The evolution of digital competence in pre-service teachers: a global perspective from 2009-2024

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Article Info

ABSTRACT

In the context of the strong digital transformation occurring in education, digital competence (DC) is one of the essential skills for pre-service teachers. Therefore, equipping students in teacher training programs with DC is a significant public concern. This study analyzes global research output on pre-service teachers' DC to identify publication trends, key contributors, and predominant research themes. To gain a comprehensive view of pre-service teachers' DC, the research team conducted a bibliometric analysis of 278 publications from the Scopus database, from 2009 to 2024. The results reveal a substantial increase in publications on DC in pre-service teachers, particularly in the last 3 years. Spain is a leading country in this collection, with the most publications and funding mentions. The most prominent author is Çebi from Turkey. The journal that published the most articles is Education and Information Technologies (EAIT). Through the analysis of co-occurring keywords, four main research trends on this topic have been identified. The findings of this study provide valuable insights into the research topic and contribute to shaping future research directions in this field.

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1. INTRODUCTION

The rapid development of digital technology has been transforming all aspects of social life. Digital competence (DC) has become a trend across various professions. "DC involves the confident, critical and responsible use of, and engagement with, digital technologies for learning, at work, and for participation in society. It includes information and data literacy, communication and collaboration, media literacy, digital content creation (including programming), safety (including digital well-being and competences related to cybersecurity), intellectual property related questions, problem solving and critical thinking" [1]. Thus, DC is the necessary competence for using digital media. It is a key factor in lifelong learning for individuals [2]. In public discourse, the term "digital literacy" is also commonly used with a similar or complementary meaning to DC. According to Spante *et al*. [3], although these terms are frequently used interchangeably, some researchers make a distinction between them. DC is understood more comprehensively, encompassing

the integration of digital tools in professional contexts along with related attitudes and values. In contrast, digital literacy tends to focus on fundamental skills and the ability to critically evaluate digital content.

Digital literacy equips individuals with the necessary skills to live, learn, and work in a digital society [4]. Digital literacy helps students access and effectively utilize a wide range of rich learning resources and intelligent learning tools [5]. Through specific activities, DC helps learners develop communication and collaboration skills in a digital environment [6] enhances self-learning and creativity; and promotes the comprehensive development of essential 21st-century skills [7]. For teachers, DC is a crucial tool to help them adapt to changes in teaching, realize instructional goals, act professionally, and guide students effectively. With their digital literacy, teachers can learn from diverse sources, create engaging and dynamic lessons, assess and monitor student's progress, and make timely adjustments to ensure that the learning process becomes more flexible and aligned with the trends of modern society [8]. Empirical studies have demonstrated a positive correlation between high DC in teachers and improved learning outcomes, such as student achievement and motivation [9]. Therefore, digital literacy is one of the essential competencies for teachers in the 21st century.

Enhancing DC for teachers has been a significant concern in education, especially since the outbreak of the COVID-19 pandemic. For instance, over 1.6 billion students were affected by school closures globally, which accelerated the adoption of online learning platforms [10]. In many countries, there was a significant increase in the use of digital tools by teachers during the pandemic. This shift highlighted the urgent need to enhance teachers' DC to ensure educational continuity and effectiveness in both emergency and long-term contexts [11]. Various solutions have been implemented, such as organizing training and workshops, encouraging teachers to use digital platforms, and creating digital learning content. Among these are long-term solutions to integrate digital education into undergraduate teacher training programs [12]. Digital education aims to enhance students' knowledge and digital skills, enabling them to creatively apply technologies and digital tools in education creatively, leading to increasingly flexible and effective teaching and learning environments [13]. Pre-service teachers will soon be responsible for the digitalization process in schools and implementing modern teaching methods. Therefore, equipping them with DC will improve their critical thinking and creativity in the future [14], bridge the gap between training and actual career requirements [15], provide opportunities to reflect on teaching methods, develop a unique style, and are essential for effective teaching in a digitalized context [16].

The issues surrounding DC for teachers and pre-service teachers have been discussed in various studies. For future teachers, study by Rodríguez *et al.* [17] provides general information on publications related to this topic in the Scopus database from 2003 to 2017. For teachers, a bibliometric analysis based on the Web of Science (WoS) database by Aydin and Yildirim [18] identifies three main research trends: DC in teacher training programs, in higher education research, and at the primary and secondary education levels. Recent studies have focused on teacher training programs. The bibliometric analysis by Wang and He [19] on DC in higher education presents four frequently explored themes: the integration of digital technology, ontology research, educational practices of digital literacy, and the evaluation of digital literacy effectiveness during the COVID-19 pandemic.

For pre-service teachers specifically, most studies have focused on exploring specific aspects of DC, such as the role of digital skills for pre-service teachers [20], training programs for DC in pre-service teachers [21], methods for developing DC in pre-service teachers [22], and challenges in developing DC for pre-service teachers [23]. To the best of the research team's knowledge, no comprehensive review has been conducted on this topic. To address this research gap, the present study aims to comprehensively review global research on pre-service teachers' DC through a bibliometric analysis. Moreover, considering that teachers' DC is influenced by national policies, technological infrastructure, and cultural characteristics, this study also analyzes the global distribution of related research. The aim is to provide comparative insights into how different countries develop and implement DC within the educational context. Therefore, to provide a holistic view of pre-service teachers' DC, serving as a foundation for selecting and conducting various research directions related to this topic in the future, the research explores data from the Scopus database and uses the bibliometric method to analyze the data, aiming to answer the following research questions:

– What are the annual growth trends and publication information of research on pre-service teachers' DC?
– Which countries, institutions, and authors have contributed most significantly to this field?
– Which publication sources have most frequently disseminated research on pre-service teachers' DC?
– What are the most influential publications and the main research themes and trends in this area?

This research is significant as it offers a global, up-to-date overview of pre-service teachers' DC, serving as a foundation for improving teacher education programs. While previous research has mainly focused on in-service teachers or explored isolated aspects of DC in pre-service teachers, no comprehensive and targeted bibliometric review has been conducted for this specific group. This study fills that gap by

presenting the first global bibliometric analysis exclusively focused on pre-service teachers, providing a systematic perspective to guide future research in the context of digital education.

2.   METHOD
2.1. Data collection
WoS and Scopus are two world-leading and competing citation databases [24]. WoS was the first bibliographic database, while Scopus, although appearing later, is considered more suitable than WoS for evaluating research outputs due to its easier data extraction, broader scope, and more comprehensive content, especially in the field of social sciences [25], [26]. Therefore, the research team used data from the Scopus database. The data search and filtering process was conducted in four steps, following the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart. Specific information for each step is presented in Figure 1.
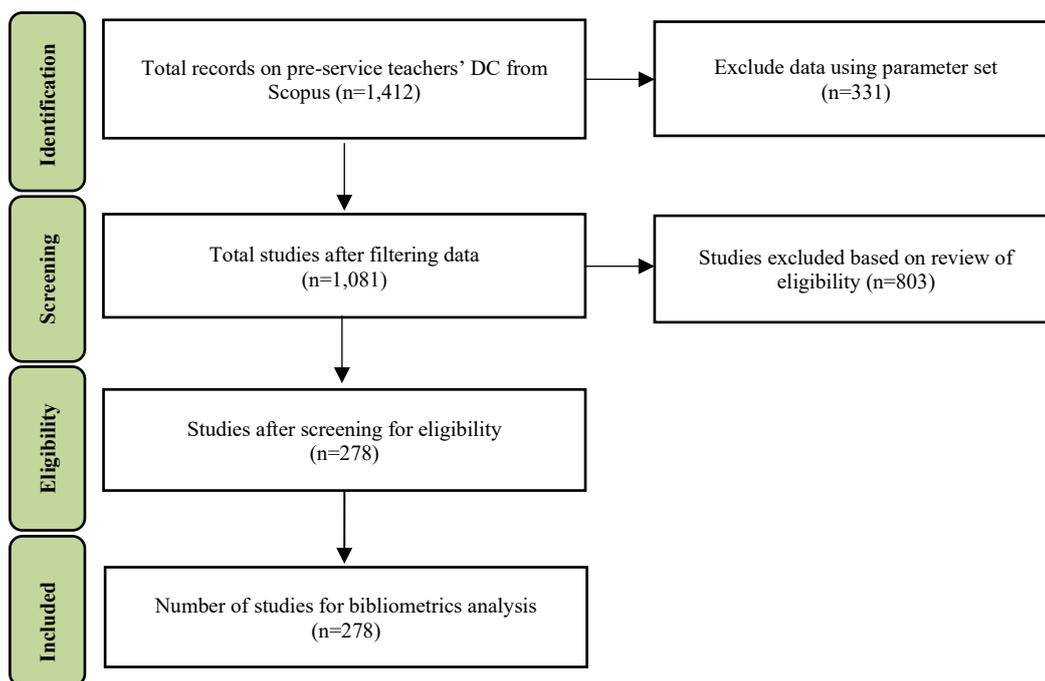

Figure 1. The PRISMA flowchart of the data search process

2.1.1. Step 1: identification
This step aimed to identify keywords related to the research topic. The main keyword identified by the research team for this study was "digital competence". Since DC includes many sub-competencies, in order not to miss relevant studies on this topic, the research team also used other narrower or synonymous terms such as "digital skills", "digital literacy", "digital literacies", and "digital education". These keywords were combined with terms representing the study subjects, such as "teacher training", "pre-service teacher", "teacher education", "student teacher", and "future teachers". The search results from the Scopus database returned 1,412 publications (data collected on July 23, 2024).

2.1.2. Step 2: screening
The screening aimed to ensure that the collected publications were relevant to the research objectives. To complete this step, the research team used the search query from step 1, combined with several criteria: i) the search focused on abstracts, keywords, and titles; ii) only peer-reviewed scientific publications, conference proceedings, and book chapters in English were included, as these are considered reliable sources due to rigorous review processes; and iii) English was chosen for its dominant position in international scientific discourse. The exclusion criteria were: documents in languages other than English, and non-journal articles such as reviews, retracted papers, data papers, editorials, short surveys, and corrigenda. This approach ensures the bibliometric analysis is based on scientifically validated and credible sources.

As a result, 1,091 publications were retrieved after applying the following search query. Duplicates or publications lacking complete information on abstracts or titles were also excluded. By the end of step 2, 1,081 publications were retained for the next step. The query statement is as:

TITLE-ABS-KEY (((“digital competence” OR “digital skills” OR “digital literacy” OR “digital literacies” OR “digital education”) AND (“teacher training” OR “pre-service teacher” OR “Teacher education” OR “Student teacher” OR “Future teachers”))) AND (LIMIT-TO (DOCTYPE, “ar”) OR LIMIT-TO (DOCTYPE, “cp”) OR LIMIT-TO (DOCTYPE, “ch”)) AND (LIMIT-TO (LANGUAGE, “English”))

2.1.3. Step 3: eligibility

This step aimed to determine whether the publications were relevant to the topic of DC for pre-service teachers. To accomplish this, assigned team members independently reviewed the titles and abstracts of the publications and then cross-checked the results. In cases where there was no consensus, the entire research team read the full text of the publication to make a final decision. In this step, 803 publications were excluded. The excluded publications were reviews or addressed teacher training at other educational levels without mentioning pre-service teachers, focused on university students in general or non-education students, involved graduate students, did not address DC or its components, or only mentioned DC or pre-service teachers in the recommendations section.

2.1.4. Step 4: included

After the first three steps, 278 publications were selected for analysis. These are the publications most relevant to the research objectives. These publications included articles, conference papers, and book chapters.

2.2. Data analysis

The study used the bibliometric analysis method to analyze the data. This is the most commonly used method in studies for statistically analyzing and evaluating scientific publications on the same topic [27]. This method helps researchers identify research trends and predict potential future research topics [26]. The analysis covers publications from 2009 to 2024 because the initial search showed that 2009 was the year the first relevant publication on pre-service teachers' DC appeared in Scopus, and extending to 2024 captures the most recent developments in this research area. To analyze the collected data, this study employs bibliometric analysis. This method enables the systematic mapping of scientific knowledge, identification of scholarly contributions, examination of relationships among publications, and tracking of the evolution of publications and citations over time [28]. Therefore, it is an appropriate approach for exploring trends, advancements, and emerging topics related to DC of pre-service teachers, thereby providing valuable insights into the development and research directions in this field. Additionally, Excel software was used for data statistics, while VOSviewer software was employed to analyze co-occurring keywords over time, thereby identifying major research directions and emerging trends in this field. The use of VOSviewer is considered reliable, as the software not only visualizes the relationships between terms but also enables in-depth analysis of key attributes such as link strength and total link strength. These indicators are essential for capturing the scale and intensity of scholarly connections, thereby contributing effectively to the understanding of the knowledge structure within a scientific field. Meanwhile, author keywords serve as concise terms that reflect the core content of the research. The Biblioshiny tool, part of the Bibliometrix package, was used to perform analyses related to the main information about the data, details on countries, affiliations, and journals, trend topics of the publication collection, and the thematic map of research directions.

3. RESULTS AND DISCUSSION

3.1. General information and growth trends of publications

The general information of the dataset on the topic of DC of pre-service teachers, after being analyzed using the Biblioshiny tool, is presented in Table 1. According to Table 1, although publications on this topic have only appeared in the Scopus database since 2009, the annual growth rate is relatively high (25.73%). As of July 31, 2024, there have been 278 publications on DC for pre-service teachers, with the document average age being 3.22 and the average citations per doc being 11.88. These publications involved 743 authors, including 51 authors of single-authored documents. The remaining authors collaborated, with a co-authors per doc rate of 3.06, and the proportion of international co-authorships accounted for 13.67%. The publications in the dataset were published across 173 different sources, with the majority being articles (212 publications), followed by book chapters (27 publications) and conference papers (39 publications). A total of 12,115 references were used in the dataset.

The information on the number of publications and the total cumulative citations per year is presented in Figure 2. According to Figure 2, the first publication on DC for pre-service teachers appeared in the Scopus database in 2009. During the first seven years (2009-2015), 16 publications were released, with only 1 to 4 publications per year. From 2016 onwards, 262 publications have been published.

The results show that although the first publication on this topic appeared in 2009, the number of publications and total citations (TC) have significantly increased. Notably, the period from 2021 to 2023 accounts for 55% of the total publications (TP) in the collection. This increase is due to the post-COVID-19 pandemic period when education focused on digitalization, improving the use of new media, information and communication technology (ICT) education for students, and preparing teachers with the necessary skills to use ICT in education [29]. The issue of enhancing DC for in-service and pre-service teachers has received considerable attention from researchers [30]. The COVID-19 pandemic has had a profound impact on the education sector worldwide. One of these effects was the acceleration of new technologies entering the field, gradually transforming teaching activities. Additionally, the global fight against the pandemic marked a rapid development and significant contributions of augmented reality (AR) and virtual reality (VR) technologies in the economies of developed nations [31]. These technologies have the potential to become the next central computing platform, offering advantages when used in educational settings [32]. Consequently, many studies in the collection have explored the application of AR and VR technologies in training pre-service teachers. In 2024, 31 publications were published. Since the data was extracted on July 31st, 2024 (mid-year), the number of studies in 2024 is not fully accounted for. Moreover, publications indexed in the Scopus database typically have an unavoidable delay compared to the actual publication date [33]. Therefore, it is evident that the topic of DC for pre-service teachers continues to attract significant research interest.

Table 1. Main information about data

| Main information about data	Results
Timespan	2009:2024
Sources (journals and books)	173
Documents	278
Annual growth rate (%)	25.73
Document average age	3.22
Average citations per doc	11.88
References	12115
Authors	743
Authors of single-authored docs	51
Single-authored docs	53
Co-authors per doc	3.06
International co-authorships (%)	13.67
Article	212
Book chapter	27
Conference paper	39
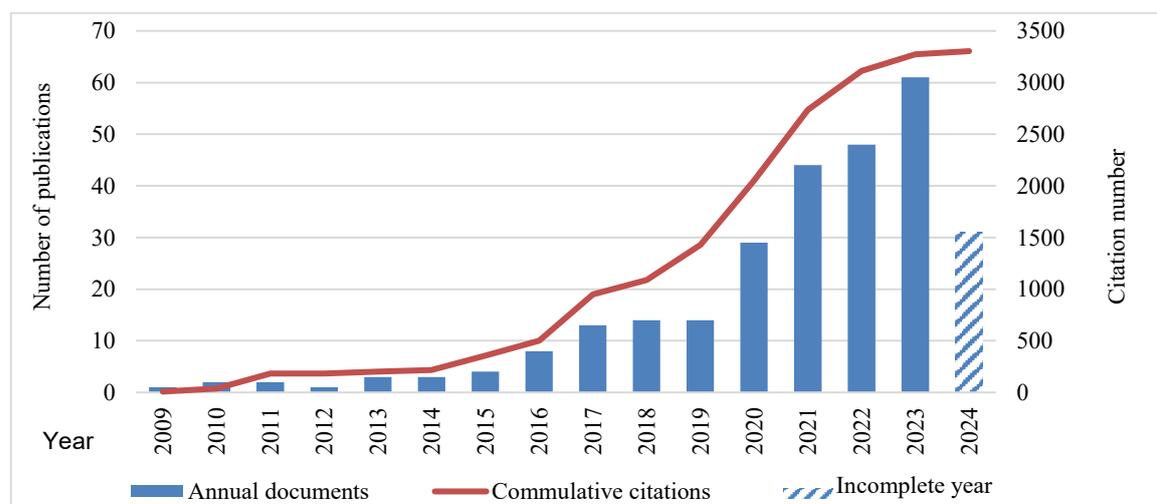
Figure 2. Number of publications and cumulative annual citations of research on DC of pre-service teachers

3.2. Contributions by countries, institutions, and authors

According to Scopus data, 51 countries worldwide have contributed publications on DC for pre-service teachers. The number of publications ranges from 1 to 34. The information on the top 9 countries with the highest number of publications is presented in Table 2. This study uses the following abbreviations: TP; TC; citation per paper (TC/TP); single country publications (SCP); multiple country publications (MCP); conference proceeding (CP); Journal (JN); year of publication start (PY_start).

Table 2. Top 9 countries with the most publications on the topic of DC by pre-service teachers

Rank	Country	TP	TC	TC/TP	SCP	MCP
1	Spain	34	551	16.2	32	2
2	Norway	17	554	32.6	14	3
3	Turkey	13	322	24.8	13	0
4	Indonesia	11	45	4.1	7	4
5	Germany	10	58	5.8	9	1
6	USA	8	125	15.6	6	2
7	Ireland	5	70	14.0	5	0
8	Malaysia	5	1	0.2	4	1
9	Poland	5	14	2.8	3	2

Spain leads the top 9 with 34 publications, twice as many as the second-ranked country, Norway. However, Spain has three fewer citations than Norway. Turkey ranks third in the top 10, with 13 publications and 322 citations. The following three countries, the USA, Germany, and Indonesia, show an inverse relationship between the number of publications and citations. Indonesia has 11 publications but only 45 citations, whereas the USA has fewer publications (8) but nearly three times as many. Germany sits between these two countries with 58 citations across 10 publications. The last three countries in the top 10 all published five articles, but there is a significant difference in citations.

By this measure, Norway ranks first with a TC/TP of 32.6, followed by Turkey with an average of 24.8. The USA, Ireland, and Spain have TC/TP values ranging from 14 to 16.2. The remaining countries have TC/TP values below 6. Regarding co-authorship, all publications from Turkey and Ireland are authored solely by domestic authors. The other seven countries had international collaborations, though the number of co-authored publications is small, ranging from 1 to 4 for each country.

To provide a clearer view of the research collaboration between countries in the collected dataset, the VOSviewer software was used to create a co-authorship map. The results in Figure 3 include the following information: each node represents a country that has collaborated with other countries on at least one publication; the lines between the nodes indicate the link strength of each country; the colors of the nodes represent the time of publication by country.

According to Figure 3, international collaboration on DC-related publications for pre-service teachers began earliest in countries like the USA, Australia, and the United Kingdom around 2019. Meanwhile, Poland, Indonesia, and China only began collaborating from 2022 onwards. In the map, Norway has the most vital research collaboration with other countries, with a total co-authorship link strength of 15. Turkey follows this (total link strength=13), Spain (total link strength=12), Portugal (total link strength=11), and Poland (total link strength=9). The remaining countries in Figure 3 have a total link strength of less than 5.

To investigate Spain's dominance in scholarly publication output, this study delves into the funding sources associated with publications from various countries. According to the data, 70 organizations have provided 104 funding instances for publications on DC for pre-service teachers. Among the 46 organizations in Europe, 18 are from Spain. Information about the top 6 organizations with the most funding instances is presented in Table 3.
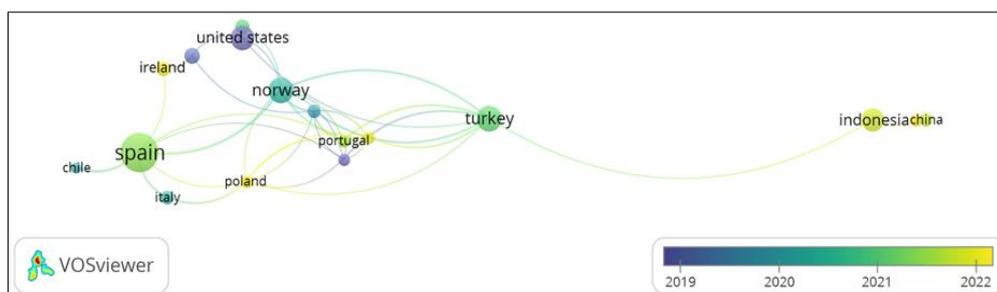

Figure 3. Map of co-authorship between countries on the field of DC by pre-service teachers over time

Table 3. Top 6 funding sponsors for publications on the topic of DC for pre-service teachers

Rank	Funding sponsor	Country/region	Number of sponsorships
1	European Commission	European	6
2	Federal Ministry of Education and Research	Germany	6
3	Ministry of Science, Innovation and Universities	Spain	6
4	Ministry of Science and Innovation	Spain	5
5	European Regional Development Fund	European	4
6	National Agency for Academic Exchange	Poland	3

The organizations listed in Table 3 are all from Europe, with the top 3 organizations being the European Commission, the Federal Ministry of Education and Research of Germany, and the Ministry of Science, Innovation, and Universities of Spain, each with six funding instances. The Ministry of Science and Innovation of Spain follows them with five cases. Thus, Spain is the country with the most funding instances for publications on the topic of DC for pre-service teachers. The European Regional Development Fund ranks fifth with four funding instances, while the National Agency for Academic Exchange of Poland ranks last with three cases. The remaining 64 organizations have provided between 1 and 2 funding instances each.

Based on the previously presented data regarding countries, affiliations, and funding sponsors, it can be seen that research on DC for pre-service teachers is concentrated primarily in European countries at the forefront of digital technology and transformation worldwide. Spain and Norway lead in the number of publications and TC (Table 2). Two European countries also integrated DC into school teaching early on. In Norway, digital skills, along with literacy, communication, and mathematics, have been part of the core competencies in all schools since 2006 [34]. A total 90% of Norway's schools ensure each student has access to a personal computer for learning [35]. In Spain, according to Education Law 02/2006, DC is one of the eight core competencies included in the national curriculum [36].

The Digital Spain 2025 Agenda aims to ensure that by 2025, 80% of the population will have basic digital skills, with 50% being women. By 2024, at least 80% of primary and secondary school teachers will have DC certification [37]. This program, launched in 2020, is funded by multiple European sources and ministries, agencies, and universities in Spain. Spain also has the most funding for research on this topic, with 18 institutions providing 31 funding instances for publications on DC for pre-service teachers. Thus, most publications from Spain received funding from various sources. Norway and Spain also have the most international collaboration in publications, primarily funded by the Erasmus Strategic Partnership Program. Other countries have generally seen less international collaboration on this research topic. This suggests that Spain is taking the lead in policy prioritization and resource allocation for developing pre-service teachers' DC, in alignment with EU digital education strategies.

In Asia, the topic of DC for pre-service teachers has gained recent attention, especially from researchers in Indonesia, the leading country in Asia in terms of publications on this topic. In Indonesia, the "Merdeka Belajar" (Freedom to Learn) program, proposed by the Ministry of Education and Culture, aims to build a workforce for the fourth industrial revolution. This program focuses on a future education system based on communication technologies, encouraging innovation, creativity, and DC development for teachers and students. To achieve this, teachers must acquire basic competencies related to the "Merdeka Belajar" curriculum before entering the classroom [38]. Therefore, DC for university students in general, and pre-service teachers in particular, has become a significant area of research.

Next, regarding contributions from institutions, the collected data show that 160 institutional affiliations have been involved in publishing research on DC for pre-service teachers. The top 10 affiliations with the highest number of publications are presented in Table 4. Leading the top 10 are two universities from Spain and Germany, with 13 publications from authors affiliated with these two universities. These are also the two countries contributing the most affiliations in the top 10 (three affiliations from Spain and two from Germany). Second on the list is UiT the Arctic University of Norway, with 12 publications. Other universities representing Australia (10 publications), Ireland (9 publications), Indonesia (8 publications), and Turkey (7 publications) follow.

With respect to authors' contributions, the dataset reveals that a total of 743 individuals have contributed to publications on DC for pre-service teachers. The authors with the most publications mainly come from Turkey, Norway, and Spain. Information about the 10 authors with the most publications is presented in Table 5.

According to Table 5, the leading author in the top 10 is Çebi from Trabzon University, Turkey, with 5 publications and 194 citations. Most of these citations come from the publication Çebi co-authored with Reisoğlu and İlknur, titled "How can the digital competences of pre-service teachers be developed? Examining a case study through the lens of DigComp and DigCompEdu," which has 118 citations. The remaining authors in the top 10 each have 3 publications. Regarding citations, two authors from Norway hold

second and third positions: Hatlevik with 73 citations and Aagaard with 58 citations. Five of the other seven authors in the top 10 are from Spain, with citations ranging from 13 to 55. The remaining two representatives are Ata from Turkey, with 48 citations, and Farrell from Ireland, with 21 citations.

Table 4. Top 10 affiliations with the most publications on the topic of DC by pre-service teachers

Rank	Affiliation	Country	Articles
1.	University of Valencia	Spain	13
2.	University of Education Weingarten	Germany	13
3.	UiT the Arctic University of Norway	Norway	12
4.	University of Seville	Spain	12
5.	University of Southern Queensland	Australia	10
6.	University of Erlangen-Nuremberg	Germany	9
7.	University of Limerick	Ireland	9
8.	Sebelas Maret University	Indonesia	8
9.	University of Murcia	Spain	8
10.	Trabzon University	Turkey	7

Table 5. Top 10 authors with the most publications on the topic of DC for pre-service teachers

Rank	Author	Institution/ country	TP	TC
1	Çebi, A.	Trabzon University, Turkey	5	194
2	Hatlevik, O.	Oslo Metropolitan University, Norway	3	73
3	Aagaard, T.	University of South-Eastern Norway, Norway	3	58
4	Gassó, H.	University of Valencia, Spain	3	55
5	Ata, R.	Muğla Sıtkı Koçman University, Turkey	3	48
6	Esteve-Mon, F.	Universitat Jaume I, Spain	3	37
7	Gisbert-Cervera, M.	Rovira i Virgili University, Spain	3	27
8	Guillen-Gamez, F.	University of Malaga, Spain	3	23
9	Farrell, R.	Ulster University, Ireland	3	21
10	Huertas-Abril, C.	Universidad de Córdoba, Spain	3	13

As shown in Tables 4 and 5, Spain is represented by three affiliations among the top 10 in terms of publication output. Nonetheless, only one of these affiliations includes an author ranked among the leading contributors to this research topic. Collaboration has been achieved among some of the top 10 authors. Two Spanish authors, Gisbert-Cervera and Esteve-Mon, co-authored the article "ETeach3D: designing a 3D virtual environment for evaluating the digital competence of preservice teachers," published in 2016. Additionally, collaboration between leading contributors is seen in the joint work between Spanish author Gassó and Norwegian author Hatlevik, who co-authored two publications, including one with 50 citations titled "Student teachers' responsible use of ICT: Examining two samples in Spain and Norway." This collaboration among top authors and leading contributing countries suggests that this research topic will continue to expand and develop. The prominence of key authors and international collaborations highlights the dynamic and expanding nature of research on DC for pre-service teachers, suggesting continued growth and relevance in this area.

3.3. Contributions by journals

According to Scopus data, a total of 136 sources have published works related to DC for pre-service teachers. The top 10 sources with the highest number of publications are detailed in Table 6. Among these, the earliest articles appeared in 2013, with the most recent published in 2022. Notably, ICPS is the only CP included in the top 10 sources, having published three papers on this topic since 2017.

According to Table 6, the two journals with the highest number of publications and citations in the top 10 are EAIT, with 13 publications, and CAE, with 643 citations. Both are Q1-ranked journals and are recognized for high-quality research on ICT integration and computer-based education. ES ranks second in publication volume but falls to fifth place in terms of citations, indicating a discrepancy between output and impact. Other notable sources include the NJDLC, with 104 citations, and the NJCIE, with 96 citations. Journals at the bottom of the top 10 list each published four papers, with International Federation for Information Processing Advances in Information and Communication Technology (IFIP AICT) being the only Q3-ranked source and receiving the fewest citations (3). Overall, the most active publication outlets in this research area are predominantly high-quality journals, mainly ranked Q1 and Q2 in the Scopus database. This concentration of publications in top-tier journals highlights the academic rigor and growing scholarly interest in the topic of DC for pre-service teachers.

Table 6. Top 10 most published sources on DC topics by pre-service teachers

Rank	Sources	Type	TP	TC	Scopus quartile 2023*	PY start
1	Education and Information Technologies (EAIT)	JN	13	178	Q1	2020
2	Education Sciences (ES)	JN	11	71	Q2	2019
3	Computers and Education (CAE)	JN	9	643	Q1	2015
4	Nordic Journal of Comparative and International Education (NJCIE)	JN	7	104	Q2	2020
5	Nordic Journal of Digital Literacy (NJDL)	JN	7	96	Q2	2013
6	Irish Educational Studies (IES)	JN	4	68	Q2	2021
7	Sustainability (Switzerland)	JN	4	67	Q2	2020
8	Frontiers in Education (FE)	JN	4	23	Q2	2022
9	International Federation for Information Processing Advances in Information and Communication Technology	JN	4	3	Q3	2014
10	ACM International Conference Proceeding Series (ICPS)	CP	3	6	-	2017

*According to data from Scimago Journal and Country Rank on August 28th, 2024.

3.4. Contributions of influential publications and thematic trends

According to the collected data, there are 278 publications on the topic of DC by pre-service teachers. The 10 most-cited publications were all published in Q1 journals between 2011 and 2021. The general information about these publications is presented in Table 7.

According to Table 7, the publication with the most citations is by Instefjord and Munthe [21], with 269 citations. This paper also has the highest TC/year ratio. The publication addresses the integration of DC in teacher training programs and recommends more longitudinal and experimental studies to identify the factors that promote DC development for teacher educators and pre-service teachers in initial teacher education programs. The second-highest citation count and TC/year ratio belong to the publication by Reisoğlu and Çebi [39], which proposes enhancing DC for students through combining theoretical content with professional practice, utilizing digital resources in teaching and learning, and empowering learners.

Table 7. Top 10 most-cited publications on the topic of DC for pre-service teachers

Rank	Document title	Journal title (Scopus quartile)	TC	TC/ year	Document
1	Educating digitally competent teachers: A study of integration of professional digital competence in teacher education	Teaching and Teacher Education (Q1)	269	33.6	[21]
2	How can the digital competences of pre-service teachers be developed? Examining a case study through the lens of DigComp and DigCompEdu	Computers and Education (Q1)	118	23.6	[39]
3	Educating online student teachers to master professional digital competence: The TPACK-framework goes online	Computers and Education (Q1)	107	10.7	[40]
4	Rethinking the use of video in teacher education: A holistic approach	Teaching and Teacher Education (Q1)	101	7.2	[41]
5	Defining digital literacy development: An examination of pre-service teachers' beliefs	Computers and Education (Q1)	86	14.3	[42]
6	Engaging preservice primary and pre-primary school teachers in digital storytelling for the teaching and learning of mathematics	British Journal of Educational Technology (Q1)	71	7.9	[43]
7	What to teach? Strategies for developing digital competency in preservice teacher training	Computers and Education (Q1)	68	17.0	[22]
8	Pre-service teachers' perceptions of the competence dimensions of digital literacy and of psychological and educational measures	Computers and Education (Q1)	66	8.3	[44]
9	Exploring the role of digital storytelling in student motivation and satisfaction in EFL education	Computer Assisted Language Learning (Q1)	66	16.5	[20]
10	A mixed research-based model for pre-service science teachers' digital literacy: Responses to "which beliefs" and "how and why they interact" questions	Computers and Education (Q1)	60	8.6	[45]

Other studies in the top 10 also propose strategies and specific solutions to improve DC for students. The third-most-cited study (107 citations) by Tømte et al. [40] shows that online training programs are one of the best ways to stimulate teachers and students to develop DC for teaching purposes. However, this aspect has not been widely integrated into actual training programs. The study by Masats and Dooly [41], with 101 citations, stems from the need for an integrated model of learning objectives and competencies, proposing specific ways to develop DC, such as positioning students as learners and teachers and allowing them to co-create the curriculum. The study by Howard et al. [22], with the third-highest TC/year in the top 10 and 68 citations, outlines four specific strategies for developing DC in students: engaging students in model research, lesson planning, practicing in authentic environments, and providing feedback. This study also

suggests several future approaches, such as systematically evaluating teaching strategies and integrating technology skills into students' teaching and learning processes. The study by List [42], ranked fifth in the top 10 with 86 citations, provides important theoretical foundations for DC development.

The remaining studies in the top 10 address student beliefs, perceptions, motivations, and satisfaction with integrating digital skills into their learning. The study by García-Martín and García-Sánchez [44] highlights the use of Web 2.0 tools as a psychological and educational means to provide opportunities to develop key skills for optimizing future teaching processes. Hava's study [20] shows significant improvements in student confidence and performance when using digital storytelling in English education. The study by Güneş and Bahçivan [45] investigating the relationship between students' epistemological beliefs, teaching and learning perceptions, and digital literacy skills reveals that students' experiences affect their beliefs and digital literacy skills, with constructivist teaching and learning beliefs contributing positively to their digital literacy skills. The study by Starčič et al. [43] demonstrates that integrating digital storytelling into learning objectives and assessment criteria positively impacts students' perceptions, enhances their problem-solving skills in mathematics, and encourages the increased use of ICT in classrooms. Thus, the most influential studies highlight a growing consensus on the need for practical, theory-informed, and psychologically grounded approaches to developing DC, signaling a strong foundation and future direction for research and teacher education practice.

Following the analysis of influential publications, keyword co-occurrence analysis was conducted using VOSviewer. The software generated a network of keywords that appeared in at least three publications. To focus on analyzing key research trends regarding DC, keywords related to the subject (pre-service teachers), such as "teacher training", "pre-service teacher", "teacher education", "student teacher", and "future teachers", were excluded. Figure 4 describes 60 author keywords, each appearing in at least three publications. The collection is divided into four main research directions corresponding to four clusters.

Figure 4. Co-occurrence network of 60 author keywords that appear together in at least three papers

The red cluster includes keywords related to the research direction of integrating and developing DC in education to enhance the quality of teaching and learning through technology integration and modern educational methods, including models like blended learning and flipped classrooms [46]–[48], and the TPACK model [40], [49]. It also includes studies on building and assessing DC frameworks for teachers [50], [51]. The green cluster focuses on research examining the impact of digitalization and digital technologies on the professional development of pre-service teachers [20], [41], such as developing DC and computational thinking during teacher education [52]. It also includes studies assessing pre-service teachers' perceptions of digital skills [53], [54] and evaluating the effectiveness of pedagogical methods for developing

DC in pre-service teachers [55]. The blue cluster focuses on studies applying VR [56] and AR [31] for professional development and DC enhancement for pre-service teachers. It also assesses pre-service teachers' attitudes toward using digital technologies [57], [58]. The yellow cluster focuses on the impact of the COVID-19 pandemic on teacher training and English as a foreign language (EFL) teaching in the context of online and remote learning. It includes studies on how COVID-19 has changed teacher training methods [59], ICT integration in higher education [14], and the effectiveness of mixed methods and reasonable use of digital tools for developing DC in pre-service teachers [60]. These keyword clusters capture the principal research themes in the field, directly responding to the thematic focus of research question 4.

To further clarify research directions on this topic, the authors analyzed author keywords from 2017 to 2023, excluding subject-related terms. According to the statistical data from Biblishiny, the most frequent keywords in publications were "digital literacy", "digital competency", and "higher education", corresponding to the red, green, and blue clusters, respectively. Two keywords, "digital literacy" and "higher education", represented prominent research areas in 2022, with the highest number of papers. "Digital literacy" was the most frequent keyword in 2021. In 2023, two emerging keywords were "digital technology" and "digital skills". Analyzing trends for these author keywords shows that "digital literacy" and "digital competence" are essential keywords reflecting major ongoing research trends in this field. Additionally, "digital technology" and "digital skills", although newer, have gained significant attention from researchers in 2023 and may serve as core keywords for future research trends.

The thematic map in Figure 5 is divided into four main areas representing different research topics based on density and centrality. Top-right quadrant (motor themes): these are well-developed, highly relevant topics. Themes like digital literacy, higher education, and education technology fall into this category, indicating they are critical and influential in the field. Top-left quadrant (niche themes): these topics are well-developed but not highly relevant to the entire research field, often specialized and studied by smaller groups. Topics like 21st-century skills, computer literacy, and distance-learning are examples. Bottom-left quadrant (emerging or declining themes): these topics have low relevance and development, potentially representing emerging or declining research areas. Themes like media literacy, digital citizenship, and digital storytelling fall here, showing less recent attention. Bottom-right quadrant (basic themes): these topics have high relevance but lower development, serving as foundational topics for future research. Examples include digital competence, digital technology, and digital skills.
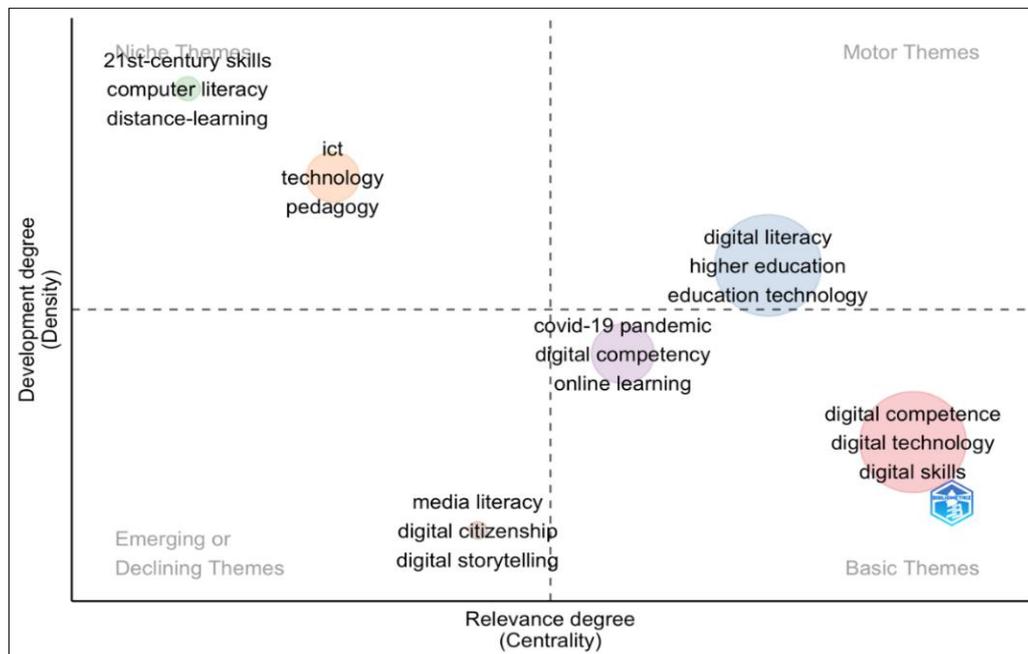

Figure 5. Thematic map of research directions related to DC of pre-service teachers

In Figure 5, topics like digital literacy, higher education, and education technology are in the motor themes quadrant, demonstrating their importance and strong development in research on digital technology and education. Meanwhile, topics like 21st-century skills, computer literacy, and distance-learning are in the

niche themes quadrant, indicating specialized but not central research. Topics like media literacy, digital citizenship, and digital storytelling are in the emerging or declining themes quadrant, indicating reduced attention recently. Basic themes include digital competence, digital technology, and digital skills, showing their foundational importance for future research.

In conclusion, the keyword analysis highlights the central role of DC in shaping the research landscape on pre-service teacher education. The frequent appearance of terms such as "digital competence", "digital technology", and "digital skills" underscores their significance as core themes and potential foundations for future inquiry. These findings carry important implications for educational practice and policy. For instance, teacher education programs should integrate DC training and provide experience with emerging technologies (AR/VR) as part of their curricula to better prepare future educators. Additionally, education policymakers can utilize these insights to formulate strategies and policies that enhance teachers' digital skills and ensure that teacher training aligns with the demands of digitally enhanced education.

4. CONCLUSION

This study provides a comprehensive overview of global research trends related to DC among pre-service teachers, based on a bibliometric analysis of 278 publications indexed in the Scopus database from 2009 to the present. The findings reveal a notable surge in interest in this topic following the COVID-19 pandemic, with over half of the publications produced between 2021 and 2023. This significant increase reflects transformative shifts in teaching and learning practices, as well as the growing influence of technology-oriented educational policies in several countries, particularly in Asia. The most prolific contributor to this research topic is Çebi from Trabzon University, Turkey. Meanwhile, the two institutions with the highest number of publications are the University of Valencia (Spain) and the University of Education (Germany). The most influential publication is that of Instefjord and Munthe, which has received 269 citations and focuses on the integration of DC into teacher education programs. Keyword analysis indicates that current research directions revolve around the integration of DC into teacher education, the application of digital technologies such as VR and AR, the impact of digitalization on professional development, and the influence of the COVID-19 pandemic on DC acquisition. However, compared to other areas of educational research, studies on DC still lack cross-disciplinary comparisons and contextual alignment, which limits a full understanding of their relevance and broader impact.

The findings also suggest substantial disparities in investment and development of DC across countries. This highlights the need for future cross-national comparative studies to examine how culture, policy, and systemic capacity influence the advancement of DC among prospective teachers. In addition, more attention should be given to underrepresented regions, where empirical data on DC development remains limited. Future research should explore regional disparities through collaborative, cross-country studies that account for cultural and contextual diversity. In practical terms, teacher education institutions should prioritize the early and structured development of DC through well-designed training programs, guided by established frameworks such as the European Commission's DigCompEdu. Furthermore, collaboration between researchers, educational institutions, and governments is crucial to establishing shared infrastructures, disseminating best practices, and fostering innovation in digital teacher preparation. Ultimately, this study demonstrates that bibliometric analysis is a valuable tool for tracking the development of knowledge, identifying influential themes and contributors, and informing evidence-based policy and future research agendas in the field of DC for pre-service teachers.

This study has several limitations that should be acknowledged. First, the analysis was based solely on data from the Scopus database and included only publications up to early 2025. As a result, some relevant studies indexed in other databases such as WoS or Google Scholar may have been excluded. Incorporating a wider range of data sources in future research could enhance the comprehensiveness and coverage of bibliometric analyses. Second, certain limitations may arise from the specific search queries, filtering criteria, and the timing of data retrieval, all of which could influence the representativeness of the dataset. Future studies should carefully address these methodological concerns to ensure more accurate and comprehensive results. Third, this study primarily focused on English-language publications. The exclusion of research published in other languages may reduce the diversity and global scope of the findings, especially in regions where English is not the dominant academic language. Future research is encouraged to address this gap by incorporating multilingual databases to capture a broader range of contributions. Finally, the study concentrated exclusively on pre-service teachers, thus omitting other relevant groups such as in-service teachers or students in different disciplines. Expanding the scope to include these populations would provide a more holistic view of DC development in education and allow for meaningful comparisons across levels, fields, and geographical contexts. Despite these limitations, this study offers valuable insights into global research trends on DC for pre-service teachers and serves as a foundation for future scholarly investigations in this field.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors declare no competing interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [HVD], upon reasonable request.

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