sustainability

MDPI

Article

Research Status, Hotspots, and Evolutionary Trends of Global Digital Education via Knowledge Graph Analysis

Duo Yang [1], Jincheng Zhou [1,2,3,*], Dingpu Shi [1], Qingna Pan [1], Dan Wang [2,3,4], Xiaohong Chen [4] and Jiu Liu [2,3,4]

[1] School of Computer and Information, Qiannan Normal University for Nationalities, Duyun 558000, China
[2] Key Laboratory of Complex Systems and Intelligent Optimization of Guizhou Province, Duyun 558000, China
[3] Key Laboratory of Complex Systems and Intelligent Optimization of Qiannan, Duyun 558000, China
[4] School of Mathematics and Statistics, Qiannan Normal University for Nationalities, Duyun 558000, China
* Correspondence: zjc8l@sgmtu.edu.cn

Abstract: With the rapid development of emerging technologies such as big data, artificial intelligence, and blockchain and their wide application in education, digital education has received widespread attention in the international education field. The outbreak of COVID-19 in December 2019 further catalyzed the digitalization process in various industries, including education, and forced the education system to carry out digital reform and innovation. Digital education transformation has become a new hotspot of great interest in countries around the world and a major direction for education reform practices. Therefore, to better understand the status of global digital education research, this study uses CiteSpace (6.1.R2) visual analysis software to visualize and quantitatively analyze the literature on digital education research in the social science citation index (SSCI). First, the basic information of digital education was analyzed in terms of annual publication volume, authors, countries, and research institutions. Secondly, the main fields, basic contents, and research hotspots of digital education research were analyzed by keyword co-occurrence analysis mapping and keyword time zone mapping. Finally, the research frontiers and development trends of digital education between 2000 and 6 September 2022 were analyzed by cocitation clustering and citations. The results show that, based on the changes in annual publication volume, we can divide the development pulse of the digital education research field into three stages: the budding stage (2000–2006), the slow development stage (2007–2017), and the rapid development stage (6 September 2018–2022); there are 26 core authors in this field of research, among which Selwyn N has the highest number of publications; the USA, England, Spain, Australia, and Germany have the highest number of publications; Open Univ is the institution with the most publications; digital education's research hotspots are mainly focused on interdisciplinary field practice research and adaptive education research based on big data support. The research frontiers are mainly related to five areas: interdisciplinary development, educational equity, digital education practice, digital education evaluation, and digital education governance. This paper systematically analyzes the latest developments in global digital education research, and objectively predicts that human–computer interdisciplinary teaching models and smart education may become a future development trend of digital education. The findings of this study are useful to readers for understanding the full picture of digital education research so that researchers can conduct more in-depth and targeted research to promote better development of digital education.

Keywords: digital education; digital education governance; digital technology; CiteSpace; COVID-19; knowledge graph

Citation: Yang, D.; Zhou, J.; Shi, D.; Pan, Q.; Wang, D.; Chen, X.; Liu, J. Research Status, Hotspots, and Evolutionary Trends of Global Digital Education via Knowledge Graph Analysis. *Sustainability* **2022**, *14*, 15157. https://doi.org/10.3390/su142215157

Academic Editors: Juan Carlos Bustamante and Carlos Peñarrubia-Lozano

Received: 14 September 2022
Accepted: 10 November 2022
Published: 16 November 2022

1. Introduction

With the rapid development of emerging technologies such as big data, artificial intelligence, and blockchain and their widespread use in education, digital education has received widespread attention in the international education sector. The sudden outbreak of COVID-19 in December 2019 further accelerated the digital transformation process in

various industries, including education. At the beginning of 2020, due to the impact of COVID-19, countries and regions around the world were forced to temporarily close schools or adopt online teaching. According to UNESCO, as of early April 2020, 194 countries worldwide were forced to temporarily close schools, affecting nearly 1.6 billion students [1]. In this context, education systems have had to undergo digital reforms and innovations.

Over the past two decades, information and communication technologies (ICT) have been increasingly used in "digital" education at public universities [2]. In recent years, digital education has been mentioned more and more frequently, but different authors have different views on its meaning. The term "digital education" was early mentioned early on in *Skills and Knowledge*, referring to the difference between left- and right-handed dexterity within dentistry [3]. In the 1980s, the term referred to education about digital and electronic technologies [4]. In the 1990s, "digital education" referred to the understanding of digital space, digital culture, and educational approaches using digital technology [5,6]. In recent years, many researchers have referred to it as e-learning [7], technology-enhanced learning [8,9], digital learning [10], blended learning [11], online learning [12], etc. Sousa and Rocha define digital education as "the use of multiple types of technological devices, such as smartphones, tablets, computers, etc., for learning activities" [13]. Z.-T. Zhu. & J Hu. consider digital education in a broad sense as a complex of socio-educational transformations in which technology is deeply integrated with the education system, and in a narrower sense as the introduction of technology into educational organizations and the innovation and transformation of products, processes, or models formed based on these technologies [14]. To conclude, digital education should be an innovative teaching model that uses computer technology and network technology to replace the traditional teaching model to assist in the progress of teaching and learning and to achieve an efficient classroom without paper and zero distance for inquiry and interaction. It is a cross-school and cross-regional education system and teaching model, which is a new trend in future education.

Since the outbreak of COVID-19, the rapid development of digital education has been pushed forward [15], and as a result, digital education has transformed the traditional education system globally through information and communication technologies (ICT). Digital education aims to create a continuous mobile learning environment [16] with parallelism, connectionism, and visualization [17,18]. Mobile technologies have brought about mobile teaching and learning, setting off a surge in distance education and changing the norm of formal education during COVID-19 [19]. Thus, the mobile learning environment has changed the traditional educational approach, transcending the constraints of time and space toward virtual online course delivery [20]. In addition, the use of mobile technology in digital education has driven teachers to actively innovate and disrupt traditional teaching methods [21].

With the accelerating pace of digital transformation in countries around the world, many countries and international organizations have introduced a series of digital education reform policies in recent years, elevating digital education to the level of national strategy and promoting their reform and development. Australia is one of the leading countries in the world in terms of the level of digital education, and the development of its digital education can be traced back to the 1980s, after more than 40 years of development, which is a reference value for global digital education reform and development. In 1983, *Teaching, Learning, and Computers: Report of the National Advisory Committee on Computers in Schools* was released, which explicitly proposed "supporting the introduction of computers into schools and proposing a framework for computer-based teaching and learning programs" as a key digital reform deployment [22]. In 2020, the Foundation Skills for Your Future program was launched, which proposed a standard framework of digital skills for the future [23]. In 2013, the United States proposed the "Connected Education Initiative", which proposes to connect schools to high-speed networks [24], and by 2019, 99% of U.S. public elementary and secondary schools will have access to fiber optics, with an average Internet speed of more than 670 kbps per student [25]; in addition, in 2017, the International Society for Technology in Education published the *ISTE standards for educators*,

which analyzed the different roles teachers play in education and teaching in the context of the information age from multiple dimensions, and defined the responsibilities and competency standards for different roles of teachers, to promote teachers' use of digital technology to innovate teaching [26]. The German federal government officially launched the *Digital Agreement for Schools* in 2019 and plans to invest 500 million euros per year for the next five years to build school information platforms [27]; in July 2021, the German Academic Exchange Service (DAAD) released the *Digital Transformation of Higher Education in the 21st Century—Global Learning Report 2021*, which focuses on four areas such as equitable access, institutional digital transformation, digital literacy, and virtual collaboration [28]. In 2017, the Government of the Russian Federation released the *Digital Economy Plan of the Russian Federation*, which defines the roadmap for the development of the digital economy, among which "talent and education" is one of the five basic development directions proposed in the plan [29]; after that, the "Digital Education Environment" project was launched in 2018 to establish a safe digital education environment [30]. In September 2020, UNESCO, the International Telecommunication Union, and UNICEF jointly released *Digital Education Transformation: Connected Schools, Empowered Students*, focusing on digital connectivity in education [31]. In the same year, the EU released the *Digital Education Action Plan (2021–2027)*, which identifies two strategic issues that need to be promoted at the EU level in the future: "Promoting the development of high-performance digital education ecosystems" and "Enhancing digital skills and competencies for digital transformation" [32]. In August 2021, the Chinese Ministry of Education approved Shanghai as a pilot zone for digital education transformation [33], and a national education work conference was held on 16–17 January 2022, where the Digital Education Strategic Initiative was implemented [34]. In summary, it can be seen that digital education has received key attention from many countries around the world, and the promotion of digital education transformation has become a national strategic goal in many countries around the world.

Since 2017, researchers have increasingly focused on digital education-related research and published a large number of papers. According to a search of the Web of Science (WoS) database, there are few review papers on digital education, and researchers mainly explore issues such as educational equity in the digital age, the application of digital technologies in various subject areas, and educational governance. The lack of review articles makes it difficult for researchers to understand the focus of digital education research and the current state of research from the huge collection of papers. Literature reviews are considered to be an effective way of gaining insight into a particular research area [35]. To understand the current state of research in the field, it is necessary to use scientometric software (CiteSpace) to conduct a systematic analysis of the field [36].

By using CiteSpace software to systematically sort through existing research, we can get a clearer picture of the research hotspots, current status, and development trends in this field, which can provide reference and direction for researchers' future research [35]. Therefore, by collecting rich materials related to digital education research, this study attempts to sort out the development of digital education as a whole, summarize the research progress, and try to get a clearer path and trend of digital education development, to better predict the future research direction. The main contributions of this study include the following three points:

(1) Analyzing the basic distribution of digital education research presence, such as authors, countries, and institutions.
(2) Analysis of the research hotspots in digital education research.
(3) Analysis of the research frontiers and research trends in digital education research.

The paper is organized as follows: In Section 2, we briefly introduce the research methodology, including data acquisition and visualization tools. In Section 3, we present the results of the visualization in seven areas: annual publication volume, authors, countries, institutions, keywords, and references cited. Section 4 summarizes the results of the study. Section 5 briefly describes the limitations and future work.

2. Materials and Methods

2.1. Data Collection

Compared with databases such as SCI and Scopus, SSCI publications mainly cover humanities and social sciences literature, and digital education belongs to this category. In addition, Alotaibi [37] has the most evident finding that the writers of texts in non-SSCI-ranked journals drew on monoglossic options nearly three times more than the writers of texts in SSCI-ranked journals did (1.36% vs. 0.493%). This finding is in line with that in Mei's [38] study where low-rated essays written by undergraduate students included more instances of monoglossic recourses compared to high-rated essays. Thus, the research in the SSCI database is more representative. Finally, SSCI covers a wide range of journals, it was founded in 1956, and in 1999 SSCI included 1809 of the world's most important social science journals in full text, while Scopus is a database launched by Elsevier in November 2004 and covers more journals but has less impact and is limited to recent articles [39]. Therefore, since the search in this paper started in 2000, and to enhance the directivity of the study, only literature from the SSCI database is analyzed in this paper. This study used the SSCI database in the Web of Science (WOS) core collection as the data source, which is different from the way Fu [36] et al. selected the data scope, and the data collection scope of this study is more targeted. The database search title was restricted to "digital education", or "Educational Digital Transformation", or "Digital Educationization", or "Digitalization in education", or "Digitalization of Education", or "Digital Transformation of Education"; the time limit for the search data was 1 January 2000 to 6 September 2022; the type of document was selected as "article"; the language was "English"; and the Web of Science category was "Education Educational Research". The literature was exported in plain text format. This filter was validated by experienced computer researchers, and the retrieved data were filtered and excluded, resulting in 368 articles related to digital education.

2.2. Analytical Methods

2.2.1. CiteSpace and Setting

In this study, a bibliometric approach was used, i.e., "a literature review through mathematical and statistical methods" [35]. The data sources were analyzed in a multivariate, time-sliced, and dynamic visualization using CiteSpace (6.1.R2), an econometric analysis tool developed by Prof. Chaomei Chen's research team [40]. Time Slicing was set to 1 year. Selection criteria under the Top N% column were set to 25%, and "Static" and "Show Merged Network" were selected for visualization. The study analyzed the global digital education research literature in terms of authors, institutions, countries, keyword co-occurrence, and citation abruptness to analyze the research hotspots, development history, research frontiers, and trends of digital education research.

2.2.2. Paths of Analysis

To comprehensively analyze the current status and development trend of digital education research, and based on the characteristics of CiteSpace analysis tools, this study analyzed its path from the following three aspects:

(1) Basic information analysis of digital education. This allowed us to have an overview of digital education in general, including the number of publications, authors, countries, institutions, etc.

(2) Analysis of the research hotspots of digital education. The analysis of keyword co-occurrence mapping and time zone maps allowed us to understand the main areas, basic content, and research hotspots of digital education research since 2000.

(3) Analysis of the research frontiers and trends of digital education. A research frontier consists of a set of co-cited core papers and references to one or more of these core papers [41]. By clustering and analyzing the co-cited references, the references that were cited more frequently were filtered out based on these clusters, and these articles were read closely to understand the current research frontiers of digital education. Abruptness

analysis was used to identify citation bursts, which refers to the intensity of the sudden appearance or disappearance of citations for a research topic in a certain research field during a certain period, and to some extent represents the direction of a shift in a certain research trend [42]. Based on the observed sudden changes in citations in different periods, the trending research themes in different periods were inferred.

3. Results and Analysis

3.1. Basic Information Analysis of Digital Education

3.1.1. Annual Distribution of Publications

Statistical analysis of the number of publications of research papers in a given field provides insight into the development of the field. The annual volume of publications in the literature presents the trend of changes in academic attention to research topics over a certain time frame [43]. According to the search results, 368 papers on digital education were published from 1 January 2000 to 6 September 2022, and the annual changes are shown in Figure 1.

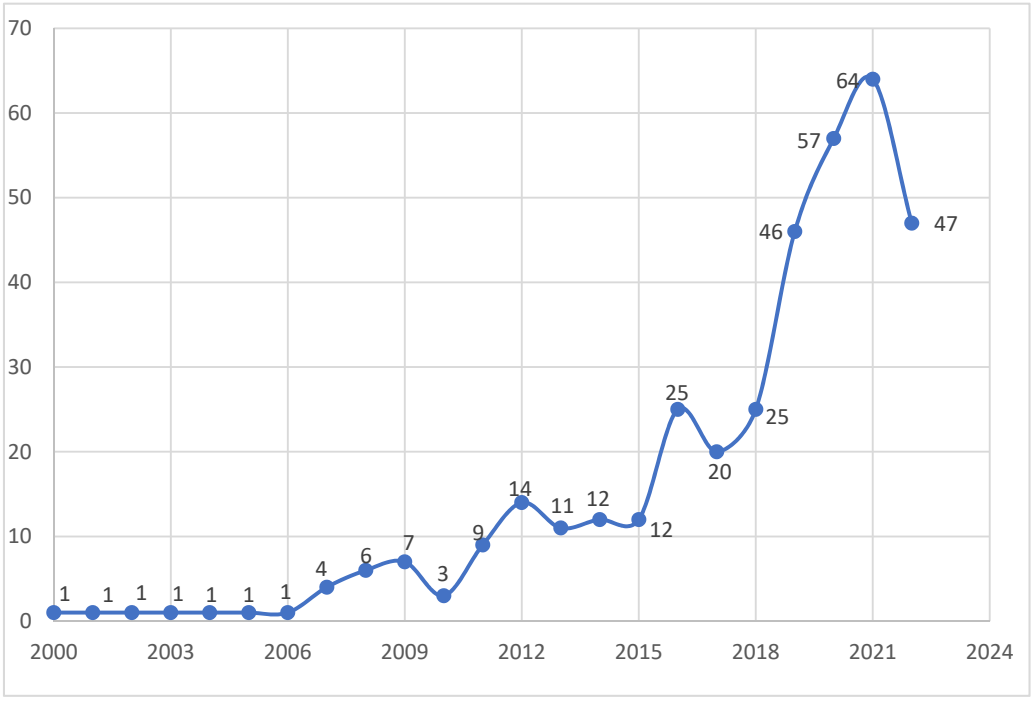

Figure 1. Digital education annual publication statistics.

Based on the changes in the number of annual publications, the development line of this research field can be divided into three phases, namely the budding phase, the slow development phase, and the rapid development phase. In the first stage (2000–2006), the budding stage, digital education research was just starting, and the number of published papers was low, averaging one paper per year. In the second phase (2007–2017), the research related to digital education showed a slow increase during the decade, and several research results appeared in this phase, with an average of about 11 publications per year. The third phase (6 September 2018–2022) is the rapid development phase, where digital education research develops rapidly; the number of literature reached 64 in 2021, and many research results emerged during this phase, with more abundant research results. During these four years, the average number of publications per year was 48.

Based on the trend in the number of publications over the period 2000-2022, we can be predicted that the number of publications will reach approximately 78 by the end of 2022. A large number of researchers focusing on the field of digital wducation have emerged

since 2020 due to COVID-19 and the use of new digital technologies in education that have forced many countries to undergo digital education transformation.

3.1.2. Core Author's Analysis

The number of publications by core authors can, to a certain extent, reflect the breadth and depth of a research field [44]. According to the core author formula: $M = 0.749(N_{max})^{1/2}$, where M is the number of publications, N_{max} is the number of papers of the author with the most publications, and an author with more than M publications is called a core author [45]. The authors with more than or equal to two publications in digital education research are core authors, and there were 26 core authors according to the formula. A statistical analysis of the core authors of digital education research (Table 1) and a co-occurrence mapping analysis of the core authors (Figure 2) led to the following conclusions:

Table 1. Statistical table of core authors analysis.

Serial Number	Author	Percentage ‰	Number of Papers
1	Selwyn N	13.587	5
2	Chang S, GrimaldiE	8.152	3
3	Battro A, Seale J, Ruiz-Corbella M, Taglietti D, Chen H, Decuypere M, Carey K, Edwards S, Lea M, Chan C, Adukaite A, Gutierrez MartinA, Ivala E, Guillen-Gamez F, Brogger K, Landri P, Bedenlier S, Meratla P, Garcia-Gutierrez J, Cantoni L, Bem-Haja P, Instefjord E, Knox J,	5.435	2

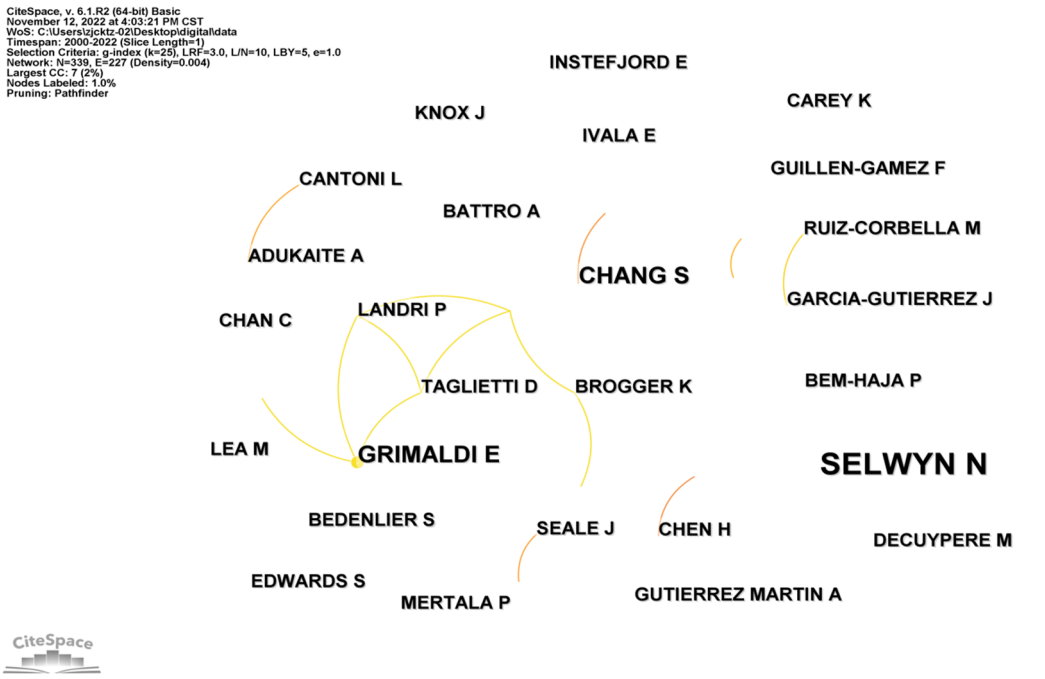

Figure 2. Author co-occurrence mapping analysis.

According to Table 1, the core author with the highest number of publications is Selwyn N, with five articles, whose research areas are mainly related to education, sociological theory, and computer science. In the field of sociology, the research focuses on digital natives [46] and the role of sociological theory in digital technology [47], respectively; in the field of computer science and education, the research focuses on the application of computer technology in university teaching [48], Web 2.0 applications as an alternative environment

for informal learning [49], and an investigation of undergraduate students' differences in academic use of the Internet [50], with the most frequently cited research literature being "*The digital native-myth and reality*", with 1256 citations. In addition, other core authors' research involves disciplines such as education, economics, computer science, mathematics, and sociology, and some researchers have interdisciplinary and cross-disciplinary research. The following information can be mapped in the author's collaborative network knowledge domain with 339 author nodes and 227 connecting lines, and the figure shows the academic collaborative relationships among authors engaged in digital education research, with the node size and connecting lines between nodes representing the number of publications and the collaborative relationships and strengths among the authors of the publications, respectively [51]. From Figure 2, it can be seen that digital education research authors show characteristics such as more nodes and fewer connections. This indicates that global digital education research has not formed a cooperative community, that there is almost no communication and cooperation among authors, which needs to be strengthened in subsequent research, and that cooperation and communication among authors can promote the output of more research results and promote international digital education transformation.

3.1.3. Country of Origin of the Article

The collaborative network of countries shows 58 nodes and 92 lines connecting the nodes (Figure 3), where the top five countries are the USA, England, Spain, Australia, and Germany with 54, 52, 44, 44, and 25 publications, respectively. In addition, the USA, England, Australia, Turkey, Canada, and Germany all have a centrality of more than 0.1. Most of the countries with high publication volume and high intermediary centrality are found in Europe, which may be due to the economic and educational environment in Europe that makes European countries form a strong research system. The alliances and organizations of European countries in digital education research, as well as the development and enactment of some policies, are important and widely referenced for the research and development of digital education. Among them, Germany has introduced several important strategies and policies in the field of digital education and promoted the digital transformation of all levels and types of education through several digital education reform initiatives. The successful experience of Germany is of great significance to the development of global digital education and the enhancement of the comprehensive strength and international competitiveness of education in each country.

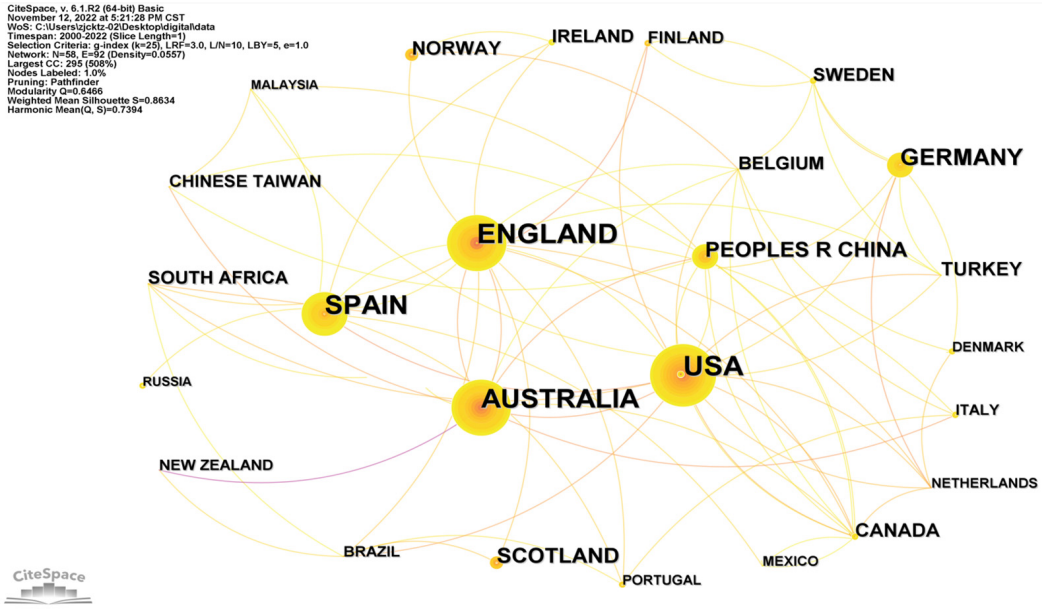

Figure 3. Country-by-country digital education research co-occurrence analysis.

3.1.4. Research Institutions

A visual analysis of research institutions reveals that 268 institutions are conducting digital education research, with only 124 collaborative links between research institutions, which is a low level of collaboration between research institutions. In recent years, six research institutions have published more than five articles in the field of digital education. Open Univ has published the highest number of high-quality papers at eight. The mapping of research institutions presented in Figure 4 also reflects the trend that more and more institutions are gradually showing a tendency to develop in teams and satisfy increasing interinstitutional communication. For example, research teams led by Monash Univ and the Australian Catholic Univ, respectively, have published a large number of papers on digital education, which is one of the reasons for the high number of papers published in the United States and Australia.

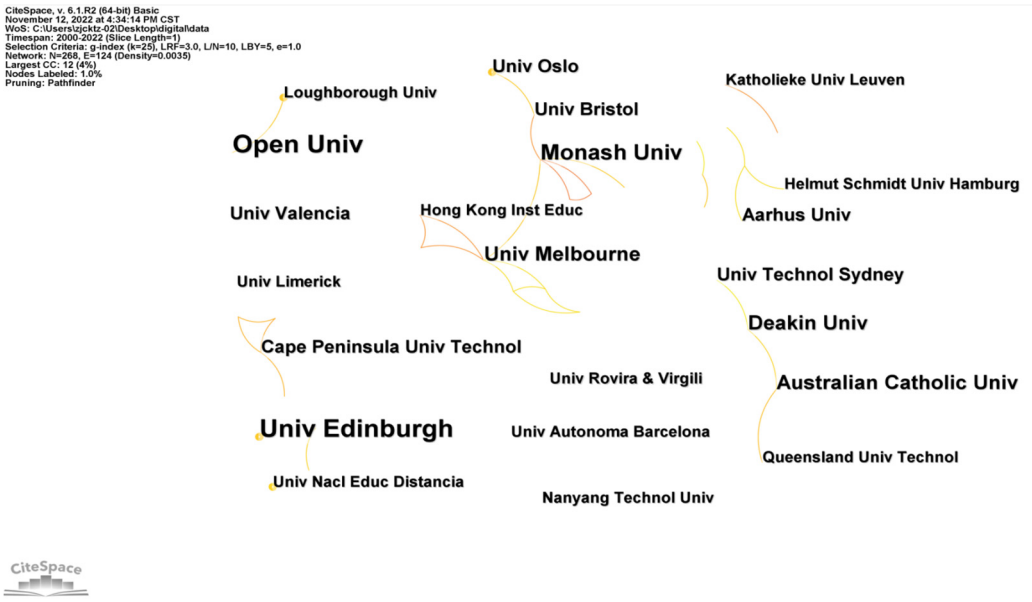

Figure 4. Analysis of co-occurrence mapping of research institutions.

In addition, the dual-map overlay analysis of published journals studied by digital education is more useful for analysts and decision-makers to understand where a journal is academically located and in which direction it may be moving in a complex pedagogical environment [52]. As shown in Figure 5, the journal dual-map overlay arcs, citation links, and trajectories over time facilitate research analysis across multiple groups of publications at the interdisciplinary, organizational, and individual publication levels, with the dashed line depicting the links between different disciplinary boundaries. Thus, the distribution of the publication portfolio presents the citation and cited intensity of 268 publishers, indicating less interinstitutional collaboration (dashed line intensity on the right side of Figure 5) [53]. Table 2 indicates the number of matches between citing and cited journals for each year. Four articles published in 2007 in the SSCI database cited references to 96 journals. The relatively small number of cited journals in the first seven years explains the large variation in citation trajectories. Similarly, a large number of cited journals after 2007 explains why the trajectory of cited journals is much more stable over the years. In summary, the research trajectories in Figure 5 show that digital education research is highly concentrated. The trajectory of cited journals is compact. In this part, in contrast to Shi et al. [53], our dual-map overlay analysis was more focused, avoiding the influence of a large number of marginal areas on digital education research and providing a more in-depth investigation of digital education journals. Further analysis of the interpretation of digital education research literature revealed that global research on digital education mainly includes education and teaching research, computer science and artificial intelligence,

computer science information systems, and interdisciplinary applications of computer science [54–56].

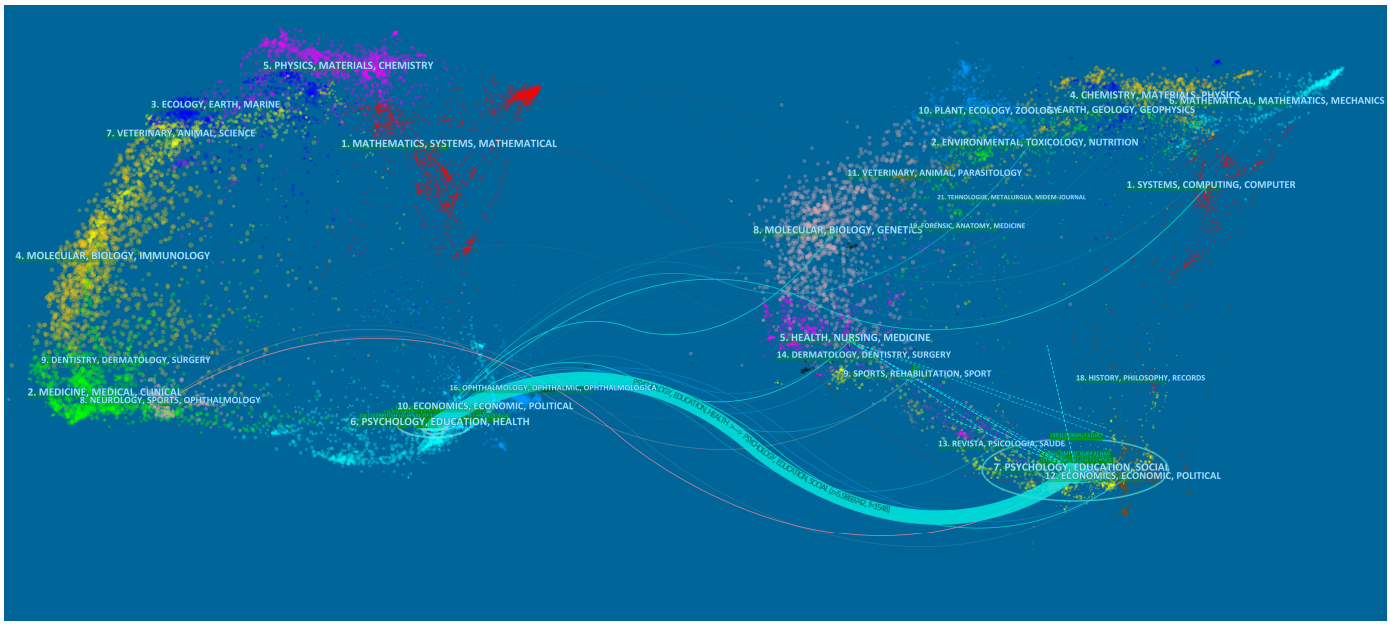

Figure 5. Journal dual-map overlay analysis.

Table 2. Number of citing and cited journals matched in each year.

Citing Journals	Cited Journals	Year	Citing Journals	Cited Journals	Year
1	0	2000	11	326	2012
1	85	2001	9	376	2013
1	28	2002	11	461	2014
1	19	2003	11	468	2015
1	15	2004	18	818	2016
1	8	2006	15	754	2017
0	0	2005	18	1025	2018
4	96	2007	36	1684	2019
5	131	2008	36	1923	2020
5	231	2009	42	2417	2021
3	92	2010	30	1608	2022
9	322	2011			

3.2. Analysis of Research Hotspots of Digital Education

The keywords of digital education-related research were analyzed using co-occurrence mapping (Figure 6), and the top five keywords with the longest existence time and frequency of occurrence were: "higher education", "technology", "digital literacy", "student", and "digital technology"; therefore, they can be considered as the most basic knowledge, main fields, and research hotspots in the field of digital education. Based on the keyword chronology chart, it can be concluded (Figure 7) that the core fundamentals of the digital education domain began to emerge after 2007, and with the continued overlay in subsequent years, they have become the key fundamentals. Among them, higher education, technology, digital literacy, and the Internet have relatively high mediating centrality values and are the mediating keywords for the digital education subject cluster and interdisciplinary studies.

In addition, the occurrence of these keywords always showed some correlation with other keywords, such as the impact of changes in data integration on traditional education [57] and the knowledge of different subject areas providing the basis for interdisciplinary integration [58]. Adaptive learning such as using online education data to enhance

student learning, reduce the heterogeneity of students' basic knowledge, and enhance the diversity of teaching models was found to deliver significant improvements in learning outcomes [59]. The dynamic changes in digital education have led to a new paradigm of digital education toward intelligence [60]. The trend of digital integration has led to a systematic pattern of interdisciplinary integration in many teaching and learning areas [61]. The indicators of instructional development in digital education are combined with instructional evaluation and are widely used in areas such as the study of students' development of learning outcomes and problem-solving skills.

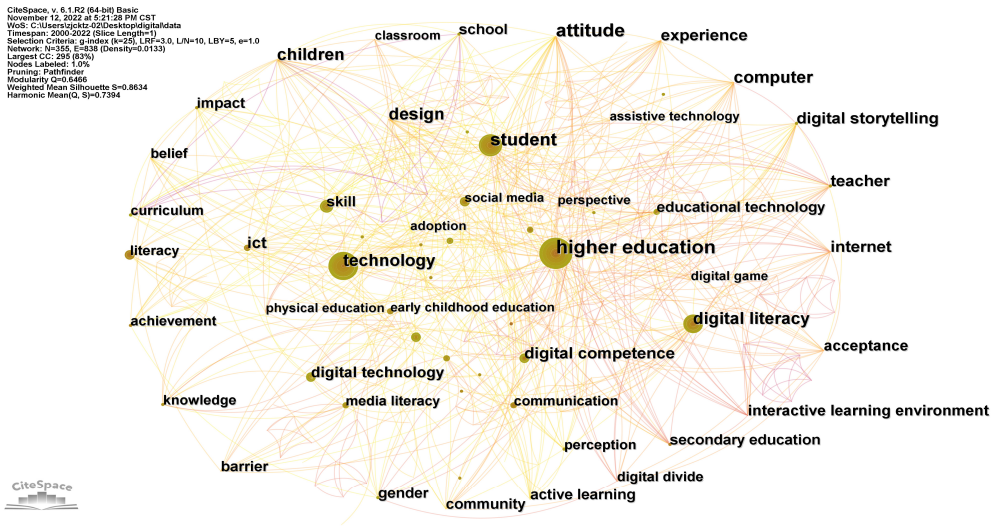

Figure 6. Keyword co-occurrence mapping analysis.

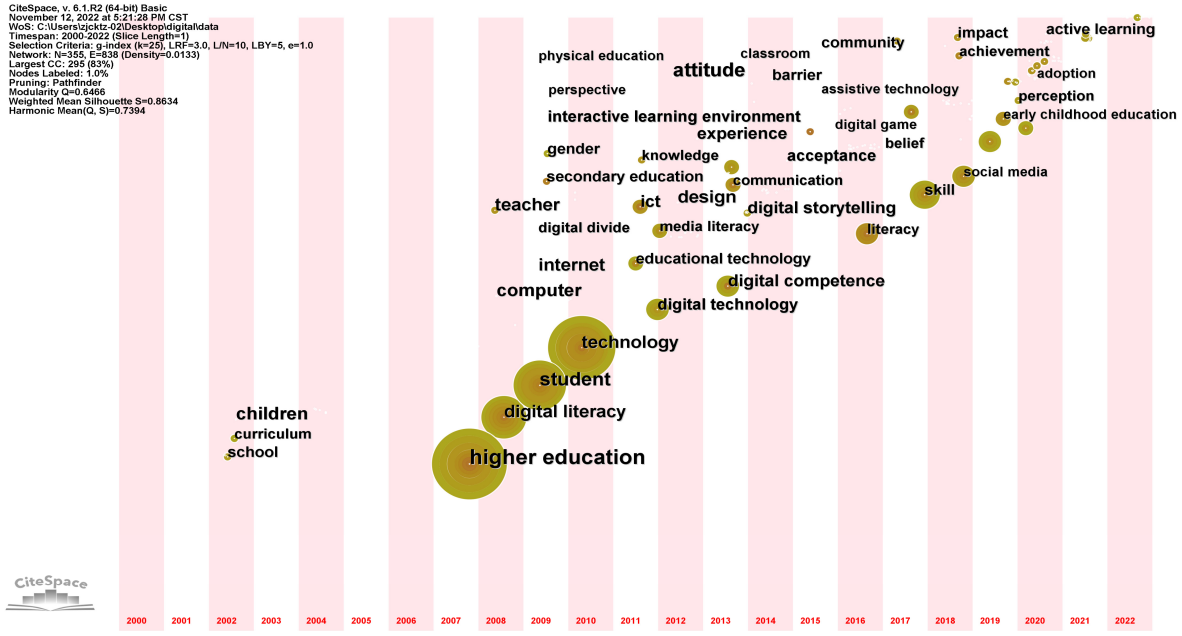

Figure 7. Keyword time zone map analysis.

Digital education focuses its research on pedagogical ecology, pedagogical environment, and pedagogical development [62–64]. Teaching ecology refers to a digital education teaching ecology formed by the variety of research fields and the connection between each research field in digital education. Pedagogical environment refers to the environmental guarantee for the realization of digital education, such as teaching resources, teaching tools, etc. Pedagogical development refers to the sustainable development and trending

topics of related fields in digital education. Digital education presents multidisciplinary and multidisciplinary coordination with a strong centrality, which serves the ultimate goal of the pedagogical ecology of digital education, which is to diversify pedagogical ecology. The planning and evaluation of digital education are oriented toward the pedagogical environment and pedagogical development, the use of digital tools for teaching objects to enhance learning activities, the coordination of the process of pedagogical activities of teachers and students, and ensuring the sustainability of the pedagogical ecology and the resources of the pedagogical environment of digital education [65]. The pedagogical environment is the vehicle and the basis on which digital education can be implemented, and the interaction of policies and economies in different countries or regions has led to changes in the development and structure of the digital education pedagogical environment [66,67].

3.3. Digital Education Research Frontiers and Trend Analysis

3.3.1. Digital Education Research Frontiers

The keyword co-occurrence clustering view of digital education was generated with the keywords of the cited references as nodes (Figure 8), and the maximum display in each node was the total number of citations. Q value represents the degree of modularity, and Q takes the value interval generally [0,1], the larger the value means that its clustering effect is better, if Q > 0.3, it indicates that the delineated clustering structure is significant. The network homogeneity evaluation index silhouette S (Silhouette), S $\geq$ 0.5 means that the clustering result is reasonable, and as the value of S is closer to 1, it reflects the higher homogeneity of the network [68]. Q = 0.6466 represents the significant modularity of the clustering network and S = 0.8634 represents the relatively high homogeneity of the network, yielding good results obtained from keyword clustering. In Figure 8, the 10 most representative and broadest clusters were analyzed, and these clusters fit the digital education domain more closely. To improve the directivity of the cluster analysis, only the five most frequently cited clusters with the highest homogeneity were presented, and then the highly relevant terms derived from these clusters were summarized (Table 3). Through in-depth reading and analysis of the frequently cited references in the core keyword clusters, we found the following five main research paths in the digital education research field today and sorted out the core contents.

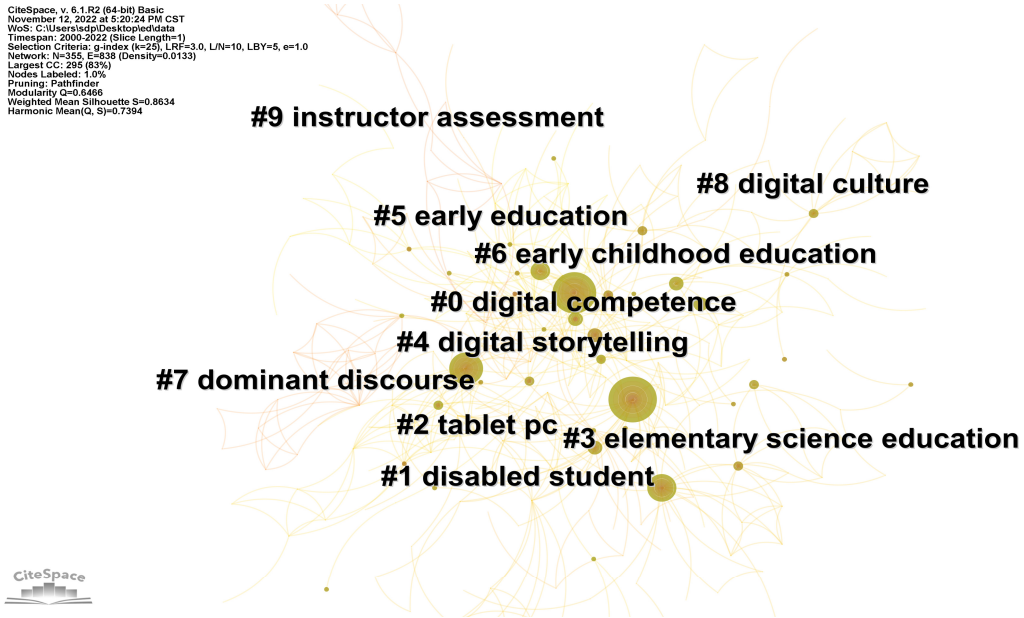

Figure 8. Keyword co-occurrence clustering view analysis.

Table 3. Keyword co-citation clustering (Top 5).

Cluster ID	Size	Silhouette	Mean (Year)	Core Terms
9	12	0.957	2010	art education; instructor assessment; learning experience; digital portfolio
4	28	0.917	2015	digital storytelling; digital game use; English-language learning; family literacy
1	36	0.914	2014	disabled student; right kind; complex relationship; changing teacher role; energy education
7	17	0.912	2012	dominant discourse; multicultural education; digital equity; Bogota Colombia
8	13	0.91	2015	digital culture; democratic citizenship; digital engagement; digital media literacy education

(1) Interdisciplinary development path

The main reason for the shift in the pedagogical perspective of digital education is the demand for new types of human resources in the new era, especially due to the development of information technology and big data modeling in recent years, which has driven the field of education gradually in the direction of digitalization. For example, the book *Education in a Digital World* states that education should be viewed from the perspective of digital technology and globalization [69]. This transformation has promoted the exchange between different disciplines and formed a form of digital education that has developed across disciplines. The terms analyzed in the above keyword clustering in this category are art education, multicultural education, digital storytelling, and English-language learning. Bolliger et al. surveyed Japanese students' perceptions of the use of digital games for English-language learning in higher education through a questionnaire and concluded that the majority of students believe that the use of digital games facilitates English-language learning [70]. Makhachashvili and Semenist conducted a comprehensive analysis of global interdisciplinary trends in digital education in the context of COVID-19 and found the interoperability of "soft skills" and digital communication skills across time and stages of liberal arts education [71]. In addition, Abdullayeva et al. suggest the possibility of an interdisciplinary transition to systematization [61].

(2) Educational Equity Development Pathways

In recent years a wide range of researchers have tended to focus on the development of systems such as teaching resources facilities and teaching opportunities to study educational equity. We can find different levels of research scope in clustering themes such as digital equity, disabled student, family literacy, etc. Resta and Laferrière [72] described the needs and challenges of the time in terms of digital equity and intercultural education and found that technology is helping to promote intercultural understanding and educational equity. Gorski argues that the first concern in the issue of educational equity needs to be the elimination of digital inequalities based on which the dominant discourse can be reconstructed if we are to achieve true multicultural education [73]. Eynon used a quantitative research approach to explore the digital divide in the UK. The study found that the reasons for important differences in learning outcomes between non-Internet users and Internet users were shaped mainly by different factors such as age, educational background, skills, attitudes, and experience [74]. To enhance educational equity practices, Prins [75] analyzed the DST curriculum in rural Ireland and concluded that the potential exists for the use of multimodal combined learning models in home learning and adult education to promote the development of educational equity.

(3) Digital Education Practices Research Pathways

Even though the practice environment for early digital education research was tough, some astute scholars found that digitalization is a new direction in education [76]. Kolesnikov conducted practical research on visualization and interaction support strategies for digital education from the perspective of human needs theory [77]. The above-mentioned cluster analysis shows that the advantages of digital education include the expansion of the boundaries of "self-directed learning", the development of leadership in the teaching environment, the creation of conditions for the formation of individual educational tra-

jectories of students, the modernization of tools for assessing students' knowledge, and the differentiation of teaching forms and methods [78]. In addition, according to a critical analysis of articles on the subject of practice research, the following potentially damaging consequences of digital education were identified: driving quality teachers with insufficient digital competencies out of education; information overload leading to redundancy; increase in cognitive distortions; deepening of the digital divide; increased formalization of education while becoming dehumanized; etc. Therefore, objectively confronting the strengths and weaknesses of digital education in practical studies on digital education is a must for the development of the field.

(4) Digital Education Evaluation Research Pathways

In recent years, a reliable and stable trend has played an important role in the development of the digital education research ecology; therefore, digital education evaluation research has become particularly important. Its research has focused on dynamic service evaluation and quantification of learning outcomes that guide and assist the teaching and learning process [79,80]. For example, children's perspectives on and experiences of using digital videos in elementary physical education classes were evaluated, and the impact of digital video use on learning motivation, feedback, self-assessment, and learning was then studied. The study concluded that the use of digital videos can enhance students' motivation, feedback, and performance during the learning process of physical education skills in elementary school [81]. One of the most difficult tasks in the field of art education is assessing students' artwork, and digital assessment can be a good solution to this dilemma. The use of digital portfolio assessment tools to assess student work is critical to how teachers develop workable criteria for assessment [82]. In exploring the impact of digital narratives on student motivation and satisfaction in EFL education, digital narratives were found to be an effective assessment tool that can be used in learning environments to support the development of students' language and digital skills [83].

(5) Digital Education Governance Research Path

The modernization of educational governance is an important part of the modernization of national governance, and the comprehensive implementation of educational governance is a major theoretical and practical issue that must be faced and solved to build a strong educational country. With the wide application of digital technology in education and the acceleration of digital education transformation, digital education governance has received attention from researchers in various countries. Dezuanni points out that while it is important for young people to develop creative and practical skills to produce their media, it is important for them to think critically about the technological context of digital media production, distribution, and use, and its impact on society and individuals is equally important [84]. Pérez points out that in the educational teaching process, teachers need to teach students not only how information and communication technology can be effectively applied, but also to develop civic literacy and a sense of responsibility [85]. Digital education governance requires not only the involvement of the state, educational administration, and schools, but also, in addition, digital education governance involves various aspects of education, such as educational evaluation and resource management [86]. In summary, the core of digital education governance is to focus on people; to promote the comprehensive, free, and personalized development of people; to create and open up new educational forms and scenarios; and to achieve the transition from "digital + education" to "education + digital" by addressing practical needs. In the process of promoting human development, the unique value of digitalization is brought into play, so that technology can serve human development.

3.3.2. Trending Topics in Digital Education Research

The citation explosion indicates that researchers are focusing on these articles [87]. In this paper, a visual analysis of SSCI database articles in the Web of Science (WOS) core collection using CiteSpace yielded references with strong citation bursts. Table 4 shows the

top 13 references with the strongest citation bursts (this paper is sorted by the onset of the citation bursts).

Table 4. Top 13 References with the strongest citation bursts. (stands for the initial letter is capitalized).

References	Year	Strength	Begin	End	2006–2022
Becta, 2008, Harnessing technology: Next generation learning 2008-14, V0, P0	2008	1.18	**2009**	2011	
Bennett S, 2008, BRIT J EDUC TECHNOL, V39, P775, DOI 10.1111/j.1467-8535.2007.00793.x, DOI	2008	2.3	**2011**	2013	
Jones C, 2010, COMPUT EDUC, V54, P722, DOI 10.1016/j.compedu.2009.09.022, DOI	2010	3.08	**2012**	2013	
Ala-mutka K, 2011, MAPPING DIGITAL COMP, V0, P7	2011	2.31	**2015**	2016	
Williamson B, 2016, J EDUC POLICY, V31, P123, DOI 10.1080/02680939.2015.1035758, DOI	2016	1.45	**2016**	2020	
Allais S, 2014, DOES MATRIC MEASURE, V0, P0	2014	1.15	**2016**	2017	
Adukaite A, 2016, J HOSP LEIS SPORT TO, V19, P54, DOI 10.1016/j.jhlste.2016.08.003, DOI	2016	1.24	**2017**	2018	
Organization for Economic Co-Operation and Development (oecd), 2015, STUD COMP LEARN MAK, V0, P0	2015	1.17	**2018**	2019	
Lupton D, 2015, SPORT EDUC SOC, V20, P122, DOI 10.1080/13573322.2014.962496, DOI	2015	2.07	**2019**	2020	
Williamson B, 2017, BIG DATA ED DIGITAL, V0, P0, DOI 10.4135/9781529714920, DOI	2017	2.07	**2019**	2020	
Van LAARE, 2017, COMPUT HUM BEHAV, V72, P577, DOI 10.1016/j.chb.2017.03.010, DOI	2017	3.22	**2020**	2022	
Bond M, 2018, INT J EDUC TECHNOL H, V15, P0, DOI 10.1186/s41239-018-0130-1, DOI	2018	1.41	**2020**	2022	
Robertson SL, 2019, COMP METHODOLOGY ERA, V0, P169	2019	1.41	**2020**	2022	

The dark green line in Table 4 indicates the citation timeline for a particular citation burst, the period for each citation burst is presented as a red line, and "strongest" indicates the sudden growth rate of the citation [53]. As can be seen from the figure, the citation bursts started as early as 2009 [88]. The strongest citation burst is associated with a review article published by Van LAARE in 2017, which focuses on the relationship between 21st-century skills and digital skills or literacy [89]. The article noted that 21st-century skills are broader than digital skills and that in addition to skills, knowledge and attitudes are considered critical for students to succeed in the learning process. Moreover, 21st-century skills are not necessarily based on information and communication technology (ICT), whereas digital skills need to be developed by relying on information and communication technology

(ICT). Both 21st-century skills and digital skills tend to focus on the skill level of citizens or students rather than on the skill level of the workforce.

In the last decade or so of digital education research, digital skills (3.22) [89] and the online generation or digital natives (3.08) [90] have been the two research themes with the highest mutational intensity. Digital education research during the period 2009–2013 focused mainly on discussing the meaning of digital natives, a period in which different researchers held different views on the meaning of digital natives [90,91]. During 2015–2019, with the development of digital education and the deep integration of digital technologies represented by artificial intelligence, blockchain, cloud computing, and big data in the field of education, the need strengthen the capacity of digital governance in education became more urgent. Therefore, the research related to digital education governance, digital technology, and digital capacity during this period has become a focus of researchers' attention [92–94]. Since 2020, due to the COVID-19 pandemic and the widespread use of new digital technologies in the education field, new learning environments have been innovated, changing the way of educational information dissemination while triggering educational teaching model changes. While researchers in this period have continued to focus on digital technology, digital literacy, and digital education governance, they have also focused on research related to digital education transformation and interactive digital teaching and learning [95–98].

4. Conclusions

This article used the CiteSpace (6.1.R2) tool to perform a statistical analysis of the research papers related to digital education in an econometric and scientific manner and presents it visually, which is useful for analyzing the current situation of the research field of digital education. The article focused on the visual analysis of authors, several publications, countries, journal institutions, keywords, and citations. The results of the study show that the annual number of articles published in digital education research worldwide has been increasing continuously since 2000 and has shown a phased development. This is similar to the results of other digital education studies. For example, Bozkurt conducted a data mining and visualization analysis for digital awareness education and found a sudden increase in educational technology-related literature after 1993, pointing out the characteristics of the phases of digital education development and exploring the possibility of interdisciplinary development of digital education [99]. As the number of publications in this field continues to increase, it indicates the growing research interest in digital education among relevant researchers worldwide.

At the level of countries, institutions, journals, and authors, it was found that the attention of digital education research is mainly influenced by macro factors such as national policies, and economic and educational structures. Digital education research has been conducted in a variety of disciplines, including education, economics, computer science, mathematics, and digital sociology, and the current state of research is interdisciplinary. More and more institutions and journals are exploring digital education research, and the links between them are getting closer. However, there are fewer collaborative exchanges among posting authors at the moment, but there has been a gradual trend toward teamwork.

A visual analysis of highly cited literature and keywords revealed that the research hotspots of digital education are mainly interdisciplinary field practice research- and adaptive education research-based on big data support. In particular, the influence of COVID-19 makes it possible for digital education research to transform into wisdom education. In terms of information technology, it involves aspects such as neural network algorithms and big data computing. In terms of pedagogical theory, digital education research based on big data support can provide students with a more scientific adaptive learning approach that is in line with their cognitive development. In addition, under the influence of the epidemic, a large digital divide can be formed in the educational practices of different countries or regions. Therefore, it is necessary to conduct teaching and learning

practices of digital education in the present time. The human-computer interdisciplinary teaching model is a global trend, and big data technology is used as a guide for teaching and learning research design.

The research in this paper can be integrated with big data from actual teaching and learning to promote the implementability and effectiveness of human–computer integrated teaching and learning. Today, many educational researchers compare digital education instruction with other educational instructional approaches, and research has shown that research on instructional practices in digital education is executable and effective.

Statistical analysis showed that there is a lack of comprehensive bibliometric research in the field of digital education research. This paper explored the current status and development of research in the field of digital education, which provides relevant information on author research teams, institutional groups, journal distribution, institutions, and countries. Finally, this paper provides an objective forecast of the research trends in digital education as a reference for subsequent research.

5. Limitations and Future Work

Although this study systematically analyzed the latest developments in digital education research, there were still some limitations. First, the limited amount of literature analyzed. We only analyzed articles from the SSCI database and they were all written in English, ignoring articles written in other languages and articles included in other databases, and the depth and comprehensiveness of the analysis were insufficient. Second, we only analyzed the literature and lacked some empirical evidence of the literature findings. When applying the CiteSpace tool for co-citation clustering, there were 10 clustering samples, and we only analyzed the research paths of 5 clusters with more citations and higher homogeneity, and the analysis was somewhat subjective. Understanding more specific research paths requires more intensive reading of the literature and more in-depth research and analysis on this basis. These shortcomings will be further addressed and analyzed in our subsequent studies.

Author Contributions: All authors confirm they have contributed to the preparation of this article. D.Y. and J.Z. proposed the structure of the study together. D.Y. performed the data analysis and completed the paper. D.S. downloaded the bibliography on WOS, analyzed the literature with CiteSpace, and wrote parts of Section 2. D.W., J.L. and J.Z. provided constructive suggestions for the study. X.C. and Q.P. performed checks and revisions. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by the National Natural Science Foundation of China (No. 61862051), the Science and Technology Foundation of Guizhou Province (No. [2019]1299), the Top-Notch Talent Program of Guizhou province (No. KY[2018]080), the Natural Science Foundation of Education of Guizhou province (No. [2019]203), the Guizhou Educational Science Planning Project under Grant (No. 2021B201, No. 2022B056), the Qianan Educational Science Planning Project under Grant (No. 2021B001), the Qiannan Theoretical Innovation of Philosophy and Social Sciences (No. Qnsk2022092) and the Funds of Qiannan Normal University for Nationalities (No. qnsy2019rc09, No. qnsyxk201807, No. 2021gh19).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Çınar, M.; Ekici, M.; Demir, Ö. A snapshot of the readiness for e-learning among in-service teachers prior to the pandemic-related transition to e-learning in Turkey. *Teach. Teach. Educ.* **2021**, *107*, 103478. [CrossRef]
2. Balyer, A.; Öz, Ö. Academicians' Views on Digital Transformation in Education. *Int. Online J. Educ. Teach* **2018**, *5*, 809–830.
3. Fawns, T. Postdigital education in design and practice. *Postdigital Sci. Educ.* **2019**, *1*, 132–145. [CrossRef]
4. Putman, B.W. *Digital Electronics: Theory, Applications, and Troubleshooting*; Prentice Hall: Hoboken, NJ, USA, 1986.

5. Cookson, P.S. Implications of Internet technologies for higher education: North American perspectives. *Open Learn. J. Open Distance E-Learn.* **2000**, *15*, 71–80. [CrossRef]
6. Towndrow, P. The impact of digital education on TESOL. *Comput. Assist. Lang. Learn.* **1999**, *12*, 157–162. [CrossRef]
7. Clark, R.C.; Mayer, R.E. *E-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning*; John Wiley Sons: Hoboken, NJ, USA, 2016.
8. Bayne, S. What's the matter with 'technology-enhanced learning'? *Learn. Media Technol.* **2015**, *40*, 5–20. [CrossRef]
9. Kirkwood, A.; Price, L. Technology-enhanced learning and teaching in higher education: What is 'enhanced'and how do we know? A critical literature review. *Learn. Media Technol.* **2014**, *39*, 6–36. [CrossRef]
10. Car, J.; Carlstedt-Duke, J.; Car, L.T.; Posadzki, P.; Whiting, P.; Zary, N.; Atun, R.; Majeed, A.; Campbell, J.; Digital Health Education Collaboration. Digital education in health professions: The need for overarching evidence synthesis. *J. Med. Internet Res.* **2019**, *21*, e12913. [CrossRef]
11. Oliver, M.; Trigwell, K. Can 'blended learning' be redeemed? *E-Learn. Digit. Media* **2005**, *2*, 17–26. [CrossRef]
12. Oliver, R.; Herrington, J. Teaching and Learning Online: A Beginner's Guide to e-Learning and e-Teaching in Higher Education. 2001. Available online: https://ro.ecu.edu.au/ecuworks/6832/ (accessed on 10 November 2022).
13. Sousa, M.J.; Rocha, Á. Digital learning: Developing skills for digital transformation of organizations. *Future Gener. Comput. Syst.* **2019**, *91*, 327–334. [CrossRef]
14. Zhu, Z.T.; Hu, J. The practical logic and development opportunities of Education Digital Transformation. *e-Educ. Res.* **2022**, *1*, 5–15. [CrossRef]
15. Agostino, D.; Arnaboldi, M.; Lema, M.D. New development: COVID-19 as an accelerator of digital transformation in public service delivery. *Public Money Manag.* **2021**, *41*, 69–72. [CrossRef]
16. Spector, J.M. Conceptualizing the emerging field of smart learning environments. *Smart Learn. Env.* **2014**, *1*, 2. [CrossRef]
17. Goldie, J.G.S. Connectivism: A knowledge learning theory for the digital age? *Med. Teach.* **2016**, *38*, 1064–1069. [CrossRef]
18. Puncreobutr, V. Education 4.0: New challenge of learning. *St. J. Humanit. Soc. Sci.* **2016**, *2*, 92–97.
19. Assunção Flores, M.; Gago, M. Teacher education in times of COVID-19 pandemic in Portugal: National, institutional and pedagogical responses. *J. Educ. Teach* **2020**, *46*, 507–516. [CrossRef]
20. Schlenker, L. Mobile Pedagogy. *Int. Assoc. Dev. Inf. Soc.* **2013**.
21. Burden, K.; Kearney, M.; Schuck, S.; Hall, T. Investigating the use of innovative mobile pedagogies for school-aged students: A systematic literature review. *Comput. Educ.* **2019**, *138*, 83–100. [CrossRef]
22. Commonwealth Schools Commission. *Teaching, Learning and Computers: 1984 Information Kit*; Commonwealth Schools Commission: London, UK, 1984. [CrossRef]
23. Australia, Department of Education, Skills and Employment. Foundation Skills for Your Future program: Digital Literacy Skills Framework. April 2020; p. 47. Available online: https://www.voced.edu.au/content/ngv:87487 (accessed on 10 November 2022).
24. Bakia, M. *Future Ready Schools: Building Technology Infrastructure for Learning*; Office of Educational Technology, US Department of Education: Washington, DC, USA, 2014.
25. Howard, T.C. *Why Race and Culture Matter in Schools: Closing the Achievement Gap in America's Classrooms*; Teachers College Press: New York, NY, USA, 2019.
26. Crompton, H. *ISTE Standards for Educators: A Guide for Teachers and Other Professionals*; Teaching & Learning Faculty Books; ISTE: Eugene, OR, USA, 2017; p. 24.
27. Berger, P.; Wolling, J. They need more than technology-equipped schools: Teachers' practice of fostering students' digital protective skills. *Media Commun.* **2019**, *7*, 137–147. [CrossRef]
28. Hesse, F.W.; Kobsda, C.; Leiser, A. (Eds.) *Digital Transformation of Higher Education-Global Learning Report 2021*; Global Learning Council: Berlin, Germany, 2021. [CrossRef]
29. Tarakanov, V.V.; Inshakova, A.O.; Dolinskaya, V.V. Information society, digital economy and law. In *Ubiquitous Computing and the Internet of Things: Prerequisites for the Development of ICT.*; Springer: Cham, Switzerland, 2019; pp. 3–15. [CrossRef]
30. Yakovleva, E.; Druzhinina, N.N.; Krasilova, I.Y.; Voiteleva, G.V. New Format for Improving the Digital Competence of Older Teachers in Primary General Education. *ARPHA Proc.* **2020**, *3*, 2771. [CrossRef]
31. Sepúlveda, A. *The Digital Transformation of Education: Connecting Schools, Empowering Learners*; UNESCO Digital Library: London, UK, 2020; p. 249.
32. Yanli, X.; Danni, L. Prospect of Vocational Education under the Background of Digital Age: Analysis of European Union's "Digital Education Action Plan (2021–2027)". In Proceedings of the 2021 International Conference on Internet, Education and Information Technology (IEIT), Suzhou, China, 16–18 April 2021; pp. 164–167. [CrossRef]
33. Zhu, Z.T.; Hu, J. The theoretical framework of Education Digital Transformation. *J. Chin. Soc. Educ.* **2022**, *4*, 41–49.
34. Lin, C.; Yan, L. Policy Analysis of education digitization reform in Australia. *Chin. J. ICT Educ.* **2022**, *7*, 32–40.
35. Marsilio, M.; Cappellaro, G.; Cuccurullo, C. The intellectual structure of research into PPPS: A bibliometric analysis. *Public Manag. Rev.* **2011**, *13*, 763–782. [CrossRef]
36. Fu, L.; Mao, S.; Chen, F.; Zhao, S.; Su, W.; Lai, G.; Yu, A.; Lin, C.T. Graphene-based electrochemical sensors for antibiotic detection in water, food and soil: A scientometric analysis in CiteSpace (2011–2021). *Chemosphere* **2022**, *297*, 134127. [CrossRef] [PubMed]

37. Alotaibi, H.S. An Exploration of Authorial Stance in SSCI-ranked Journals versus Non-SSCI-ranked Journals. *3L Southeast Asian J. Engl. Lang. Stud.* **2019**, *25*, 5. [CrossRef]
38. Mei, W.S. The use of engagement resources in high- and low-rated undergraduate geography essays. *J. Engl. Acad. Purp.* **2007**, *6*, 254–271. [CrossRef]
39. Chadegani, A.A.; Salehi, H.; Yunus, M.M.; Farhadi, H.; Fooladi, M.; Farhadi, M.; Ebrahim, N.A. A comparison between two main academic literature collections: Web of Science and Scopus databases. *arXiv* **2013**, arXiv:1305.0377. [CrossRef]
40. Chen, C. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 359–377. [CrossRef]
41. Upham, S.; Small, H. Emerging research fronts in science and technology: Patterns of new knowledge development. *Scientometrics* **2010**, *83*, 15–38. [CrossRef]
42. Zhang, Q.; Rong, G.; Meng, Q.; Yu, M.; Xie, Q.; Fang, J. Outlining the keyword co-occurrence trends in Shuanghuanglian injection research: A bibliometric study using CiteSpace III. *J. Tradit. Chin. Med. Sci.* **2020**, *7*, 189–198. [CrossRef]
43. Zhang, J.; Cenci, J.; Becue, V.; Koutra, S.; Ioakimidis, C.S. Recent evolution of research on industrial heritage in Western Europe and China based on bibliometric analysis. *Sustainability* **2020**, *12*, 5348. [CrossRef]
44. Serenko, A.; Bontis, N.; Booker, L.; Sadeddin, K.; Hardie, T. A scientometric analysis of knowledge management and intellectual capital academic literature (1994–2008). *J. Knowl. Manag.* **2010**, *14*, 3–23. [CrossRef]
45. Xiao, L.; Yang, Y.J.; Liu, Q.; Peng, J.; Yan, J.F.; Peng, Q.H. Visualizing the intellectual structure and recent research trends of diabetic retinopathy. *Int. J. Ophthalmol.* **2021**, *14*, 1248. [CrossRef] [PubMed]
46. Selwyn, N. The digital native–myth and reality. In *Aslib Proceedings*; Emerald Group Publishing Limited: Bingley, UK, 2009. [CrossRef]
47. Selwyn, N. Making sense of young people, education and digital technology: The role of sociological theory. *Oxf. Rev. Educ.* **2012**, *38*, 81–96. [CrossRef]
48. Selwyn, N. The use of computer technology in university teaching and learning: A critical perspective. *J. Comput. Assist. Learn.* **2007**, *23*, 83–94. [CrossRef]
49. Selwyn, N. Web 2.0 Applications as Alternative Environments for informal Learning—A Critical Review. In *Paper for CERI-KERIS International Expert Meeting on ICT and Educational Performance; Institute of Education*; University of London: London, UK, October 2007; Volume 16, p. 17.
50. Selwyn, N. An investigation of differences in undergraduates' academic use of the internet. *Act. Learn. High. Educ.* **2008**, *9*, 11–22. [CrossRef]
51. Colombo, G.B.; Burnap, P.; Hodorog, A.; Scourfield, J. Analysing the connectivity and communication of suicidal users on twitter. *Comput. Commun.* **2016**, *73*, 291–300. [CrossRef]
52. Chaomei CH, E.N.; Leydesdorff, L. Patterns of connections and movements in dual-map overlays: A new method of publication portfolio analysis. *J. Assoc. Inf. Sci. Technol.* **2014**, *65*, 334. [CrossRef]
53. Shi, D.; Zhou, J.; Wang, D.; Wu, X. Research Status, Hotspots, and Evolutionary Trends of Intelligent Education from the Perspective of Knowledge Graph. *Sustainability* **2022**, *14*, 10934. [CrossRef]
54. Pillay, N.; Maharaj, B.T.; van Eeden, G. AI in engineering and computer science education in preparation for the 4th industrial revolution: A South African perspective. In Proceedings of the 2018 World Engineering Education Forum-Global Engineering Deans Council (WEEF-GEDC), Albuquerque, NM, USA, 12–16 November 2018; pp. 1–5. [CrossRef]
55. Li, S.; Wang, Y. Research on interdisciplinary characteristics: A case study in the field of artificial intelligence. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *677*, 052023. [CrossRef]
56. Goundar, S.; Purwar, A.; Singh, A. (Eds.) *Applications of Artificial Intelligence, Big Data and Internet of Things in Sustainable Development*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2022. [CrossRef]
57. Romero, C.; Ventura, S. Educational data mining and learning analytics: An updated survey. *WIREs Data Min. Knowl. Discov.* **2020**, *10*, 1355. [CrossRef]
58. Siedlok, F.; Hibbert, P. The Organization of Interdisciplinary Research: Modes, Drivers and Barriers. *Int. J. Manag. Rev.* **2013**, *16*, 194–210. [CrossRef]
59. Liu, M.; McKelroy, M.; Corliss, S.B.; Carrigan, J. Investigating the effect of an adaptive learning intervention on students' learning. *Educ. Tech. Res. Dev.* **2017**, *65*, 1605–1625. [CrossRef]
60. Li, Y. Innovative Development Based on Educational Technology in the Era of Big Data. In *Frontier Computing. FC 2021*; Lecture Notes in Electrical Engineering; Hung, J.C., Yen, N.Y., Chang, J.W., Eds.; Springer: Singapore, 2022; Volume 827. [CrossRef]
61. Mahamadjanovna, A.N.; Zievadinovich, U.N.; Obidovna, K.M.; Kizi, N.K.I. Use of Educational Technologies to Increase the Effectiveness of Natural Education. (Integrated Integrated Education and Technological Steam). *Ann. Rom. Soc. Cell Biol.* **2021**, *25*, 1155–1161.
62. Fawns, T.; Aitken, G.; Jones, D. Ecological Teaching Evaluation vs the Datafication of Quality: Understanding Education with, and Around, Data. *Postdigit. Sci. Educ.* **2021**, *3*, 65–82. [CrossRef]
63. Paesani, K. Teacher professional development and online instruction: Cultivating coherence and sustainability. *Foreign Lang. Ann.* **2020**, *53*, 292–297. [CrossRef]
64. Sun, M.; Li, Y. Eco-Environment Construction of English Teaching Using Artificial Intelligence Under Big Data Environment. *IEEE Access* **2020**, *8*, 193955–193965. [CrossRef]

65. Park, H.Y.; Licon, C.V.; Sleipness, O.R. Teaching Sustainability in Planning and Design Education: A Systematic Review of Pedagogical Approaches. *Sustainability* **2022**, *14*, 9485. [CrossRef]
66. Codd, J. Teachers as "managed professionals" in the global education industry: The New Zealand experience. *Educ. Rev.* **2005**, *57*, 193–206. [CrossRef]
67. Vasilev, V.L.; Gapsalamov, A.R.; Akhmetshin, E.M.; Bochkareva, T.N.; Yumashev, A.V.; Anisimova, T.I. Digitalization peculiarities of organizations: A case study. *Entrep. Sustain. Issues* **2020**, *7*, 3173–3190. [CrossRef]
68. Wu, Y.; Wang, H.; Wang, Z.; Zhang, B.; Meyer, B.C. Knowledge mapping analysis of rural landscape using CiteSpace. *Sustainability* **2019**, *12*, 66. [CrossRef]
69. Selwyn, N. *Education in a Digital World: Global Perspectives on Technology and Education*, 1st ed.; Routledge: London, UK, 2012. [CrossRef]
70. Bolliger, D.U.; Mills, D.; White, J.; Kohyama, M. Japanese students' perceptions of digital game use for English-language learning in higher education. *J. Educ. Comput. Res.* **2015**, *53*, 384–408. [CrossRef]
71. Makhachashvili, R.; Semenist, I. Interdisciplinary trends of digital education in the COVID-19 paradigm: Global event horizon. *J. Syst. Cybern. Inform.* **2021**, *19*, 57–64. [CrossRef]
72. Resta, P.; Laferrière, T. Digital equity and intercultural education. *Educ. Inf. Technol.* **2015**, *20*, 743–756. [CrossRef]
73. Gorski, P.C. Insisting on digital equity: Reframing the dominant discourse on multicultural education and technology. *Urban Educ.* **2009**, *44*, 348–364. [CrossRef]
74. Eynon, R. Mapping the digital divide in Britain: Implications for learning and education. *Learn. Media Technol.* **2009**, *34*, 277–290. [CrossRef]
75. Prins, E. Digital storytelling in adult education and family literacy: A case study from rural Ireland. *Learn. Media Technol.* **2016**, *42*, 308–323. [CrossRef]
76. Dinis Sousa, R.; Karimova, B.; Gorlov, S. Digitalization as a New Direction in Education Sphere. *E3S Web Conf.* **2020**, *159*, 09014. [CrossRef]
77. Kolesnikov, A.M.; Lomachenko, T.I.; Kokodey, T.A.; Khitushchenko, V.V.; Mihailov, Y.I. A Strategy of Visualization and Interactive Support for University Level Educational Digitalization. In Proceedings of the 2019 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus), Moscow, Russia, 28–30 January 2019. [CrossRef]
78. Frolova, E.V.; Rogach, O.V.; Ryabova, T.M. Digitalization of education in modern scientific discourse: New trends and risks analysis. *Eur. J. Contemp. Educ.* **2020**, *9*, 313–336.
79. Neumann, R. Communicating Student Evaluation of Teaching Results: Rating Interpretation Guides (RIGs). *Assess. Eval. High. Educ.* **2000**, *25*, 121–134. [CrossRef]
80. Dindar, M.; Alikhani, I.; Malmberg, J.; Järvelä, S.; Seppänen, T. Examining shared monitoring in collaborative learning: A case of a recurrence quantification analysis approach. *Comput. Hum. Behav.* **2019**, *100*, 335–344. [CrossRef]
81. O'Loughlin, J.; Chróinín, D.N.; O'Grady, D. Digital video: The impact on children's learning experiences in primary physical education. *Eur. Phys. Educ. Rev.* **2013**, *19*, 165–182. [CrossRef]
82. Dikici, A. An application of digital portfolio with the peer, self and instructor assessments in art education. *Eurasian J. Educ. Res.* **2009**, *9*, 91–108.
83. Hava, K. Exploring the role of digital storytelling in student motivation and satisfaction in EFL education. *Comput. Assist. Lang. Learn.* **2021**, *34*, 958–978. [CrossRef]
84. Ezuanni, M. Re-visiting the Australian Media Arts curriculum for digital media literacy education. *Aust. Educ. Res.* **2021**, *48*, 873–887. [CrossRef]
85. Pérez, V.G. Education for Democratic Citizenship in a Digital Culture. Comunicar. *Media Educ. Res. J.* **2011**, *19*, 4. [CrossRef]
86. Yuan, Z.G. Education governance under the vision of digital transformation. *J. Chin. Soc. Educ.* **2022**, *8*, 1–6,18.
87. Su, H.N.; Lee, P.C. Mapping knowledge structure by keyword co-occurrence: A first look at journal papers in Technology Foresight. *Scientometrics* **2010**, *85*, 65–79. [CrossRef]
88. Becta. *Harnessing Technology: Next Generation Learning 2008–14*; Becta: Coventry, UK, 2008.
89. Van Laar, E.; Van Deursen, A.J.; Van Dijk, J.A.; De Haan, J. The relation between 21st-century skills and digital skills: A systematic literature review. *Comput. Hum. Behav.* **2017**, *72*, 577–588. [CrossRef]
90. Jones, C.; Ramanaua, R.; Cross, S.; Healing, G. Net generation or Digital Natives: Is there a distinct new generation entering university? *Comput. Educ.* **2010**, *543*, 722–732. [CrossRef]
91. Bennett, S.; Maton, K.; Kervin, L. The 'digital natives' debate: A critical review of the evidence. *Br. J. Educ. Technol.* **2008**, *39*, 775–786. [CrossRef]
92. Williamson, B. Digital education governance: Data visualization, predictive analytics, and 'real-time' policy instruments. *J. Educ. Policy* **2016**, *31*, 123–141. [CrossRef]
93. Adukaite, A.; Van Zyl, I.; Cantoni, L. The role of digital technology in tourism education: A case study of South African secondary schools. *J. Hosp. Leis. Sport Tour. Educ.* **2016**, *19*, 54–65. [CrossRef]
94. Redecker, C. European Framework for the Digital Competence of Educators: DigCompEdu (No. JRC107466). Joint Research Centre (Se-ville Site). 2017. Available online: https://ideas.repec.org/p/ipt/iptwpa/jrc107466.html (accessed on 10 November 2022).
95. Vial, G. Understanding digital transformation: A review and a research agenda. *Manag. Digit. Transform.* **2021**, 13–66. [CrossRef]

96. Bond, M.; Marín, V.I.; Dolch, C.; Bedenlier, S.; Zawacki-Richter, O. Digital transformation in German higher education: Student and teacher perceptions and usage of digital media. *Int. J. Educ. Technol. High. Educ.* **2018**, *15*, 1–20. [CrossRef]
97. Robertson, S.L. Interactive digital instruction: Pedagogy of the 21st century classroom. In *Handbook of Research on Promoting Higher-Order Skills and Global Competencies in Life and Work*; IGI Global: Hershey, PA, USA, 2019; pp. 166–180. [CrossRef]
98. Cattaneo, A.A.; Antonietti, C.; Rauseo, M. How digitalised are vocational teachers? Assessing digital competence in vocational education and looking at its underlying factors. *Comput. Educ.* **2022**, *176*, 104358. [CrossRef]
99. Bozkurt, A. Educational Technology Research Patterns in the Realm of the Digital Knowledge Age. *J. Interact. Media Educ.* **2020**, *1*, 18. [CrossRef]