insufficient attention paid to organizational infrastructure, digital leadership, security and ethics (Aydin and Yildirim, 2022). By encompassing the entire educational field, this study offers a more holistic and comprehensive perspective.

Methodology

The present study adopted two main approaches: bibliometric analysis and systematic literature review. Bibliometrics is a statistical technique for assessing and quantifying the number of publications and their citations in a particular research field; it allows researchers to identify the intellectual structure, trends of publications, and future directions (Garfield, 1979). Systematic review was used to support the qualitative analysis of published articles, seeking to identify detailed and specific gaps in the literature. As an increasing number of researchers use both bibliometric analysis and systematic review (Amarathunga et al. 2023; Phommanee et al. 2023), this combination has been shown to provide a more comprehensive and accurate analysis of the literature (Rialti et al. 2019).

Database and search strategy. Data for the study were retrieved in May 2024 from the Web of Science Core Collection platform, which is recognized as the world's premier database for published articles and citations. Web of Science is the most frequently used database for bibliometric analysis in academic domains; various researchers in the education domain suggest it is the most reliable and robust database (Marín-Marín et al. 2021; Fauzi, 2022).

After an initial search in the WoS database, several keywords were identified for digital competence with consideration of the educational field. Keywords that reflect education include "education", "teach", "learn" and "student". Therefore, the following search query was used for data gathering:

TS = (("digital competence" AND "Education") OR ("digital competence" AND "teach*") OR ("digital competence" AND "learn*") OR ("digital competence" AND "student"))

As demonstrated in Fig. 1, the data retrieval process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines to ensure the quality of the review (Page et al. 2021; Haddaway et al. 2022). A total of 2,046 relevant publications were identified in the database. Subsequently, articles that did not meet the inclusion criteria were excluded, leaving 1054 articles for bibliometric analysis. In the systematic review, a content analysis was conducted, focusing on research themes with a narrow scope derived from the bibliometric analysis results (Duong et al. 2022). The bibliometric coupling analysis revealed the dynamic knowledge domain based on scientific connections and developments. Further analysis was performed on the top ten papers from each of the five clusters ($n = 50$), generating thematic groups that serve as theoretical foundations for future studies (Molina-García et al. 2022).

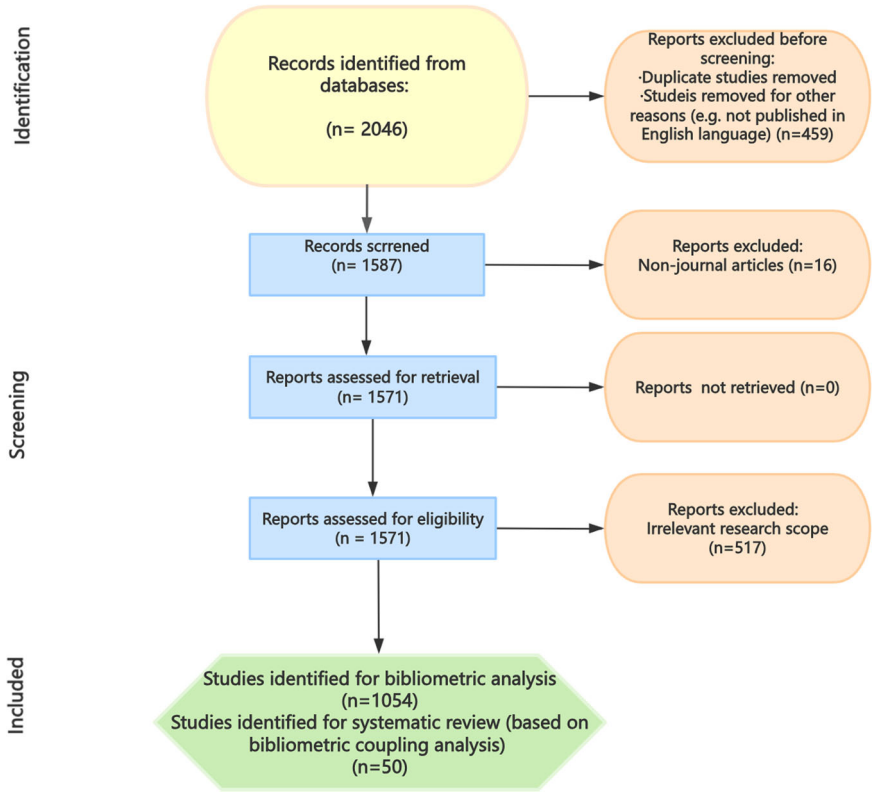

Fig. 1 Searching procedure following PRISMA.

Analysis methods. Both performance analysis and science mapping techniques were employed for bibliometric analysis. Performance analysis mainly quantifies the contributions and performance of research constituents (Donthu et al. 2021), while science mapping identifies the structural connections and evolution of a research field (Heradio et al. 2016). VOSviewer and Bibliometric R-based Biblioshiny software were utilized as bibliometric analysis tools. These two open-source tools, developed by van Eck and Waltman (2014) and Aria and Cuccurullo (2017), respectively, offer various bibliometric techniques.

In this study, performance analysis was conducted using R-based Biblioshiny, presenting numbers, percentages, rankings, and thematic evolution. The construction and visualization of the co-occurrence, co-citation, and science mapping were carried out using VOSviewer. After generating a map of the articles and their citation relationships, and identifying the clusters of related research, a systematic analysis was conducted to examine the abstracts and keywords of the articles in each cluster.

Results

Publication trends. The scientific production collected on digital competence is from 2009, as researchers proposed frameworks and assessments for digital competence (Cartelli, 2008), until 2024. As depicted in Fig. 2, the evolution of research within this field can be divided into three distinct stages. The initial phase, spanning from 2009 to 2018, exhibited an annual research output not exceeding 50 publications. The development phase, from 2019 to 2020, observed a marked increase, with annual outputs surpassing 90 publications, effectively doubling the previous phase's productivity. From 2021 onwards, the number of related studies consistently surpassed 100 publications annually, including the year 2024. The year 2023, in particular, witnessed a substantial rise in research output, reaching a peak of 260 publications. Considering that this data was collected in May 2024 and the output had already reached 113 publications, it is reasonable to expect a continued rapid increase in related research. The scientific production figure illustrates that research on digital competence is a relatively new yet widely discussed topic within the international educational sphere.

Table 2 summarizes the main information of the data analyzed in this study. The data consists of journal articles on digital competence published from 2009 to 2024, totaling 1054 articles from 353 sources. The annual growth rate reached 27.37%, which reflects the great increasing interest in this field. The document's average age was 3.58, suggesting the research on digital competence in education is relatively new. The average citation per document was 9.802, and the total number of references cited across all the documents in the dataset amounted to 30,936. This indicates its substantial impact as well as the depth and diversity of the research.

Additionally, the descriptive analysis reveals significant information regarding authors' contribution and international collaboration. Of the 2571 authors contributing to this topic, 128 are sole authors. Nevertheless, the international co-authorships among these authors is merely 16.13%, with an average of about 3.07 authors per paper. This suggests that the majority of research on digital competence in the educational field is conducted by authors from the same country.

Figure 3 illustrates the connections among countries, keywords, and authors. The size of the boxes represents the volume of articles, while the thickness of the lines indicates the strength of the connections between them. According to the Three-Field Plot analysis, Spain dominates this research topic, with significant contributions also from Norway, Sweden, Ukraine, and China. The most frequently appearing keyword is "higher education," indicating that research on digital competence mainly focuses on higher education. Additionally, "secondary education" and

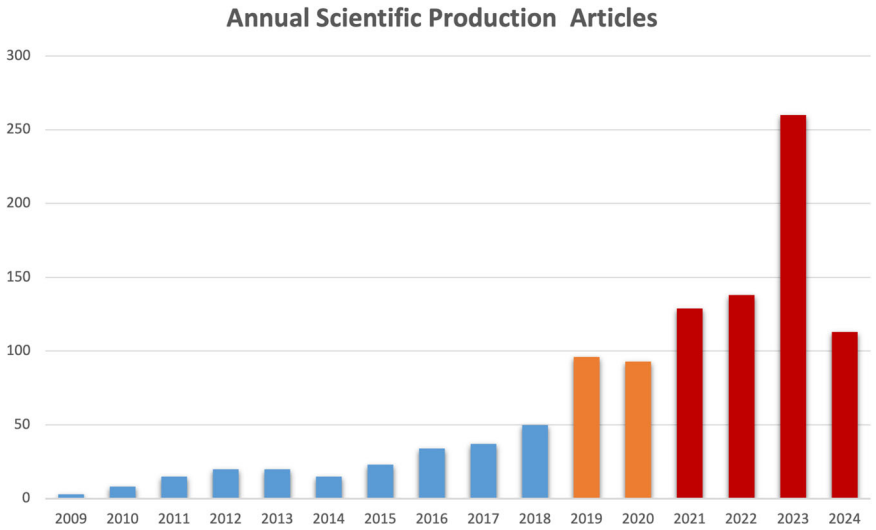

Fig. 2 Distribution of paper publications in the field of digital competence in education.

Table 2 Main information about data.

Description	Results
Timespan	2009:2024
Sources	353
Documents	1054
Annual growth rate %	27.37
Document average age	3.58
Average citations per doc	9.802
References	30,936
Authors	2571
Authors of single-authored docs	128
Co-authors per doc	3.07
International co-authorships %	16.13

"primary education" also appear in the results, demonstrating that this topic significantly impacts all educational levels. Furthermore, teacher-related keywords such as "teacher training," "teacher education," and "teachers" frequently appear in the results, indicating that existing research places substantial emphasis on training teachers in digital competence.

Trending topics and their evolution. Both keywords plus and the author's keywords were analyzed in the present study, as keywords plus describes the knowledge structure and the author's keywords indicate the main issues of the study (Li et al. 2016). Figure 4 presents the results of a word cloud analysis of Keywords Plus, where the larger the font, the higher the frequency of the keyword's occurrence. The most common keywords are "technology," "education," "information," and "ICT." Other frequently appearing keywords include "pedagogical content knowledge," "framework," "integration," along with terms related to specific groups like "teachers," "students," and "preservice teachers."

Figure 5 illustrates the trend topics analysis of the author's keywords, dynamically displaying the evolving research hotspots and the latest research directions in this field. From 2011 to 2018, keywords related to research methods like "qualitative research" were prominent, indicating a substantial amount of qualitative studies appeared up to 2021. During this period, technology-related terms such as "ICT," "digital literacy," "digital native," and teaching-related keywords like "language learning," "communicative competence," "skills," "curriculum," "innovation," "flipped classroom," and "gamification" were frequently mentioned. In 2019, keywords related to assessment, such as "evaluation" and "assessment," emerged, suggesting a focus on testing and evaluation. Keywords like "student," "lifelong learning," "blended learning," and "technology" were also commonly mentioned. From 2020 to 2022, keywords related to educational stages, such as "primary education" and "higher education" appeared. Additionally, there was a significant focus on teachers, with frequent mentions of "teacher education" and "teacher training." From 2023 onwards, new research hotspots such as "digital divide," "digital technologies," and "professional digital competence" appeared, reflecting an increased focus on macro perspectives, such as the accessibility of digital resources for teachers and students across regions. Notably, "digcompedu" emerged as a trending topic, exploring digital competence as a critical skill for citizens in the digital age, attracting substantial international attention in the educational sector. The appearance of "COVID-19" underscored the pivotal role of digital teaching in education.

Through the thematic evolution analysis of author's keywords, Fig. 6 depicts the thematic evolution of research on digital competence in education. From 2009 to 2021, the focus was on themes related to teachers and digital literacy training, such as "digital competence of teachers," "teacher training," and "initial teacher training." Between 2022 and 2024, the emphasis shifted towards the integration of technology in education, with terms like "instructional design" and "teacher education" becoming prominent. Additionally, from 2022 to 2024, there was a greater focus on the promotion of "digital citizenship," emphasizing the development of "collaborative learning," "learning strategies," "STEM," and "skills." To better prepare teachers and students, keywords such as "pre-service teachers" and "early childhood education" received significant attention. The focus from 2009 to 2021 on "literacy" and "evaluation" transitioned to a focus on the "digital divide" and educational equity from 2022 to 2024.

Influential and productive sources of publication. Figure 7 highlights the top ten highly productive sources where publications of digital competence in the education field were published. The results indicate that "Education and Information Technologies" ranked first, with 66 publications on this topic. It is followed by "Education Sciences," which published 56 related articles. Both "Computers & Education" and "Information Technologies and Learning Tools" contributed 24 articles each, tying for third place. "Frontiers in Education" published 23 articles, placing it next.

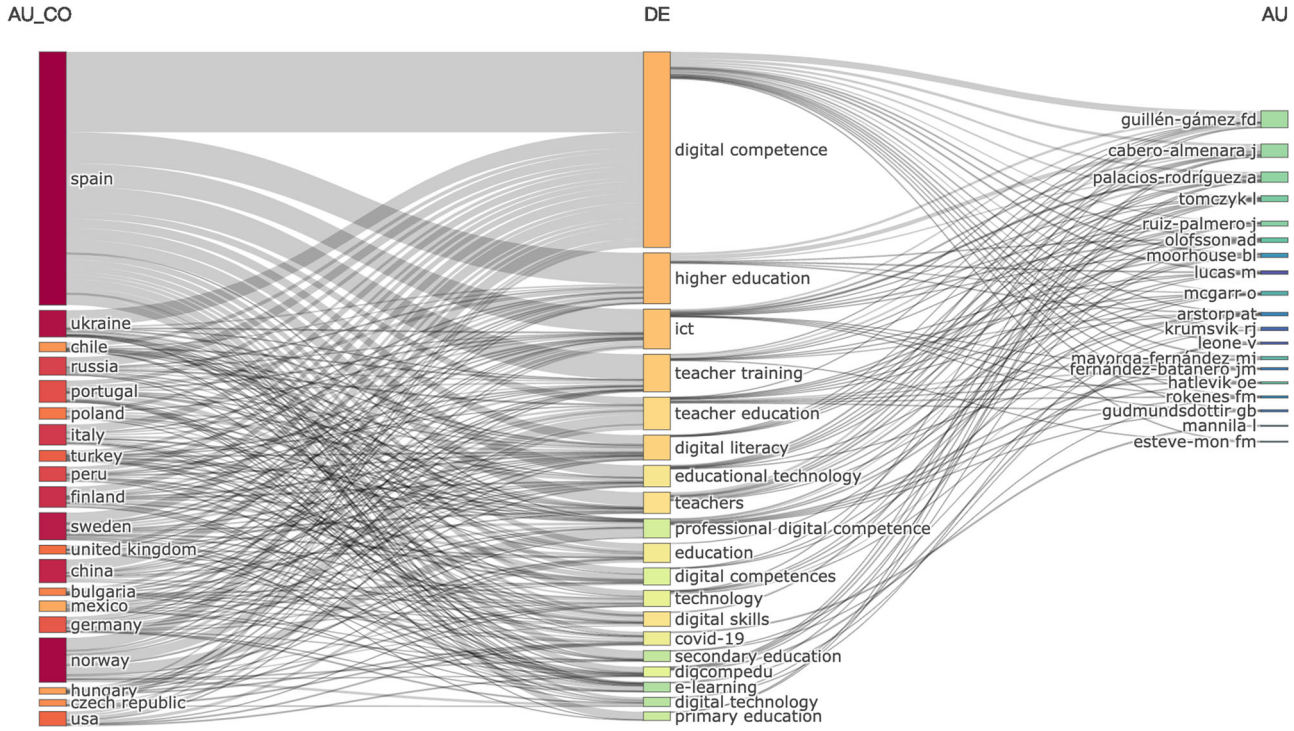

Fig. 3 Three-Field Plot in the field of digital competence in education.

Fig. 4 Word cloud (by keywords plus) in the field of digital competence in education.

The "EDULEARN19: 11th International Conference on Education and New Learning Technologies" and the "Nordic Journal of Digital Literacy" each published 16 articles. The "European Journal of Teacher Education," "Technology, Knowledge and Learning," and the "British Journal of Educational Technology" also made the top ten, contributing 14, 12, and 11 articles, respectively.

Table 3 provides an analysis of the top ten journals preferred by researchers studying digital competence in education, based on h-index, g-index, m-index, total citations (TC), net production (NP), and publication starting year (PY_start). The results indicate that "Computers & Education" is the most influential journal in this field, with the highest h-index (17) and g-index (24). "Education and Information Technologies" follows as the second most influential journal (h-index = 14; g-index = 23), with a total of 677 citations. In terms of the m-index, "Education Sciences" ranks first (m-index = 2.167), "Education and Information Technologies" second (m-index = 2), and "Technology and Learning" third (m-index = 1.6).

Influential and productive countries. Table 4 presents the top ten corresponding authors' countries along with the number of SCPs (single-country publications) and multiple-country publications (MCPs). Single-country publications denote articles produced by corresponding authors from the same country, while multiple-country publications refer to those involving at least one co-author from a foreign country. In terms of publication volume, corresponding authors from Spain contributed 30% of the articles in this field, publishing 316 articles, of which 283 are single-country publications and 33 are multiple-country publications. Norway ranks second, contributing 61 articles (5.8% of total publications), including 52 single-country and 9 multiple-country publications. Sweden ($N = 55$) and Ukraine ($N = 54$) rank third and fourth, respectively, followed by China ($N = 35$) and Russia ($N = 32$) in fifth and sixth positions. Regarding international collaboration rates, China (22.9%) and Italy (19.2%) exhibit the highest rates of international cooperation.

The results of Fig. 8 indicate that Spain is the most cited country with over 3760 citations in the field, the average article citations is 11.90. Norway, ranked second, received 1640 citations, averaging 11.90 citations per article. Following closely are Sweden and Germany, with 756 and 697 citations, respectively. Meanwhile, the Netherlands (59.2) and Germany (33.2) achieved the highest average citations per article.

Despite significant contributions from Spain, Norway, and Sweden, countries such as China and Italy, with high collaboration rates, remain underrepresented in terms of overall publication output. This suggests a need for future research to focus on fostering collaboration and increasing publication activities in these regions. Additionally, greater attention should be directed toward emerging research hubs like Ukraine and Russia, which demonstrate potential for higher impact but remain less cited. Encouraging international partnerships in underrepresented

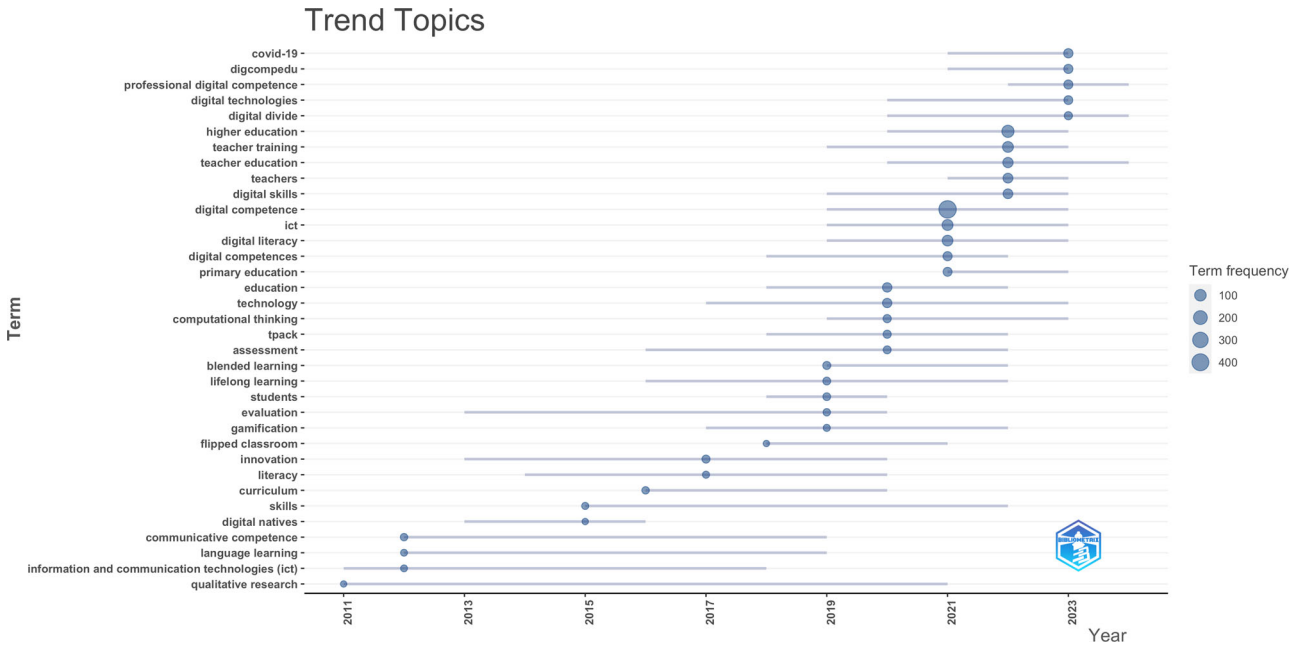

Fig. 5 Trend Topics (by author's keywords) in the field of digital competence in education.

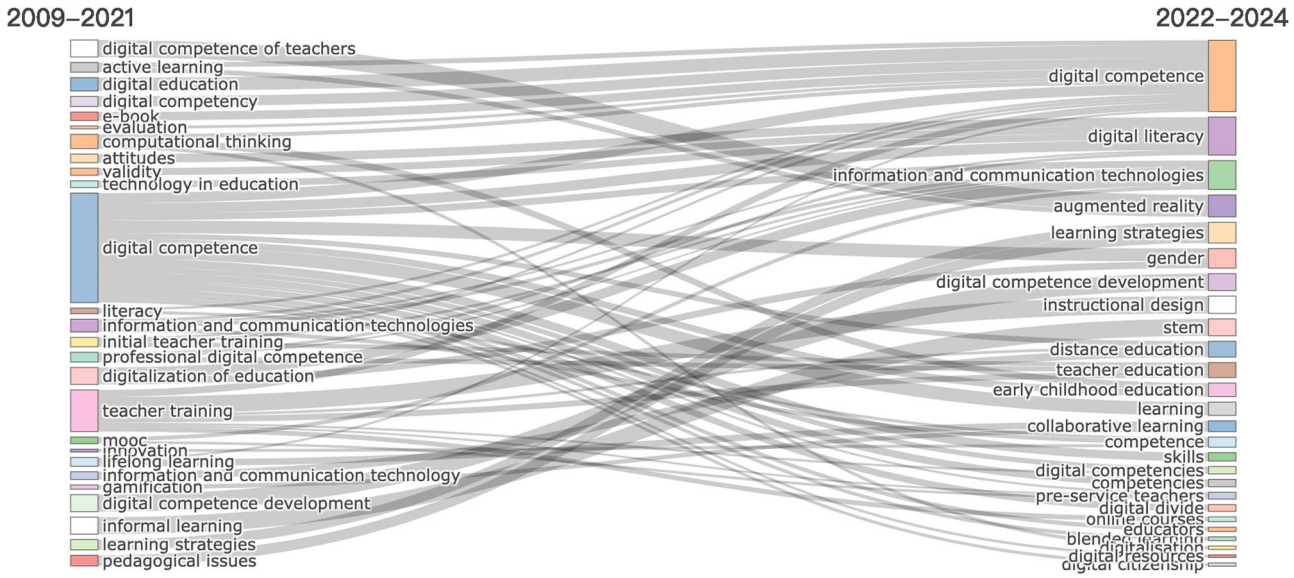

Fig. 6 Thematic Evolution in the field of digital competence in education.

regions may enhance the diversity and scope of digital competence research.

Most influential and productive authors and affiliations. Figure 9 dynamically showcases the publication output of the top ten most productive researchers in this field over various periods, with the size of the circles indicating the number of articles published during each period. Francisco D. Guillén-Gámez stands out as the most productive researcher, with 23 articles published from 2019 to 2024, peaking in 2021 with 6 articles. Julio Cabero-Almenara follows as the second most productive researcher, contributing 15 articles between 2020 and 2024, particularly in 2022 when she published 5 articles. Ove Edvard Hatlevik, the earliest to publish among the top ten prolific researchers, started in 2010 and continued until 2020. Notably, Francisco D. Guillén-Gámez, Carmen Llorente-Cejudo, Julio Cabero-Almenara, Anders D. Olofsson, and Oliver McGarr were all actively publishing in 2024.

Table 5 displays the ten most preferred and influential authors in the field, based on the h-index, g-index, m-index, total citations (TC), net production (NP), and publication starting year (PY_start). Francisco D. Guillén-Gámez tops the list with an h-index of 10, followed by Julio Cabero-Almenara and Ove Edvard Hatlevik, each with an h-index of 7, placing them second and third. Regarding the g-index, Francisco D. Guillén-Gámez again holds the top position (g-index = 18), followed by Julio Cabero-Almenara (g-index = 15) and Antonio Palacios-Rodríguez (g-index = 14). In terms of total citations, Ove Edvard Hatlevik leads with 847 citations, Greta Björk Gudmundsdottir follows with 451 citations, and Francisco D. Guillén-Gámez ranks third (TC = 340).

By analyzing the top ten institutions with the highest number of publications, Fig. 10 shows that the Ministry of Education and Science of Ukraine is the leading contributor to research on digital competence in education ($N = 87$). The University of

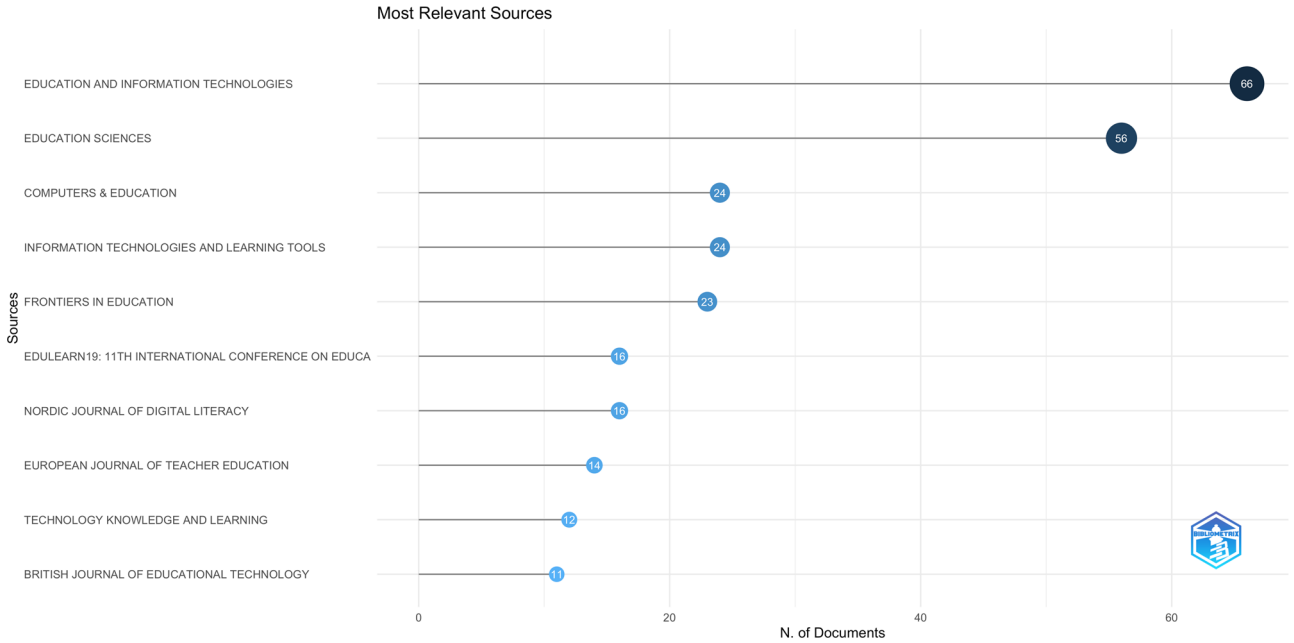

Fig. 7 Top ten productive sources of publication in the field of digital competence in education.

Table 3 Top ten most influential sources' local impact in the field of digital competence in education.

Source	h_index	g_index	m_index	TC	NP	PY_start
Computers & Education	17	24	1.308	1485	24	2012
Education and Information Technologies	14	23	2	677	66	2018
Education Sciences	13	17	2.167	383	56	2019
Comunicar	9	10	0.692	965	10	2012
British Journal of Educational Technology	8	11	0.533	331	11	2010
European Journal of Teacher Education	8	14	0.889	996	14	2016
International Journal of Educational Technology in Higher Education	8	11	0.889	481	11	2016
Technology and Learning	8	12	1.6	255	12	2020
Technology Pedagogy and Education	7	11	0.438	174	11	2009
Journal of Computer Assisted Learning	6	7	0.6	160	7	2015

Table 4 Top ten most productive corresponding author's countries in the field of digital competence in education.

Country	Articles	Articles %	SCP	MCP	MCP %
Spain	316	30	283	33	10.4
Norway	61	5.8	52	9	14.8
Sweden	55	5.2	49	6	10.9
Ukraine	54	5.1	51	3	5.6
China	35	3.3	27	8	22.9
Russia	32	3	28	4	12.5
Italy	26	2.5	21	5	19.2
Bulgaria	22	2.1	21	1	4.5
Germany	21	2	19	2	9.5
Turkey	21	2	19	2	9.5

Seville in Spain ranks second ($N = 47$). The third to seventh positions are also occupied by Spanish universities: Universidad de Málaga ($N = 34$), University of Granada ($N = 34$), University of Salamanca ($N = 31$), Universitat Rovira i Virgili ($N = 24$), and Universidad de Córdoba ($N = 22$). Notably, apart from the eighth-ranked University of Oslo ($N = 20$), all other institutions in the second to tenth positions are Spanish universities, including the University of Valencia ($N = 19$) and Complutense University of Madrid ($N = 18$), ranked ninth and tenth respectively.

Most influential documents in the field. The identification and analysis of the most influential journal articles offer researchers valuable insights into the seminal works that have shaped the direction of research in this field, aiding in understanding core concepts, theoretical frameworks, research methodologies, historical and intellectual foundations of research in this domain. This understanding is essential for future researchers and policymakers to achieve new breakthroughs and developments.

Table 6 highlights the top ten most cited journal articles on digital competence in education. The most cited article is by König et al. (2020), titled "Adapting to online teaching during COVID-19 school closure: teacher education and teacher competence effects among early career teachers in Germany," with 452 citations. This study emphasizes the crucial role of digital competence for teachers during the COVID-19 pandemic, identifying the primary challenges and factors influencing online teaching. The second to sixth-ranked studies also focus on developing teachers' digital competence. Gudmundsdottir and Hatlevik (2017) surveyed the professional digital competence levels of 356 newly qualified teachers in Norway, while Fernández-Cruz and Fernández-Díaz (2016) examined the digital skills of 1433 teachers in Spain, both pointing out current training deficiencies and the need for improvement in digital competence. Falloon (2020) differentiated between digital literacy and digital competence, introducing the teacher digital competence (TDC)

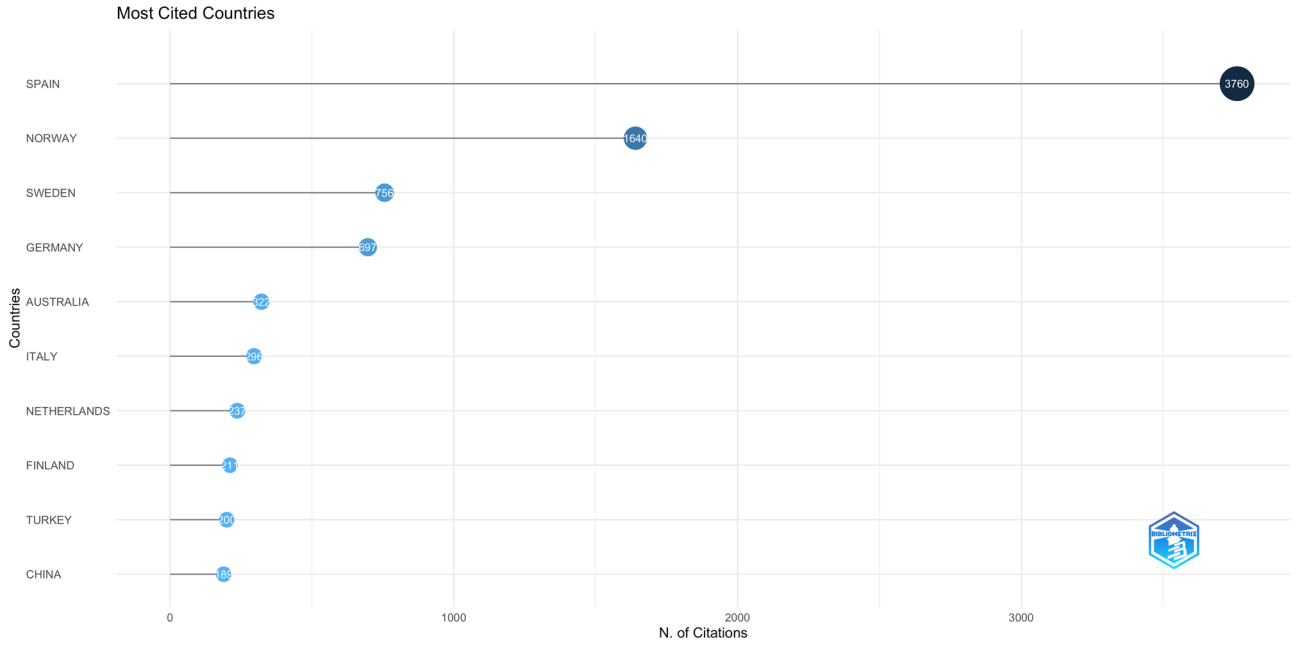

Fig. 8 Most cited countries.

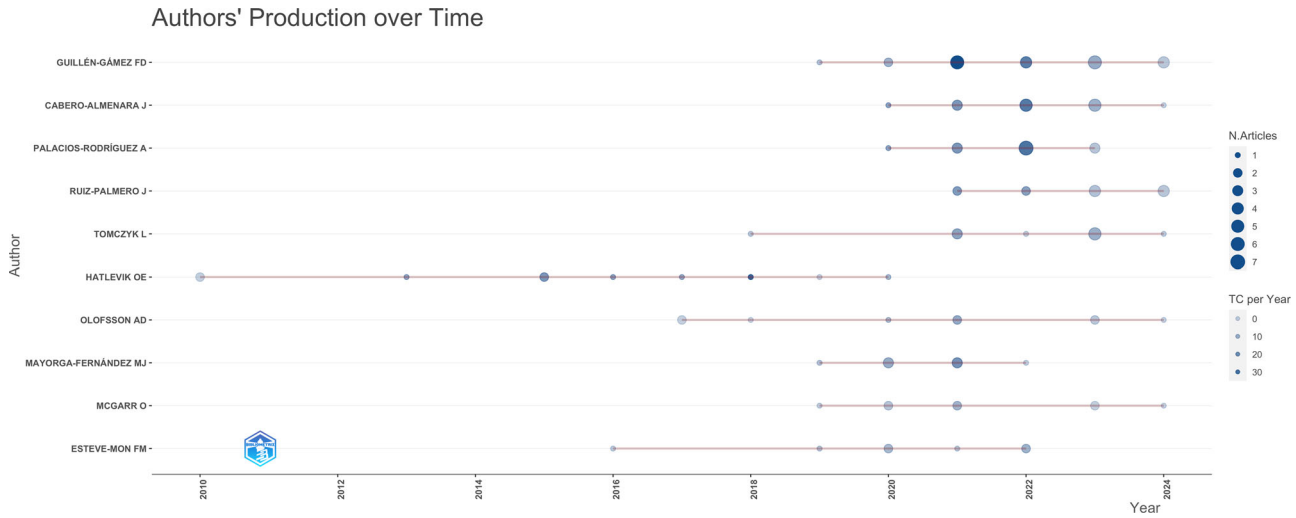

Fig. 9 Top ten most productive Authors' production over time in the field of digital competence in education.

Table 5 Top ten most influential authors' local impact in the field of digital competence in education.

Author	h_index	g_index	m_index	TC	NP	PY_start
Francisco D. Guillén-Gámez	10	18	1.667	340	23	2019
Julio Cabero-Almenara	7	15	1.4	247	15	2020
Ove Edvard Hatlevik	7	10	0.467	847	10	2010
Francesc M. Esteve-Mon	6	7	0.667	113	7	2016
Linda Mannila	6	7	0.75	212	7	2017
José Mayorga-Fernández,	6	8	1	171	8	2019
Antonio Palacios-Rodríguez	6	14	1.2	239	14	2020
Łukasz Tomczyk	6	10	0.857	107	11	2018
Greta Björk Gudmundsdottir	5	6	0.5	451	6	2015
Oliver McGarr	5	7	0.833	61	8	2019

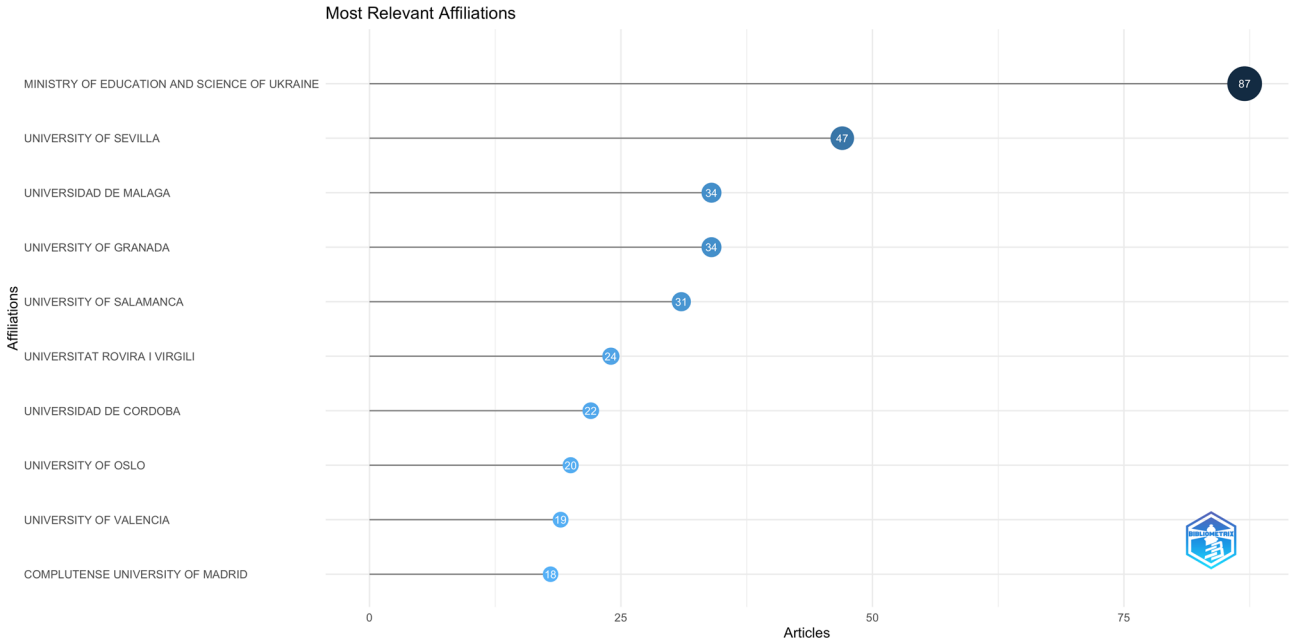

Fig. 10 Top ten most productive affiliations in the field of digital competence in education.

Table 6 Top ten most globally cited papers on digital competence in education.

Paper	DOI	Total citations	TC per year	Normalized TC
König et al. (2020)	https://doi.org/10.1080/02619768.2020.1809650	452	90.40	20.03
Gudmundsdottir and Hatlevik (2017)	https://doi.org/10.1080/02619768.2017.1416085	233	33.29	13.28
Fernández-Cruz and Fernández-Díaz (2016)	https://doi.org/10.3916/C46-2016-10	217	24.11	7.61
Falloon (2020)	https://doi.org/10.1007/s11423-020-09767-4	212	42.40	9.39
Instefjord and Munthe (2017)	https://doi.org/10.1016/j.tate.2017.05.016	208	26.00	14.36
Caena and Redecker (2019)	https://doi.org/10.1111/ejed.12345	204	34.00	19.01
Bond et al. (2018)	https://doi.org/10.1186/s41239-018-0130-1	185	26.43	10.55
Pettersson (2017)	https://doi.org/10.1007/s10639-017-9649-3	181	25.86	10.32
Janssen et al. (2013)	https://doi.org/10.1016/j.compedu.2013.06.008	176	14.67	8.63
Krumsvik (2012)	https://doi.org/10.1080/00313831.2012.726273	172	15.64	7.17

framework. Instefjord and Munthe (2017) used three national surveys to demonstrate the critical role of teacher educators in digital classrooms. Krumsvik (2012) also recognized the vital role of teacher educators' digital competence and further examined the digital competence model's micro-level applicability. Caena and Redecker (2019) discussed the challenges teachers face regarding digital competence in the 21st-century digital era and the European framework for the Digital Competence of Educators (DigCompEdu). Bond et al. (2018) analyzed the views of 200 students and 381 teachers in Germany on digital tools, finding limited usage and emphasizing the importance of enhancing teachers' digital competence to benefit students who have access to digital facilities but lack digital skills. Janssen et al. (2013) discussed expert views on digital competence, highlighting different perspectives.

By analyzing 30,936 locally cited references, Fig. 11 presents the top ten most cited references. Among them, the article "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge" by Mishra and Koehler (2006) ranks first with 143 citations. This paper builds on previous research to propose a conceptual framework for educational technology, aimed at integrating technology and pedagogy for teachers. It provides theoretical, pedagogical, and methodological insights for future research. Ranked second is "DigComp 2.1: The Digital Competence Framework for Citizens" by Stephanie et al. (2017). This study also presents a framework, but its focus is on enhancing digital competence among citizens. The research outlines the terminology related to digital competence, including eight levels with descriptions and examples, to support the digital transformation of education. The third-ranked article also appears second in the top ten most globally cited papers. Additionally, the articles ranked fourth, sixth, and seventh in the top ten most locally cited references have also been listed in the top ten most globally cited papers. Ranked fifth is "Digital Competence–An Emergent Boundary Concept for Policy and Educational Research" by Ilomäki et al. (2014). The article highlights that digital competence is a relatively novel term that has not been well-defined. Therefore, through a review of 76 relevant papers, the study identifies the key elements of digital competence. The eighth-ranked article, "Digital Competence in Practice: An Analysis of Frameworks" by Ferrari (2010), provides an analysis of frameworks for digital competence and emphasizes its importance as a crucial skill for the 21st century. Similarly, Falloon's (2020) "From Digital Literacy to Digital Competence: The Teacher Digital Competency (TDC) Framework" offers a framework specifically aimed at developing teachers' digital competence. The tenth-ranked study by Ferrari et al. (2013) focuses on the DIGCOMP framework, which aims to better understand and develop digital competence. This competence is recommended by the European Union as one of the key competences for the 21st century.

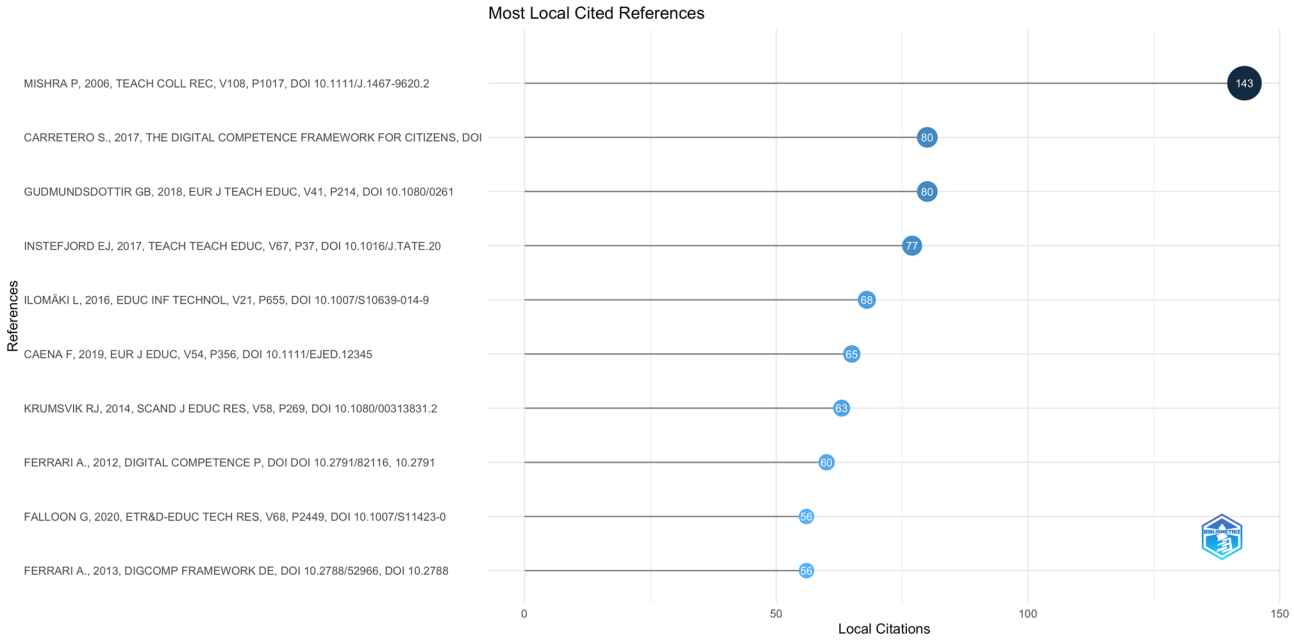

Fig. 11 Top ten most locally cited references in the field of digital competence in education.

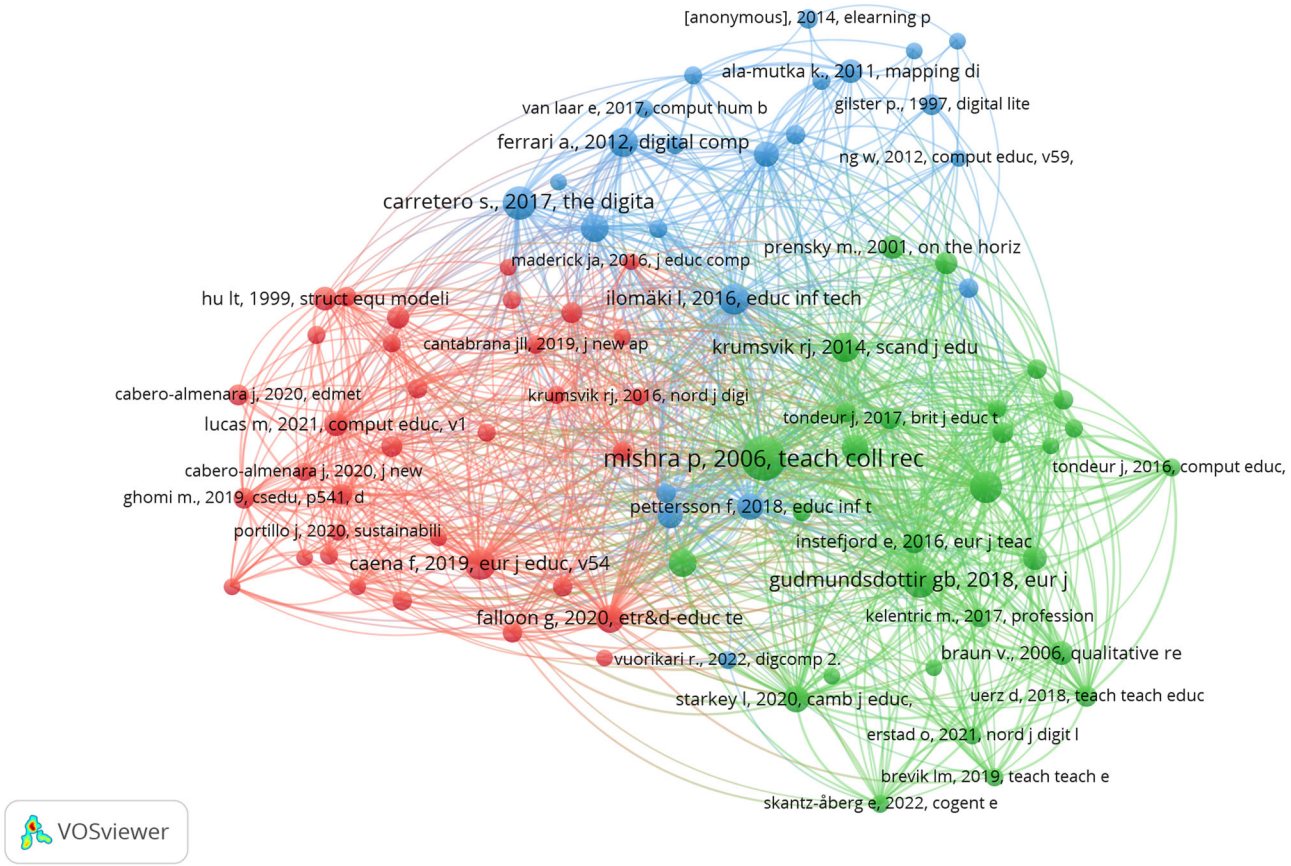

Fig. 12 Co-citation analysis of references in the field of digital competence in education.

Network analysis

Co-citation analysis. Co-citation analysis is a valuable tool in science mapping, suggesting that publications frequently cited together are likely centered on the same theme (Donthu et al. 2021). This method assists in mapping the context and scope of a subject domain, comprehending foundational themes in current research, and identifying key research clusters along with the intellectual structure of the field. Figure 12 provides a visualization network of the co-citation analysis of references, encompassing 86 references within 3 clusters. The blue cluster, containing 23 items, is led by Ilomäki et al. (2014) with their work "Digital Competence–An Emergent Boundary Concept for Policy

and Educational Research." The green cluster, comprising 29 items, is led by Mishra and Koehler (2006) with "Technological Pedagogical Content Knowledge: A Framework for Teacher Knowledge." The red cluster, including 34 items, is led by Caena and Redecker (2019) with their article "Aligning Teacher Competence Frameworks to 21st Century Challenges: The Case for the European Digital Competence Framework for Educators (Digcompedu)."

Co-occurrence analysis. Among the 2357 keywords entered by the authors in 1054 studies, the co-occurrence analysis identified 134 keywords with a threshold of co-occurrence at least 5 times. The results of the co-occurrence analysis are depicted in Fig. 13, where the size of circles and fonts reflects the frequency of co-occurrence, and different colors indicate high-frequency co-occurrence words from different time periods. Overall, the most frequently appearing keywords include digital competence, higher education, ICT, teacher training, digital literacy, teacher education, teachers, digital skills, educational technology, and COVID-19. Regarding different time periods, keywords before 2019 primarily include technology, secondary education, TPACK, language learning, communicative competence, innovation, assessment, evaluation, and lifelong learning. The high-frequency co-occurrence keywords in 2020 include teacher training, digital literacy, digital skills, primary education, e-learning, blended learning, and distance education. Keywords from 2022 and 2023 include higher education, teacher education, educational technology, DigCompEdu, and professional digital competence.

Systematic literature review. The study performed bibliometric coupling for data clustering, which occurs when two works reference a common third work. As a result, two documents are bibliographically coupled when they cite one or more documents in common (Rialti et al. 2019). As previously mentioned, this study combines bibliometric analysis and systematic literature review. The first step of the quantitative analysis phase encompasses 1054 articles, while the second step, the qualitative analysis, includes the top ten cited papers from each cluster to identify the main streams and themes within the research domain. Similar methods have been employed by numerous researchers and have been proven to provide a more in-depth analysis of high-quality literature (Rialti et al. 2019; Bhandari, 2022; Ma et al. 2024).

Cluster 1: examine digital competence level. This cluster encompasses 30 articles primarily focused on measuring the digital competence levels of various groups in the education sector. including early childhood education teachers (Casillas Martín et al. 2019), higher education educators (Cabero-Almenara et al. 2021), university students (López-Meneses et al. 2020), secondary education educators (Miguel-Revilla et al. 2020), adolescents aged 14–16 (Calvani et al. 2012), primary students (Pérez-Escoda et al. 2016), and both university teachers and students (Bond et al. 2018). Additionally, this cluster includes studies dedicated to developing valid and reliable tools for teachers to assess their digital competence (Usart Rodríguez et al. 2020).

Empirical research overwhelmingly suggests that the digital competence of current educators and students is generally low and that they have not received sufficient training. Particularly for so-called "digital native" students, although they exhibit high digital confidence and skills, their digital competence is significantly lacking (Gallardo-Echenique et al. 2015). While 21st-century students may be more willing and adept at using digital devices, this should not lead to the assumption that they automatically possess digital competence. Despite data indicating low digital competence among teachers and students, researchers have demonstrated that this can be overcome through interventions (Miguel-Revilla et al. 2020). Further research is needed to design suitable interventions, provide effective training, and engage both educators and students in these programs.

Cluster 2: factors and variables. Cluster 2 contains 18 articles primarily investigating the factors and variables associated with digital competence. Lucas et al. (2021) identified several factors, including the number of tools, gender, age, confidence in using digital technology, and openness to new technology. Moreira-Fontán et al. (2019) described ICT-related variables such as digital self-efficacy, perceived institutional support, ICT positive emotions, satisfaction with institutional support, autonomous motivation, and work engagement. Reisoğlu and Çebi (2020) conducted a qualitative study on teachers' digital competence, recommending that preservice teachers be trained in information and data literacy, communication and collaboration, digital content creation, safety, and problem-solving. They also suggested that digital competence training should cover professional engagement, teaching and learning, assessment, and empowering learners. Guillén-Gámez et al. (2020) analyzed the relationship between factors such as gender and age with digital competence and found statistically significant differences between the knowledge and use of 2.0 tools. Cattaneo et al. (2022) identified factors such as attitude toward technology, digital tool use frequency, teacher workload, and curriculum support. Gudmundsdottir et al. (2020) demonstrated a positive relationship between student teachers' perceived understanding of concepts and suggested that concepts related to privacy issues, cyberbullying, and the ability to evaluate digital content should be taught separately. Fernández-Batanero et al. (2020) conducted a systematic review of qualitative studies and found that teachers face difficulties in digital competence due to a lack of teacher training and insufficient ICT training. They recommended administration training and leadership as key factors. Similarly, Pettersson (2017), in their review, emphasized that knowledge of digital competence related to organizational infrastructures and strategic leadership is sparse and suggested addressing organizational infrastructures and digitally competent leadership.

Cluster 3: digital competence and teacher education. Cluster 3 is centered on the integration of digital competence within teacher education programs. König et al. (2020) underscored the critical role that digital competence and opportunities to develop this competence play in enhancing teachers' instructional capabilities, particularly during online teaching scenarios. Falloon (2020) extended this by contending that digital competence transcends traditional technical and literacy skills. He proposed a conceptual framework advocating for a more holistic and comprehensive understanding that emphasizes safety and productivity in diverse, digitally mediated environments. Instefjord and Munthe (2017) discussed the crucial role of teacher educators in equipping teachers for professional work in digital classrooms. Røkenes and Krumsvik (2016) and Instefjord and Munthe (2015) examined the extent to which digital competence is integrated into current teacher education, revealing that it is not yet regarded as a vital component of teachers' professional competence. They called for heightened awareness among teacher educators to incorporate digital competence into preservice teacher curricula. Research also indicates that preservice teachers' self-assessments of their digital competence are often inaccurate and lack validity. Despite this, self-assessment aids preservice teachers in reflecting on and adjusting their understanding of their digital skills.

Cluster 4: students' digital competence. Cluster 4 focuses on evaluating students' digital competence and identifying

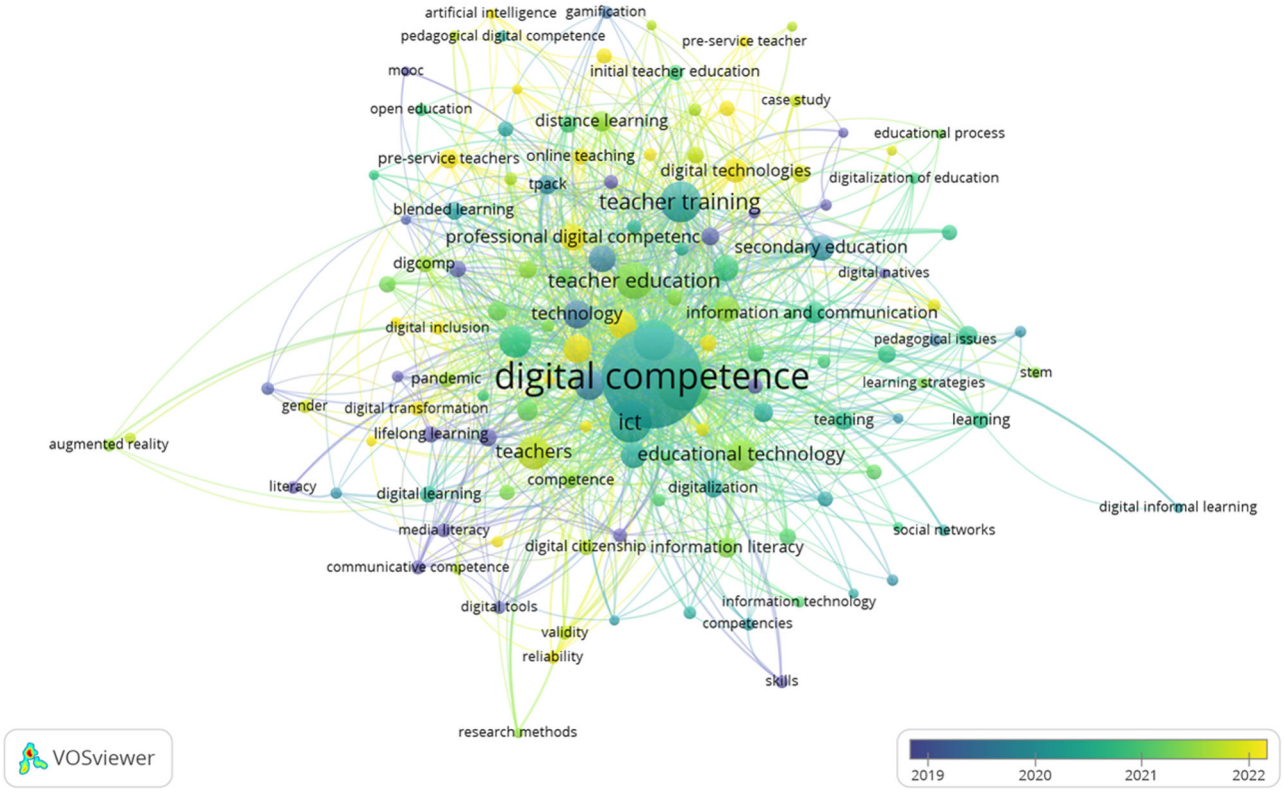

Fig. 13 Co-occurrence analysis of author keywords in the field of digital competence in education.

predictors. Hatlevik and Christophersen (2013) examined factors predicting students' digital competence, such as language integration, cultural capital, mastery orientation, and academic aspirations, which contribute to need-based interventions. In 2015, Hatlevik et al. addressed digital diversity among upper secondary students, revealing that cultural capital, language integration at home, self-efficacy, strategic use of information, and average grades predict 20% of the variation in students' digital competence scores and 49% of the variation between schools' average digital competence scores (Hatlevik et al. 2015). They also concluded that higher levels of mastery orientation and self-efficacy (i.e., motivation) and the student's family background (i.e., language integration and the number of books at home) were predictors of students' levels of digital competence. Furthermore, when school leaders reported higher levels of professional development culture among teachers, increased levels of digital competence were found among students (Hatlevik et al. 2014). Arrosagaray et al. (2019) confirmed a relationship between technology use and increased self-perceived confidence in digital competence, particularly in distance language learning. Siddiq et al. (2016) systematically reviewed instruments and suggested that more studies should target primary and upper secondary schools, emphasizing that early assessment may identify the need for interventions to enable all children to use ICT constructively for future learning.

Cluster 5: digital competence and academic performance. The focus of Cluster 5 is on examining the connection between digital competence and students' academic performance. Despite the growing emphasis on developing digital competence by educators and researchers, its effect on academic performance still needs empirical evidence. Mehrvarz et al. (2021) analyzed data from 319 Iranian university students using AMOS for structural equation modeling and found a positive effect of digital competence on both digital informal learning and academic performance. He and Zhu (2017) studied 235 Chinese university students and, using PLS path modeling, demonstrated that personal innovativeness and digital competence, mediated by attitudes towards digital informal learning, influence digital informal learning. In 2019, He and Li emphasized the critical role of digital competence and technology expectancy in digital informal learning, noting that cultural differences significantly affect the motivational patterns of digital informal learning behaviors (He and Li, 2019). Heidari et al. (2021) further supported these findings, showing that digital competence is positively and significantly related to students' digital informal learning and academic engagement. These studies provide substantial evidence of the benefits of cultivating digital competence for students' learning, serving as significant references for researchers and educators.

Future directions for digital competence research. Table 7 shows the agenda for future research into digital competence in education, future directions based on the comprehensive literature analysis are as follows:

(1) *Integrating digital competence in curriculum documents for teacher education*: Although the importance of digital competence is widely recognized and extensively researched, if educators, particularly those involved in teacher education, do not acknowledge its criticality, a digital divide may emerge. This divide is not due to a lack of access to technology but rather the absence of learning opportunities to acquire necessary digital skills. Future research should prioritize enhancing awareness among educators about the importance of digital competence in teacher education. Further studies could also explore the progression of student teachers' digital competence, engage in comparative research, and analyze various influencing factors to offer valuable insights for educational practice.

Table 7 Agenda for future research into digital competence in education.

Aspects	Research questions
Integrating digital competence in Curriculum Documents	- How can awareness about the importance of digital competence be enhanced among educators involved in teacher education? - What are the progression patterns of student teachers' digital competence? - What are the comparative differences in digital competence across various teacher education programs? - What factors influence the development of digital competence in teacher education?
Initial training of digital competence in future professions	- What are the most effective strategies for engaging teachers and students in digital competence training programs? - How can training programs be designed to meet the diverse needs of different professional fields? - What key competencies should be prioritized in digital competence training? - How can trainers effectively serve as role models in digital competence?
Development of digital competence in specific subjects	- How does digital competence vary across different subjects and fields? - What intervention programs can be developed to enhance digital competence in specific disciplines? - How do cultural settings influence digital competence development?
Expanding research samples and targeting younger students	- How can future studies improve the generalizability of findings? - What is the current state of digital competence among primary and secondary school students? - What early interventions are needed to ensure effective ICT use among young students?
Overcoming the limitations of self-assessment in measuring digital competence	- What are the research methods that can address the limitations of self-assessment in measuring digital competence? - How can longitudinal studies be designed to monitor digital competence development over time? - What methods can provide more accurate and comprehensive data on digital competence?
Understanding the needs of teachers and students	- What specific digital competence needs do teachers and students have across various fields? - How can these needs inform the development of more effective intervention programs and training sessions? - How can curricula be designed to better address the digital competence needs of teachers and students?
Strengthening administrative support	- What role does organizational infrastructure play in developing digital competence in education? - How can digital leadership foster a digitally competent educational environment? - What macro-level strategies can support the development of digital competence among educators and students?

(2) *Initial training of digital competence in future professions*: Emphasizing the development of effective digital competence training programs and curricula is crucial for future research. The design of these training programs should consider the diverse needs of different fields and strategies to engage teachers and students in acquiring digital competence, especially in areas they may not prefer but are essential. Training programs should highlight key competencies, teach important digital skills separately, and underscore the importance of trainers serving as role models.

(3) *Development of digital competence in specific subjects and contexts*: Digital competence varies significantly among teachers and students across different subjects and fields, necessitating tailored approaches. Future researchers should investigate digital competence within various disciplines and cultural settings, aiming to develop suitable intervention programs for specific groups.

(4) *Expanding research samples and targeting younger students*: The generalizability of current research findings is often limited by small sample sizes. Future studies should aim to include larger, more representative samples. Furthermore, targeting primary and secondary school students will help assess digital competence at an early age, identifying the need for interventions to ensure all children can effectively use ICT for learning purposes.

(5) *Overcoming the limitations of self-assessment in measuring digital competence*: Reliance on self-assessment in existing studies poses limitations, as participants may under- or overestimate their digital competence. Future research should adopt longitudinal studies to monitor competence development over time, providing more accurate and comprehensive data.

(6) *Understanding the needs of teachers and students*: Future research should investigate the specific needs of teachers and students across various fields in relation to digital competence. This will provide critical insights for educators and curriculum designers in developing more effective intervention programs, training sessions, and syllabi.

(7) *Strengthening administrative support*: Digital competence should not be considered an isolated phenomenon at the individual level. The importance of organizational infrastructure and digital leadership should be acknowledged. Future research should focus on the macro-level development of digital competence, emphasizing the role of leadership and decision-making in fostering a digitally competent educational environment.

Conclusion

The study provides a comprehensive and in-depth overview of existing studies on digital competence in the educational domain by combining bibliometric analysis and systematic review. Performance analysis provides an objective evaluation, identifying trends, influential publications, and key researchers by analyzing citation patterns and publication data. The distribution of published articles indicates that digital competence is a relatively new research topic in the field of education, with a sharp increase in studies since 2021, demonstrating high research potential and value. Trend analysis offers a visual representation of the field's evolution, highlighting the shift from innovation and evaluation to teacher training and professional digital competence, aiding future researchers in predicting research directions.

Based on the analysis of the most productive and cited countries and international collaboration, the study underscores notable regional disparities in the field of digital competence research. Countries like China and Italy exhibit strong international collaboration rates but remain underrepresented in overall publication output. Emerging research hubs such as Ukraine and Russia exhibit significant potential for impactful contributions but face challenges in achieving greater visibility and influence. These gaps highlight the need for targeted policy and practice interventions to foster global inclusivity and the equitable development of research. Encouraging international partnerships can foster cross-border collaboration, enabling underrepresented regions to benefit from shared expertise and resources. Additionally, implementing region-specific funding initiatives and institutional support mechanisms is crucial to empowering emerging hubs and fostering sustainable research development. Addressing these disparities will enhance the diversity of research perspectives, ensuring that digital competence frameworks become more inclusive and better suited to a wide range of educational contexts and challenges.

The study also identifies influential journals such as "Computer & Education" and a productive journal, "Education and Information Technologies," assisting funding agencies and institutions in allocating resources effectively. Key authors (Francisco D. Guillén-Gámez) and affiliations (the Ministry of Education and Science of Ukraine) were identified in this research, fostering author collaboration and attracting relevant talent to institutions. Analysis of key research provides seminal papers on digital competence in education that have significantly impacted the field, guiding new researchers to foundational and groundbreaking works. Additionally, the study offers network analysis. Co-citation visualizes interconnections within the research field, highlighting influential publications and identifying best practices in research methodology. Furthermore, co-occurrence analysis of keywords provides a visual map of interconnected concepts, revealing the intellectual structure of the field and facilitating the identification of relationships and associations between keywords.

To better present research streams and identify gaps and future directions, the second part of this study conducted a systematic review of the top papers from five clusters identified in bibliometric coupling results. This review provides seven future directions along with an agenda for future research into digital competence. These efforts aim to assist future researchers in prioritizing key areas that require further investigation, addressing current challenges, and exploring emerging trends in the field.

Limitations

While this study provides a comprehensive and in-depth analysis of the existing research on digital competence through a combination of bibliometric analysis and systematic literature review, several limitations should be acknowledged. The literature review may not encompass all relevant studies due to language restrictions, and database limitations. Consequently, some significant research might have been overlooked. Moreover, while the study identifies five major themes, it might not fully capture the breadth of issues and perspectives related to digital competence. Other relevant themes or emerging areas of research might not have been thoroughly explored.

Data availability

The datasets generated during and analysed during the current study are available from the corresponding author on reasonable request.

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Author contributions

Both authors contributed equally to this work.

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The authors declare no competing interests.

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Informed consent

This article does not contain any studies with human participants performed by any of the authors.

Additional information

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