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Visualizing research trends and research theme evolution in E-learning field: 1999–2018

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Abstract
This paper aims to provide a comprehensive understanding of the evolution of major research themes and trends in e-learning research. A co-word analysis is applied for the analysis of the 21,656 keywords collected from 7214 articles published in 10 journals in the field of e-learning from the years 1999 to 2018. Specifically, a cluster analysis, social network analysis, strategic diagram, and graph theory were applied in the analysis for two time periods: 1999–2008 and 2009–2018. The study detects the bridging, popular, and core topics in e-learning research for the two periods. The research results indicate that e-learning research has undergone a health evolution over the past two decades. There is a temporal continuity of e-learning research because some research topics have kept their continuity over the studied 20 years. Meanwhile, the research traditions in the e-learning field are also continuously evolving with the development of new technologies. The results also offer useful hints on the future direction of how the field may evolve.

Keywords E-learning · Co-word analysis · Research theme · Research trends

Introduction

Since the inception of personal computers, electronic learning (e-learning) has been a hot topic in research and practice for several decades. E-learning employs telecommunication technologies to deliver knowledge for the purpose of training and learning (Chou and Pi 2015; Choudhury and Pattnaik 2020). Numerous learners have benefited from e-learning, and countless educators and technicians have dedicated themselves to making e-learning more favorable

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for teaching and learning. Such endeavors, accompanied by a rapid advance of web, multimedia, and Internet technologies, have transformed e-learning, making it a highly dynamic and fast-evolving discipline.

Over the past two decades, the number of studies on e-learning has been expanding greatly. Scholars have explained that e-learning is technology driven, delivery system oriented, and communication oriented in nature (Arkorful and Abaidoo 2015; Rodrigues et al. 2019). As a result, academics have investigated e-learning from various perspectives, producing a diversity of topics discussed. Scholars from various backgrounds have added their own expertise to e-learning research, making it one of the most fruitful and dynamic disciplines of all the scientific communities.

The rapid advance and evolution of research topics over the past decades—along with calls for a need to examine how knowledge has been accumulated in the field, developed, and evolved—has come with a need to identify the most important research topics in the field of e-learning. Such effort can serve as important evidence to document the development of the field and to identify new research trends for freshman researchers.

Previous studies have made a few important attempts to scrutinize a specific theme in e-learning research, such as that of workplace e-learning (Cheng et al. 2014), learning style (Özyurt and Özyurt 2015), digital collaborative learning in nursing education (Männistö et al. 2020), evaluation of e-learning in medicine education for postgraduates (De Leeuw et al. 2019) and in low- and middle-income countries (Barteit et al. 2020), gamification in e-learning (Antonaci et al. 2019), and mobile learning for language learning (Elaish et al. 2019). Even though these research endeavors have provided scholars with an improved understanding of a certain research theme in e-learning, a more comprehensive understanding of the overall picture and development of research themes in the field—here being built upon recent literature—is missing. To fill in the above research void, we analyze over 7200 research papers that were published as early as 1999, aiming to identify the evolution of important research topics and to reveal key research trends, structural characteristics, and interconnections between different research themes in the field. We also attempt to identify the important contributions of different e-learning outlets to the development of particular research topics and themes over the past 20 years. Specifically, the current study was designed to answer the following research questions: (1) How do different e-learning outlets contribute to the knowledge diversity in the e-learning field? (2) What are the main research themes over the past 20 years? (3) Based on a comparison of knowledge structures of the two different development periods of e-learning (1999–2008 and 2009–2018), how did the research themes evolve? We collected the keywords of articles published at 10 major e-learning outlets between 1999 and 2018. A clustering method, social network analysis, and strategic diagram to visualize a knowledge map were utilized to analyze the network of keywords.

The remainder of the current paper is organized as follows: The literature review section summarizes past studies in the e-learning field. Subsequently, the research methods applied in the current study are discussed. After that, we present the research results and discuss the main findings. Finally, we conclude the paper with a discussion on the contribution of the present study and its potential limitations before giving probable avenues for future research.

Research background

As an important scientific discipline, e-learning has a long history. We have witnessed the development of e-learning from a computer-based system to a multimedia environment and to Web 2.0 and 3.0 (Choudhury and Pattnaik 2020). Different forms of information and communication technologies have also been integrated into e-learning practices, such as social media, augmented/virtual reality, 3D, and wearable devices. Evidently, the rapid and constant advancement of educational technologies have steered the development of e-learning practice and research, which might have also led to both the emerging new research topics as well as the fading old ones which lost their importance in e-learning field.

A few studies have attempted to analyze the knowledge structure and the research trends in the e-learning field. By analyzing 890 articles published in the 1990s from four main distance education journals, Berge and Mrozowski (2001) found that pedagogical themes, such as learner characteristics, design issues, and strategies for active learning and increased interactivity, dominate the research in the e-learning field. Shih et al. (2008) conducted a content analysis of the articles published at four journals from 2001 to 2005 in the field of cognition in e-learning, revealing that instructional approaches, information processing, and motivation in e-learning are the three most popular research topics in e-learning field (Shih et al. 2008). Based on a study of a total of 689 peer-reviewed articles published between 2000 and 2008, Hung (2012) investigated the longitudinal trends of e-learning research via text mining techniques, and reported that e-learning research has shifted from a foci on the effectiveness of e-learning to teaching and learning practices and that e-learning research is still at its early stage (Hung 2012). Cheng et al. (2014) conducted a bibliometric analysis of 324 articles published between 2000 and 2012 on workplace e-learning; they found that continuing education and professional development, e-learning in the healthcare sector, the use of social media, and integration of knowledge management were the four main research themes (Cheng et al. 2014). Chang et al. (2018) investigated the trend of mobile learning applications in nursing education based on a meta-analysis of journal articles published between 1971 and 2016. They noted that the application of mobile technologies in nursing education has increased during the investigated period, while the relevant research topics have also become more and more diverse (Chang et al. 2018). Chen et al. (2020) also investigated the latent topics and research trends in educational technologies over the past four decades via structural topic modelling based on 3963 articles published in journal Computer and Education between 1976 and 2018. Evidently, even though prior research has investigated a specific theme of e-learning, a more comprehensive study on more recent literature that looks at the overall picture of the evolution of the e-learning research topic and research trends is lacking.

Research methods

Co-word analysis

A co-word analysis is a bibliometric technique used to analyze and illustrate the evolution of the structure of the concepts and ideas within a research field; this is done based on a co-occurrence analysis (Callon et al. 1983, 1991) It has been widely applied to identify the knowledge structure in numerous domains, such as information systems

(Liu et al. 2016), information science (Deng et al. 2020; Hu et al. 2013), operation research and management science (Chen et al. 2019) and higher education (Dehdarirad et al. 2014). In line with these studies, a co-word analysis was applied in the current study.

A co-word analysis exhibits at least two methodological advantages. First, Callon et al. (1986) stated that the co-word approach can help trace the evolution of research topics and distinguish them from those research topics that have quickly disappeared in a research domain; this approach also helps uncover the links between the research topics in a network of a research domain. Second, a co-word analysis can facilitate the identification of the knowledge structure of a research field directly because the approach is built upon analyzing the scientific content of publications (He 1999).

Data

The research data included in the current study were collected from 10 major journals in the e-learning field. To obtain a complete pool of the e-learning literature, 20 journals from the Q1 level (top 20) journals in SCImago Journal Rank (SJR) 2017 in the category of e-learning were identified. After excluding the journals not related to e-learning (e.g., New Review of Academic Librarianship) and without keywords in articles (e.g., British Journal of Educational Technology), a total of 10 journals were retained (see Table 1). We only extracted the articles published within 20 years between the years 1999 and 2018. As a result, a total of 7214 articles were collected in this research, and 21,656 keywords were collected from these articles.

To obtain more precise results, we standardized the keywords included in this study in the following ways: (1) merging synonyms (e.g., multimedia systems and hypermedia systems; mobile phones and cell phones; and innovation diffusion and diffusion of innovation, virtual lab and virtual laboratory), abbreviations (e.g., massive open online courses and MOOCs; technology acceptance model and TAM), and singular and plural forms of gerunds and nouns (e.g., learning community and learning communities, social network site and social network sites); (2) filtering out keywords that are too general to be representative of topics (e.g., primary, secondary, professional, social, empirical, etc.); and (3) filtering out the keyword of e-learning and its other versions (e.g., electronic learning, Elearning, digital learning) in the data analysis because it is virtually a keyword for all the articles in the e-learning field in line with past studies (He et al. 2017; Hu and Zhang 2015). Two authors conducted the keyword merging.

We first examined the distribution of keyword frequency with the software IBM SPSS Statistics 22.0. As shown in Fig. 1, the power-law distribution of all the keywords has an exponent value of − 0.981 ($P < 0.001$, $R2 = 0.986$), which indicates that the research structure in the field of e-learning over the past 20 years (1999–2018) is a scale-free network. In other words, in the keyword network, a small number of nodes (keywords) are well connected and dominate the connectivity, while the other nodes have sparse connections (Barabási and Réka 1999). These "very connected" keywords in e-learning studies shape the way the network operates (Barabási and Réka 1999; Cho 2014). Therefore, it is reasonable to select a relatively small number of keywords but with high frequencies in database of 21,656 keywords to represent the major research structures in the e-learning field in the studied 20 years.

Table 1 Selected journals

Journals	Starting year	Keyword available from (year)	Count of articles collected	Count of keywords collected
Internet and Higher Education (IHE)	1998	2000	476	1393
Computers and Education (CE)	1976	1999	2711	9014
Journal of Computer-Assisted Learning (JCAL)	1985	2000	344	987
International Review of Research in Open and Distance Learning (IRRODL)	2000	2001	771	2188
Educational Technology and Society (ETS)	1999	1999	1410	3245
International Journal of Mobile Learning and Organization (IJMLO)	2007	2007	245	1571
IEEE Transactions on Learning Technologies (ITLT)	2008	2008	316	792
Distance Education (DE)	1980	2008	233	617
Interactive Learning Environments (ILE)	1990	2008	479	1268
Open Learning (OL)	1986	2004	229	581
Total	–	–	7214	21,656

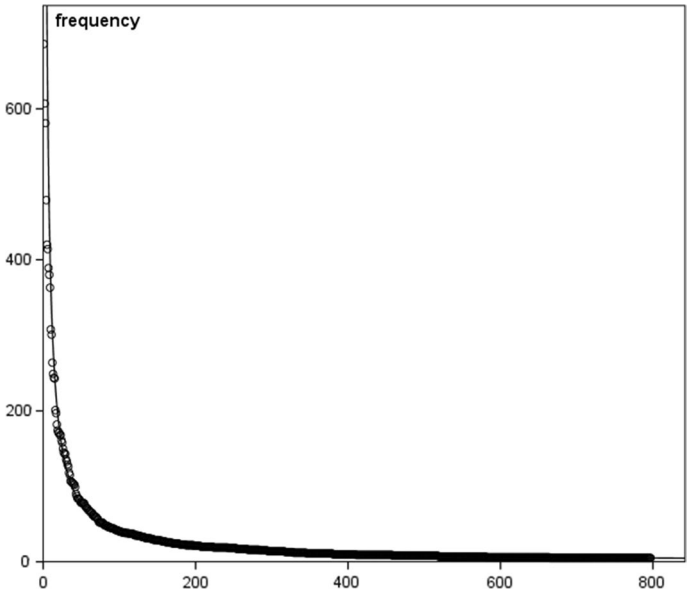


Fig. 1 Power-law distribution of keywords frequencies

Methods

Keyword matrix constructing

Constructing the relationships between keywords helps recognize the structure of the associated topics. We constructed a corresponding paper-word matrix and a co-word matrix. The construction of both matrixes use a latent semantic analysis (LSA) based on Python programming, in which the words represent the main semantic meaning of the documents and the relationships between the words express the knowledge structure represented by the collection of documents (Landauer et al. 2009). A paper-word matrix measures whether a keyword is presented in a paper. In other words, it directly maps a keyword into a certain vector space according to the keyword distribution in certain papers. Then, a clustering can be applied to get the keyword classes for different word positions. A co-occurrence matrix exhibits the frequencies of two specific keywords appearing together in an article, while patterns of the co-occurrence of keywords reflect different research themes (He 1999). Based on the co-occurrence matrix, a social network analysis (SNA) and strategic maps are used to further analyze the structure and characteristics of the knowledge networks in a research field.

Clustering

In a co-word analysis, a well-connected cluster of keywords represents a research theme. Specifically, a hierarchical cluster analysis assigns each keyword to one cluster and then merges the closest keyword pairs until all the keywords are merged. The process can be

divided into two parts: calculating the distance or similarity between keywords and using clustering algorithms to aggregate keywords. A Bray–Curtis dissimilarity is utilized to assess the similarity of the keywords. A Bray–Curtis dissimilarity is robust to nonlinearities and has been found to exhibit good performance when analyzing categorical or binary data (Beals 1984) or dealing with data that have many dimensions of zero values (Field et al. 1982). The Bray–Curtis dissimilarity algorithm has been used in many types of research on cluster studies or for a community division (Anderson et al. 2016; Jayabarathi et al. 2015). Ward's method that uses a hierarchical algorithm can further be used for agglomerative clusters, which is commonly used in bibliometrics studies for hierarchical analysis (e.g., Lee and Jeong 2008; Liu et al. 2016). The package scipy of Python was employed in cluster analysis in this study.

Social network analysis (SNA)

Based on analyzing the number and strength of the connections between the nodes of a network, a SNA helps explain the unique structure of the interrelationships among individual nodes; this method has been widely used in bibliometric research and scientific development research (Jalali and Park 2018; Chen et al. 2019). Such as several SNA methods can be applied to quantify the characteristics of the knowledge structure of a research field by conducting both structural holes and a core-periphery analysis and then computing the values of both the degree centrality and network density. The package networkX of Python was applied in SNA in this study.

Structural hole analysis This analysis measures the degree to which a node builds relationships between two disconnected nodes (Burt 1992). The greater the structural hole value of a keyword is, the more effective the keyword will be in connecting other isolated keywords. The value of the structural holes can be estimated based on the effective size of a network introduced by Burt (1992).

Core-periphery analysis This method identifies the core nodes that are densely connected with each other, and each peripheral node is connected to the core nodes, but no peripheral nodes are sparsely connected to each other (Borgatti and Everett 1999). Thus, this method could separate the topics closely associated with each other (core topics) from those relatively isolated in a given network. The core's value is computed to estimate the core-periphery values.

Centrality and density The centrality measures the degree of connections of a research theme with other themes in the network (Nielsen and Thomsen 2011). The stronger the cluster's connections with other clusters, the more central this theme will be to the entire network (Callon et al. 1991). The density estimates how strong the nodes which describe the subnetwork or network are tied with each other internally (He 1999). The density value describes the capacity of a cluster to maintain itself and to develop over time.

Strategic diagram

The strategic diagram is a two-dimensional space visualizing the distribution of the estimations for density and centrality with x-axis representing the centrality values and y-axis presenting the density values (Bauin et al. 1991). Distributed in different quadrants of the

coordinates, the themes' internal structural traits and external development potential are highlighted, and the themes of similar features can be grouped.

Specifically, a strategic diagram consists of four quadrants. In the diagram, Quadrant I is located at the upper right quadrant, and the research themes in this quadrant reflect the motor research themes with high values in both centrality and density; Quadrant II is at the upper left quadrant, and the themes in this quadrant are associated with each other but not closely tied with other themes externally; Quadrant III is at the lower left quadrant, and the themes in this quadrant are not well developed, such as the research themes either fade or emerge in the field; whereas Quadrant IV is at the lower right quadrant, and the research themes in this quadrant are weakly structured because of having a low density but have a high/medium centrality; these have the potential to evolve and become important research themes (Viedma-del-jesús and López-herrera 2012; Liu et al. 2016).

Results

To detect the paradigm changes in the field of e-learning over the past 20 years, the sample data were split into two sub-datasets pertinent to the two studied periods: 1999–2008 and 2009–2018. There are fewer papers published in the first period of 1999–2008 (N = 1677) than the second period of 2009–2018 (N = 5537), suggesting that research in the field of e-learning has made a fast grow over the past 10 years.

In accordance with the power-law distribution of keyword frequency, for our analysis, we retained the top keywords that appeared more than 10 times during 1999–2008 and more than 34 times during 2009–2018. As a result, a total of 98 keywords (total frequency: 5068) covering 1412 (84.20%) of the 1677 papers were selected to represent the main research topics for the period of 1999–2008, whereas 97 keywords (total frequency: 16,588) covering 4338 (78.35%) of the 5537 published papers were selected for the period of 2009–2018. Therefore, with fewer but popular keywords, we could reliably characterize the entire network of keywords in e-learning.

Figure 2 describes the most commonly occurring keywords for each periods 1999–2008 and 2009–2018 based on WordArt (www.wordart.com), a Web 2.0 service for creating word clouds. The more popular keywords in the respective period are presented with much bigger size of font size. For instance, "distance education", "online learning" and "pedagogical issues" were the most frequently used keywords in 1999–2008, while "interactive learning environments" and "mobile learning" were the most popular ones in 2009–2018.

When comparing the keywords, 35 of the 97 keywords (36.08%) in the period of 2009–2018 are new, indicating that an important change in the major research themes has occurred over the past 20 years. The distribution of new keywords pertinent to major e-learning journals explains how these journals have contributed to the field of e-learning through initiating new research topics (Bozkurt et al. 2015), and we employed a correspondence analysis between 35 novel new keywords appeared in 2009–2018 and the selected journals in this study. As shown in Fig. 3, different e-learning journals have facilitated different new topics that have appeared in 2009–2018 to various degrees, and most of the new emerging keywords lie mainly in the center of the graph and are also close to the major e-learning journals, implying that the major journals in the field of e-learning have collaborated to support the development of new research topics in e-learning.

(a) 1999–2008

(b) 2009–2018

Fig. 2 The word cloud based on the keywords in the periods 1999–2008 and 2009–2018

It is interesting to note that three journals—OL, IRRODL, and DE—are located quite close to each other (see Fig. 3). These three journals mainly focus on the research areas of open learning and distance learning, aiming to address the issues of education resources and regional imbalances via both open and distance learning. The journals ETS, IJMLO, JCAL, CE, and ILE are located close to each other and, thus, form a small group. These journals occupy rich research topics mainly on the use of new techniques in e-learning. The journal IHE is specialized in the research context of higher education from the perspective of educators or teachers, hence focusing on the areas like community of inquiry, instructional design model, and teaching presence. The journal ITLT remains farther away from the other journals and close to the topic "Computer-assisted instruction," which indicates that ITLT has attracted a lot of research articles on topics related to instruction technologies.

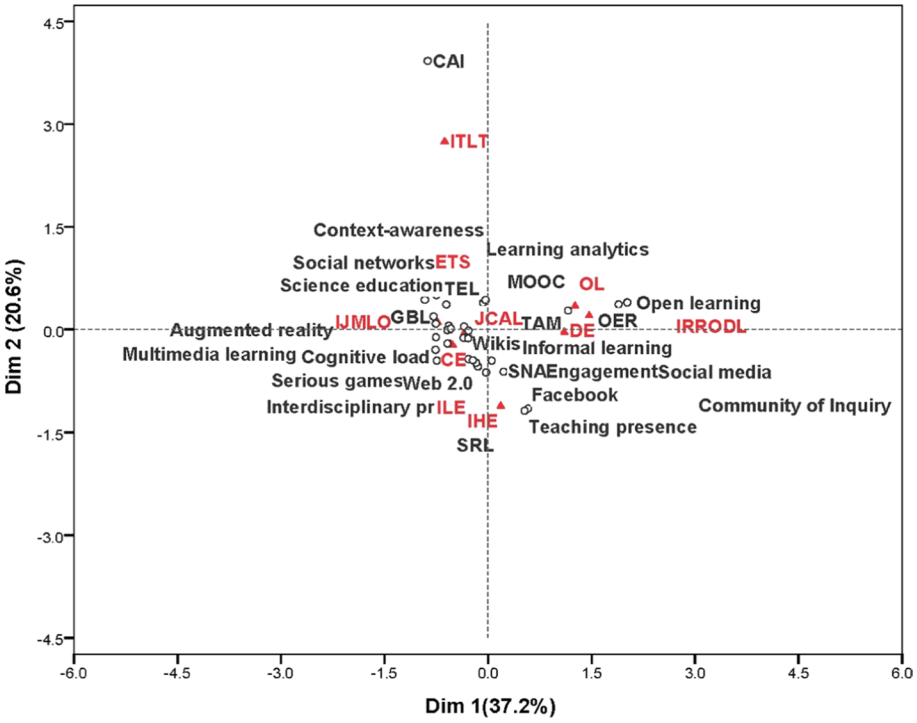


Fig. 3 The distribution of new emerging keywords in the selected e-learning journals. *Note MOOC* massive open online courses, *OER* open education resources, *GBL* game-based learning, *TAM* technology acceptance model, *TEL* technology-enhanced learning, *SRL* self-regulated learning, *Wikis* Wikis, *SNA* social network analysis, *CAI* computer-assisted instruction, *IBL* inquiry-based learning, *TPCK* technological pedagogical content knowledge. The texts with red color refer to the 10 selected journals, and the texts in black refer to the topics. (Color figure online)

Bridging, core, and popular topics in e-learning research

We computed the co-occurrence matrices of the keywords for further analysis. Based on the matrix, the core research topics in e-learning research were identified for the two periods (1999–2008 and 2009–2018) via the core-periphery analysis. The results revealed a total of 21 keywords with a concentration value of 0.828 for the period 1999–2008 and a collection of 11 keywords with a concentration value of 0.817 for the period 2009–2018 (see Tables 2, 3). The concentration value measures the core research topics of the keywords network in e-learning research for the two periods.

The top 21 keywords in terms of frequency and structural hole values of the period 1999–2008 are presented in Table 2. Keywords with a high frequency mean these topics are popular and commonly used, keywords with a high core value reflect that these topics are the core topics and they underpin each other in order to form as the core topics in research, whereas keywords with high structural hole values represent the bridge topics that agglutinate other separated topics together and, therefore, form a research power center.

As shown in Table 2, 16 topics were identified as both the core and popular research topics in 1999–2008, demonstrating a high consistency within the period 1999–2008. The

Table 2 Bridging, core, and popular topics in e-learning research (1999–2008)

No.	Popular topics	Frequency	Core topics	Core value	Bridge topics	Structure hole value
1	Distance education	151	Interactive learning environments	0.391	Distance education	44.624
2	Interactive learning environments	150	Teaching and learning strategies	0.365	Computer-mediated communication	42.518
3	Teaching and learning strategies	129	Pedagogical issues	0.301	Online learning	42.141
4	Computer-mediated communication	128	Computer-mediated communication	0.284	**Computer-supported collaborative learning**	**37.909**
5	Pedagogical issues	106	Cooperative/collaborative learning	0.252	**Evaluation**	**36.347**
6	Online learning	105	Improving classroom teaching	0.248	**Mobile learning**	**33.407**
7	Cooperative/collaborative learning	91	**Human–computer interface**	**0.168**	**Higher education**	**32.563**
8	Improving classroom teaching	89	**Distance education and telelearning**	**0.161**	Interactive learning environments	32.149
9	Mobile learning	88	**Media in education**	**0.161**	Lifelong learning	32.002
10	**Distance learning**	**72**	**Multimedia/hyper-media systems**	**0.158**	**Distance learning**	**30.958**
11	**Higher education**	**69**	Distance education	0.154	Teaching and learning strategies	30.105
12	**Human–computer interface**	**63**	**Distributed learning environments**	**0.144**	Learning communities	29.077
13	**Evaluation**	**61**	Learning communities	0.14	**Postsecondary education**	**28.504**
14	**Media in education**	**61**	**Architectures for educational technology systems**	**0.139**	Cooperative/collaborative learning	27.547
15	**Computer-supported collaborative learning**	**60**	Evaluation of CAL systems	0.138	Pedagogical issues	27.231
16	**Distance education and telelearning**	**60**	**Secondary education**	**0.135**	Collaboration	25.987
17	Learning communities	57	Online learning	0.131	Improving classroom teaching	24.694
18	**Multimedia/hyper-media systems**	**57**	Applications in subject areas	0.12	Constructivism	24.676
19	**Secondary education**	**54**	**Postsecondary education**	**0.118**	Intelligent tutoring system	24.52
20	**Distributed learning environments**	**53**	Elementary education	0.117	Simulations	24.372
21	**Architectures for educational technology systems**	**50**	Evaluation methodologies	0.115	Internet	24.17

Boldface is used to identify the keywords that appear at least twice within the three featured groups

Table 3 Bridging, core, and popular topics in e-learning research (2009–2018)

No.	Popular topics	Frequency	Core topics	Core value	Bridge topics	Structure hole value
1	Interactive learning environments	536	Interactive learning environments	0.443	Game-based learning	35.95
2	Mobile learning	493	Teaching and learning strategies	0.442	**Computer -supported collaborative learning**	**67.763**
3	Teaching and learning strategies	478	**Improving classroom teaching**	**0.297**	Mobile learning	66.54
4	Online learning	374	Pedagogical issues	0.281	Online learning	62.484
5	**Improving classroom teaching**	**325**	Computer-mediated communication	0.204	Higher education	56.654
6	Pedagogical issues	314	**Media in education**	**0.203**	Interactive learning environments	50.805
7	Higher education	294	**Cooperative/collaborative learning**	**0.186**	Computer-mediated communication	50.377
8	Computer-mediated communication	261	**Postsecondary education**	**0.174**	**Secondary education**	**49.446**
9	**Media in education**	**240**	Online learning	0.172	**Distance education**	**47.652**
10	**Distance education**	**229**	Elementary education	0.169	Blended learning	45.517
11	**Cooperative/collaborative learning**	**217**	Mobile learning	0.154	Teaching and learning strategies	42.819
12	**Computer-supported collaborative learning**	**204**	Applications in subject areas	0.151	Motivations	39.657
13	Elementary education	201	**Secondary education**	**0.15**	Elementary education	38.011
14	**Postsecondary education**	**198**	Higher education	0.133	Pedagogical issues	37.754

Boldface is used to identify the keywords that appear at least twice within the three featured groups

evaluation of CAL systems, applications in subject areas, elementary education, and evaluation methodologies were found to be associated with relatively low popularity and bridging, suggesting that although these topics are a part of the core network structure, they only connected to a limited number of isolated research topics in 1999–2008. Furthermore, research into distance education, interactive learning environments, teaching and learning strategies, computer-mediated communication, pedagogical issues, online learning, cooperative/collaborative learning, improving classroom teaching, and learning communities are bridging, core, and popular topics, indicating that these research topics were the most important research topics in the e-learning field in 1999–2008. In addition, mobile learning, distance learning, higher education, evaluation, and computer-supported collaborative learning are bridging and popular topics but not core topics, implying that though these topics are popular, but they have a very weak link to the identified core topics in e-learning research in 1999–2008.

A total of 14 keywords were categorized as the core research topics in 2009–2018 (see Table 3). A smaller number of core topics identified at the second period than in the first period indicates that e-learning research has been increasingly focused on a few topics. Among the 14 keywords, 10 are listed as both popular and bridging topics, including interactive learning environments, mobile learning, teaching and learning strategies, online learning, pedagogical issues, higher education, computer-mediated communication, distance education, computer-supported collaborative learning, and elementary education. This suggests that bridging topics have attracted a considerable amount of attention from scholars, maintaining cohesion in e-learning research. It is worth noting that interactive learning environments, mobile learning, teaching and learning strategies, online learning, pedagogical issues, higher education, computer-mediated communication, and elementary education were found to be popular, core, and bridging topics. This indicates a high consistency of e-learning research, implying that e-learning has developed in a healthy direction from 2009 to 2018.

Furthermore, even though research on game-based learning, blended learning, and motivations is neither popular nor core, these topics exhibit high structural hole values. In other words, these topics have played a crucial role in agglutinating various relatively isolated research topics to form a cohesion in e-learning research. The topics of "distance education" and "computer-supported collaborative learning" are not core but popular and bridging, indicating that they are relatively general terms compared with the core topics and help to condense other discrete topics. Although "application in subject area" has a high core value in the 2009–2018, it does not represent a popular or bridging topic. The results imply that e-learning application in different disciplines is a basic and traditional research area in e-learning research.

It is worth noting that "mobile learning" and "higher education" appeared as new core topics in the period 2009–2018 but not as new popular topics and bridging topics; they were found to display an increase in the rank in the groups of both bridging and popular topics. The results implies that the two topics have been pushed into the core structure of e-learning research by researchers in the past 20 years. A few popular and core topics in 1999–2008 are neither popular nor core topics in 2009–2018, such as human–computer interface, distance education and telelearning, distributed learning environments, multimedia/hypermedia systems, architectures for educational technology systems, and learning communities. This means that these topics have gradually faded regarding their importance in e-learning research.

The bridging topics have greatly evolved over the investigated 20 years. A total of 12 keywords for the first period disappear in the second period, while five new keywords

with high structure hole values emerge in the second period. Nonetheless, the core topics of the second period exhibit minor changes. For instance, 10 of the 12 core topics retain their original central position. This indicates that the core research topics are relatively stable over the past 20 years, even though there might be changes in how different perspectives and research methods have been applied to investigate these topics. For example, learning communities, cooperative/collaborative learning, and computer-supported collaborative learning reflect the research on e-learning collaboration and have declined as a function of the aggregation of other topics. Meanwhile, game-based learning and blended learning have become more important in bridging related research topics. In addition, interactive learning environments, teaching and learning strategies, computer-mediated communication, pedagogical issues, and online learning are popular, core, and bridging in both periods, indicating that they are the classic but also valuable research topics in the field.

The major research themes in e-learning research

We computed a keyword correlation matrix based on whether two keywords appear in the same article via the Scipy package of Python. The Bray–Curtis dissimilarity algorithm (Bray and Curtis 1957) was adopted to calculate the distance between topics, while Ward's method was used to divide all the topics into clusters (Ward 1963). The final outputs of the cluster analysis are illustrated in Appendices 1 and 2. A total of 12 clusters (labeled A1–A12, see Table 4) for the period of 1999–2008 and 10 clusters (labeled B1–B10, see Table 5) for the period of 2009–2018 were returned.

Each cluster represents a research subfield or a research theme in the e-learning field. Specifically, A2 from the first period (Table 4) is related to the development and application of learning tools and systems. With a lot of common keywords, research theme B2 (Table 5) from the second period shares great similarities to theme A2. Indeed, elementary and secondary education is a general research topic related to basic education (Cronjé 2013). As shown in Tables 4 and 5, A3 and B3 are research themes from the area concerning strategic and pedagogical issues of integrating e-learning with school teaching. A7 contains only four keywords, but it provides a clear indication that ontology could be used in e-learning design, such as with other models like SCORM.

To understand the status and importance of each research cluster, the values for total frequency for keyword, total frequency for co-word, average frequency for keyword, and average frequency for co-word were calculated for each cluster to measure the degree to which e-learning scholars have directed a focus on specific research clusters and a specific research topic in the e-learning field.

As shown in Tables 6 and 7, clusters A1 (computer-mediated communication; cooperative/collaborative learning; distance education and telelearning), A2 (interactive learning environments; human–computer interface; multimedia/hypermedia systems), and A3 (teaching and learning strategies; pedagogical issues; improving classroom teaching) from 1999 to 2008 and clusters B1 (computer-mediated communication; cooperative/collaborative learning; learning communities), B3 (interactive learning environments; teaching and learning strategies; improving classroom teaching), and B9 (online learning; higher education; distance education) from 2009 to 2018 have both the highest values for average frequency for both keywords and co-words, implying that the topics included clusters A1, A2, A3 and B1, B3, B9 were the most popular ones in their respective periods.

Table 4 Research clusters in 1999–2008

Cluster (size)	Keywords
A1 (8)	**Computer-mediated communication; cooperative/collaborative learning; distance education and telelearning;** learning communities; distributed learning environments; architectures for educational technology systems; lifelong learning; adult learning
A2 (9)	**Interactive learning environments; human–computer interface; multimedia/hypermedia systems;** evaluation of CAL systems; simulations; intelligent tutoring system; virtual reality; authoring tools and methods; programming and programming languages
A3 (11)	**Teaching and learning strategies; pedagogical issues; improving classroom teaching;** media in education; secondary education; evaluation methodologies; postsecondary education; elementary education; applications in subject areas; country-specific developments; gender studies
A4 (5)	**Mobile learning; ubiquitous learning; PDAs;** mobile phones; SMS
A5 (8)	**Internet; technology; education;** computers; attitudes; learning styles; gender; mathematics
A6 (8)	**Collaboration; undergraduates; hypermedia;** case studies; questionnaire; communication; accessibility; World Wide Web
A7 (4)	**Learning objects; learning design; ontologies;** SCORM
A8 (2)	**Learning outcomes; content analysis**
A9 (6)	**Constructivism; problem-solving; instructional design;** problem-based learning; control group; visualization
A10 (4)	**Learning; interactions; learning management systems;** community
A11 (18)	**Computer-mediated learning; computer-supported collaborative learning; teacher education;** navigation; educational technologies; pedagogy; knowledge management; technology integration; community of practice; human–computer interaction; personalization; teacher training; cross-cultural projects; professional development; web-based instruction; activity theory; motivations; social presence
A12 (15)	**Distance education; online learning; distance learning**; higher education; evaluation; web-based learning; ICTs; online learning environments; blended learning; online education; multimedia; learning technologies; information technology; continuance intention; innovation

Boldface is used to identify the top three keywords that appear with high frequencies in the clusters

Maturity and cohesion of the research themes in e-learning research

Based on the co-occurrence matrix, we calculated the centrality and density values for each research cluster via the software UCINET to further understand their levels of cohesion and maturity. We developed the strategic diagrams for e-learning research in 1999–2008 and 2009–2018, which help visualize the position of each research cluster (see Fig. 4). The average values of the centrality and density are 0.533 and 0.751 for 1999–2008 and 0.786 and 8.859 for 2009–2018, respectively. The research themes of the first periods are depicted in Fig. 4.

1. Clusters A1 (computer-mediated communication; cooperative/collaborative learning; distance education and telelearning) and A2 (interactive learning environments; human–computer interface; multimedia/hypermedia systems) are located in Quadrant I, which have high centrality and density values. The results indicate that the research topics included in Clusters A1 and A2 are well developed (high centrality) and widely

Table 5 Research themes in 2009–2018

Cluster (size)	Keywords
B1 (8)	**Computer-mediated communication; cooperative/collaborative learning; learning communities;** distance education and telelearning; adult learning; lifelong learning; country-specific developments; gender studies
B2 (12)	**Human–computer interface; evaluation methodologies; simulations;** multimedia/hypermedia systems; evaluation of cal systems; intelligent tutoring system; virtual reality; architectures for educational technology systems; distributed learning environments; interdisciplinary projects; authoring tools and methods; programming and programming languages
B3 (9)	**Interactive learning environments; teaching and learning strategies; improving classroom teaching;** pedagogical issues; media in education; elementary education; postsecondary education; secondary education; applications in subject areas
B4 (3)	**Community of Inquiry; social presence; teaching presence**
B5 (10)	**Computer-mediated learning; computer-supported collaborative learning; Web 2.0;** collaboration; social networks; informal learning; social media; Wikis; Blogs; Facebook
B6 (4)	**ICTs; teacher education; technology integration;** technological pedagogical content knowledge
B7 (24)	**Massive open online courses; open education resources; blended learning;** distance learning; learning management systems; learning analytics; technology acceptance model; educational technologies; technology-enhanced learning; self-regulated learning; instructional design; online education; learning styles; science education; interactions; self-efficacy; gender; problem-based learning; social network analysis; online learning environments; inquiry-based learning; learning strategies; content analysis; flipped classroom
B8 (16)	**Motivations; evaluation; game-based learning;** learning; education; cognitive load; technology; multimedia learning; feedback; serious games; augmented reality; computer-assisted instruction; engagement; educational games; problem-solving; mathematics
B9 (5)	**Online learning; higher education; distance education;** pedagogy; open learning
B10 (6)	**Mobile learning; ubiquitous learning; mobile phones;** internet; context-awareness; mobile technologies

Boldface is used to identify the top three keywords that appear with high frequencies in the clusters

Table 6 The attributes of keyword and co-word in each cluster in 1999–2008

Cluster	Total frequency for keyword	Total frequency for co-word	Average frequency for keyword	Average frequency for co-word	Centrality	Density
A1	507	296	**63.375**	**37.000**	0.700	1.000
A2	468	241	**52.000**	**26.778**	0.573	0.944
A3	656	509	**59.636**	**46.273**	0.506	0.945
A4	138	40	27.600	8.000	0.387	1.000
A5	161	41	20.125	5.125	0.533	0.679
A6	146	48	18.250	6.000	0.522	0.750
A7	66	13	16.500	3.250	0.234	0.667
A8	23	3	11.500	1.500	0.188	1.000
A9	105	17	17.500	2.833	0.565	0.600
A10	88	11	22.000	2.750	0.436	0.667
A11	339	40	18.833	2.222	0.825	0.216
A12	666	162	44.400	10.800	0.928	0.543
Average	280.25	118.417	30.977	12.711	0.533	0.751

Boldface is used to identify the top three clusters that appear with high average frequencies for both keyword and co-word

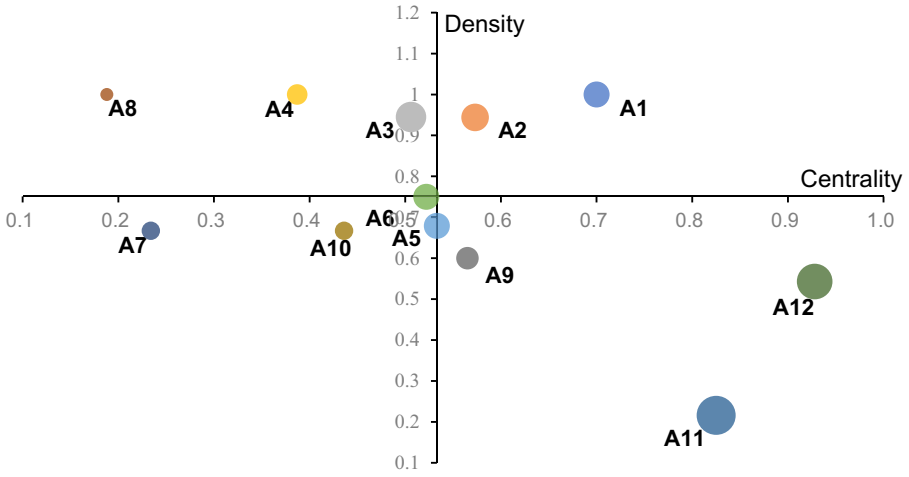
Table 7 The attributes of keyword and co-word in each cluster for 2009–2018

Cluster	Total frequency for keyword	Total frequency for co-word	Average frequency for keyword	Average frequency for co-word	Centrality	Density
B1	2644	2235	**293.778**	**248.333**	0.864	1.000
B2	1081	392	90.083	32.667	0.694	0.970
B3	944	335	**118.000**	**41.875**	0.809	0.964
B4	164	64	54.667	21.333	0.330	1.000
B5	725	121	72.500	12.100	0.920	0.733
B6	210	24	52.500	6.000	0.667	1.000
B7	1599	257	66.625	10.708	0.959	0.417
B8	897	158	56.063	9.875	0.901	0.575
B9	995	228	**199.000**	**45.600**	0.891	1.000
B10	767	168	127.833	28.000	0.824	0.933
Average	1002.6	398.200	113.105	45.649	0.786	0.859

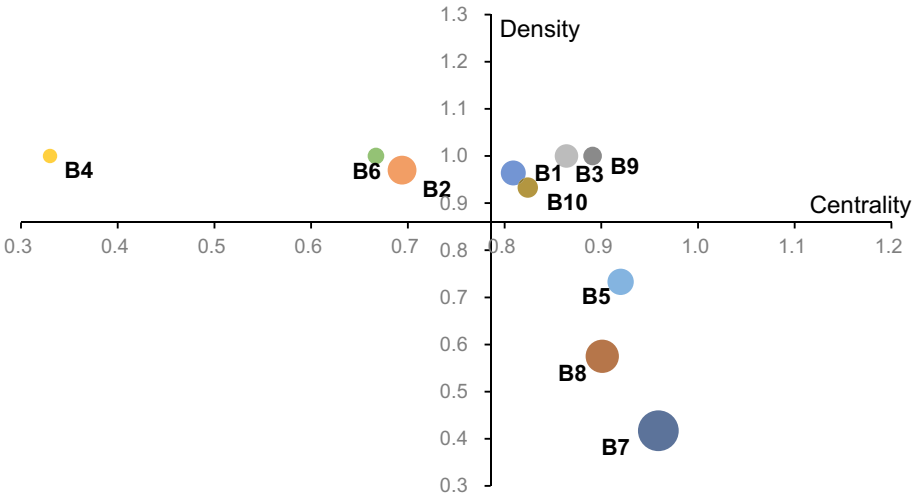
Boldface is used to identify the top three clusters that appear with high average frequencies for both keyword and co-word

connected to each other (high density), and these themes can be regarded as the core research themes in the field in 1999–2008.

2. Clusters A3 (teaching and learning strategies; pedagogical issues; improving classroom teaching), A4 (mobile learning; ubiquitous learning; PDAs), and A8 (learning outcomes; content analysis) are located in Quadrant II with relatively high density but low centrality values. The results indicate that the topics in clusters A3, A4 and A8 are mature but marginal because the high density reflects that the topics in each cluster are closely connected with each other internally, and the low centrality value shows that they are isolated from each other.
3. Clusters A5 (Internet; technology; education), A6 (collaboration; undergraduates; hypermedia), A7 (learning objects; learning design; ontologies), and A10 (learning; interactions; learning management systems; community) are in Quadrant III, which have relatively low centrality and density, indicating that the topics in clusters A5, A6, A7 and A10 are loosely connected with each other and that the four clusters have low connections with the other clusters. The results suggest that the topics included in these four clusters are subject to change, such as either being fading or emerging research topics in the e-learning field.
4. Clusters A9 (constructivism; problem-solving; instructional design), A11 (Computer-mediated learning; Computer-supported collaborative learning; Teacher education), and A12 (distance education; online learning; distance learning) lie in Quadrant IV, which have low values for density but high values for centrality. The results imply that the topics included in clusters A9, A11, and A12 are core but undeveloped research topics in e-learning field in 1999–2008. Meanwhile, Clusters A9, A11, and A12 have high values for the total frequencies for keywords, implying that researchers in e-learning field have carried out fundamental research work on the topics included in the three clusters in the period of 1999–2008 to develop them as more cohesive research subfields in e-learning research.



(a) 1999–2008



(a) 2009–2018

Fig. 4 Strategic diagrams for e-learning research: 1999–2008 and 2009–2018. *Note* The size of the node is used to represent the total frequency for the keywords included in a cluster

Between 2009 and 2018, the clusters are spread over three quadrants:

1. Cluster B1 (computer-mediated communication; cooperative/collaborative learning; learning communities), B3 (interactive learning environments; teaching and learning strategies; improving classroom teaching), B9 (online learning; higher education; distance education), and B10 (mobile learning; ubiquitous learning; mobile phones) lie in Quadrant I with a relatively high centrality and density, suggesting that the topics here developed with good levels of internal maturity and link with each other. Accordingly,

the topics included in these four clusters are the core research themes in e-learning field in 2009–2018.

2. Clusters B2 (human–computer interface; evaluation methodologies; simulations), B4 (community of inquiry; social presence; teaching presence), and B6 (ICTs; teacher education; technology integration) are found in Quadrant II, which have high values for density but low values for centrality. The results suggest that although these research topics are mature, they are marginal in the network. The research topics belonging to the three clusters have been highly developed but isolated from other topics. For further development, it would be useful for these topics to be associated with other e-learning themes.
3. Clusters B5 (computer-mediated learning; computer-supported collaborative learning; Web 2.0), B7 (massive open online courses; open education resources; blended learning), and B8 (motivations; evaluation; game-based learning) lie in Quadrant IV with high centrality but low density, indicating that these themes have the potential to become core research themes even though they are underdeveloped in the period of 2009–2018.

Figure 4 provides a comprehensive understanding of the positions and identify of different research themes in e-learning field by comparing the degree centrality between the two decades. For example, clusters A11 and A12 are at the center of e-learning research because both clusters have the highest value of degree centrality. Also, the two clusters have the largest cluster group size and cover a broad range of keywords in the field of IT-related methods, perspectives, and theories in e-learning. In other words, the findings imply that e-learning research is largely grounded on IT artifacts and its convenience for learning by fusing them in new methods, theories, and perspectives in learning. In addition, about half of the keywords in clusters A11 and A12 are distributed to different clusters in 2009–2018, suggesting that the center of e-learning research has changed rapidly in the 20 years with the emergence of new technologies and research perspectives, such as mobile technologies, social media, and artificial intelligence. This is consistent with the view of Sangra et al. (2012) that we cannot ignore the nature of quick change in the uses of technologies when considering e-learning. Choudhury and Pattnaik (2020) have also highlighted the changing trend of e-learning technologies.

Visualizing the evolution of research topics in e-learning research

To trace the evolution of research topics in e-learning research, the software CorText was employed to generate an evolution map by visualizing the research topics included in the clusters in the time periods of 1999–2018 based on flow-diagrams (Leydesdorff and Goldstone 2014). If one research topic (Shown as bars in Figs. 5 and 6) in e-learning research in a year keeps as a research topic in the following year (s), the flow of the research topic in the network will show as a linked belt connecting the bars in different years.

As shown in Fig. 5, interactive collaborative learning is one main research area in the period of 1999–2008 with continuous development. The topics related to the area seem to be weak in 1999–2000 but have been developed from 2000 to 2006 via interactions with various other topics (such as “improve classroom teaching,” “distributed learning environment,” “interactive learning environment,” and “teaching and learning strategies”) and further strengthened in the later phase of the period 1999–2008. Many of the research topics are absorbed in this research area, whereas some topics are distributed in other research themes during this period. In the later phase of this period (such as 2007–2008), mobile

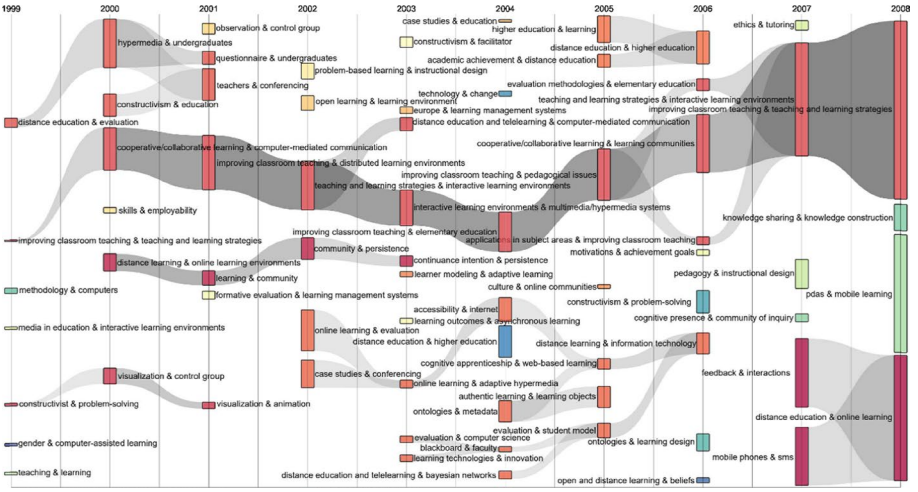


Fig. 5 Evolution of research topics in e-learning (1999–2008)

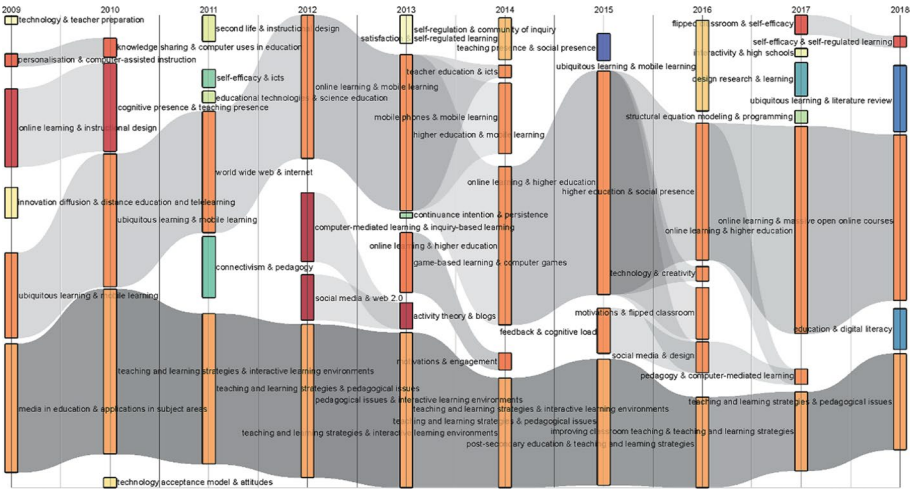


Fig. 6 Evolution of research topics in e-learning (2009–2018)

learning and distance education and online learning are developed as another two subdivisions at the initial stage.

In the period 2009–2018, there are two main subdivisions in e-learning research. These are presented on the topic evolution map as follows: interactive collaborative learning and online learning. Interactive collaborative learning keeps its strong continuity in this period but becomes relatively weaker in the late phase (such as year 2016–2018) compared with a strong development of the subdivision of online learning. In 2009–2010, mobile learning and online learning developed as two branches (such as ubiquitous learning and mobile learning and online learning and instructional design). Starting from 2012, the topics in

mobile learning and online learning interact with some topics such as the "mobile gaming," "teaching education," "ICT," "higher education," and so forth and merge as one subdivision focusing on online learning in the e-learning field. The results imply that online learning has become a strong research theme in e-learning research.

As shown in Fig. 6, some topics related to social media are scattered on the map from 2011 to 2018, including topics such as "second life and instructional design," "social media and Web 2.0," "social media and design," "activity theory and blogs." The results indicate that social media has been an important research context in e-learning research.

Discussion and conclusion

By employing bibliometric methods, the current study attempts to understand major research themes and their evolution in e-learning research over the past 20 years. Several insights can be drawn. First, we found that a few research themes have become the cumulative tradition in e-learning research. These research traditions include the topics of Clusters B1 (computer-mediated communication; cooperative/collaborative learning; learning communities), Clusters B2 (human–computer interface; evaluation methodologies; simulations), B3 (interactive learning environments; teaching and learning strategies; improving classroom teaching), B9 (online learning; higher education; distance education), Clusters B5 (computer-mediated learning; computer-supported collaborative learning; Web 2.0), and B10 (mobile learning; ubiquitous learning; mobile phones). These research topics have dominated e-learning research in 2009–2018 and were inherited from the earlier period of 1999–2008, such as clusters A1 (computer-mediated communication; cooperative/collaborative learning; distance education and telelearning), A2 (interactive learning environments; human–computer interface; multimedia/hypermedia systems), A3 (teaching and learning strategies; pedagogical issues; improving classroom teaching), A4 (mobile learning; ubiquitous learning; PDAs), A11 (Computer-mediated learning; Computer-supported collaborative learning; Teacher education), and A12 (distance education; online learning; distance learning. The topics in these clusters keep their continuity across the 20 years, implying a temporal continuity of e-learning research even though there are evolutions of research themes in e-learning research, such as emerging new research themes and fading of some research themes in e-learning research.

It is also worth noting that the research traditions in e-learning research are continuously evolving. New topics increasingly emerge and are absorbed by different research themes and/or are replaced by old topics. For instance, Clusters B5 (computer-mediated learning; computer-supported collaborative learning; Web 2.0) has undergone a rapid evolution with an enhanced connection to new technologies, such as Web 2.0; social networks; social media; Wikis; blogs; and Facebook. Based on the fact that the research topics in e-learning keep their continuity and also develop with technology development, we assume that there might be a constant evolution of these research topics in e-learning research in the future. Such as in the future the research topics in the e-learning field is expected to change with the technology development because changes in e-learning techniques always take place, such as artificial intelligence, robots, cloud computing, and augmented reality (Rodrigues et al. 2019). Thus, future studies should not only research on the traditional research themes, but also explore the applications of new education technologies in e-learning field.

The results also offer useful hints on the future direction of how the field may evolve. Specifically, research themes Clusters B2 (human–computer interface; evaluation

methodologies; simulations), B4 (community of inquiry; social presence; teaching presence), and B6 (ICTs; teacher education; technology integration) in Quadrant II have low centrality values, albeit high density values. This indicates that the research related to these themes is located at the border of the e-learning research map, hence exhibiting a high risk of fading away. The topics of these research themes are likely to be replaced by other research topics if they are not integrated into the topics that are located in a more central position. In this vein, traditional topics with a low centrality value are likely to fade away over the next decade. Thus, future research in e-learning should focus on the core and emerging new research themes, but not on these fading research themes.

Research theme Clusters B5 (computer-mediated learning; computer-supported collaborative learning; Web 2.0), B7 (massive open online courses; open education resources; blended learning), and B8 (motivations; evaluation; game-based learning) lie in Quadrant IV with high centrality but low density, indicating that the research topics included in the three clusters are positioned at the center of e-learning research although research on these topics is not integrated with existing topics and their connections are relatively sparse. The themes include many new and emerging topics that, to some extent, point to the directions of the future of e-learning research. Such as future research can consider about the research topics related to collaborative learning, open education, gamified and motivational learning systems, and blended learning as these research themes are new emerging topics in e-learning research.

Research themes Cluster B1 (computer-mediated communication; cooperative/collaborative learning; learning communities), B3 (interactive learning environments; teaching and learning strategies; improving classroom teaching), B9 (online learning; higher education; distance education), and B10 (mobile learning; ubiquitous learning; mobile phones) have been well developed over the past decade. The research topics included in the four clusters are central to e-learning research; indeed, scholars have obtained an enhanced understanding of the relationships between these topics. The findings indicate that these topics are the mainstream topics in e-learning field that are very likely to remain in e-learning research in the future. Thus, future research should keep researching on these core topics in e-learning field.

The findings in this study implies that e-learning research has undergone a healthy evolution over the past two decades. New e-learning techniques emerge that are then researched and absorbed into the existing knowledge landscape, advancing the whole field. In this trend, different journals have exhibited different preferences over research topics, while their efforts jointly shape and impel the future development of the field.

Limitations and future research directions

The current study has several limitations. First, the study investigated the keywords from 10 journals in the e-learning field from 1999 to 2018. Therefore, the research findings may lead to a deviation from the evolution of the entire e-learning field. Thus, future research can include more journals and even conference proceedings in e-learning field to obtain a more complete understanding of the knowledge picture of the field. Second, although this study offers a description of the existing knowledge structure of the field, contributions from various research institutions and scholars are not studied. Future research can apply other bibliometric methods (such as a co-citation and co-authorship analysis) to help identify the research contributions of research institutions and scholars in the e-learning field.

Appendix 1

See Fig. 7.

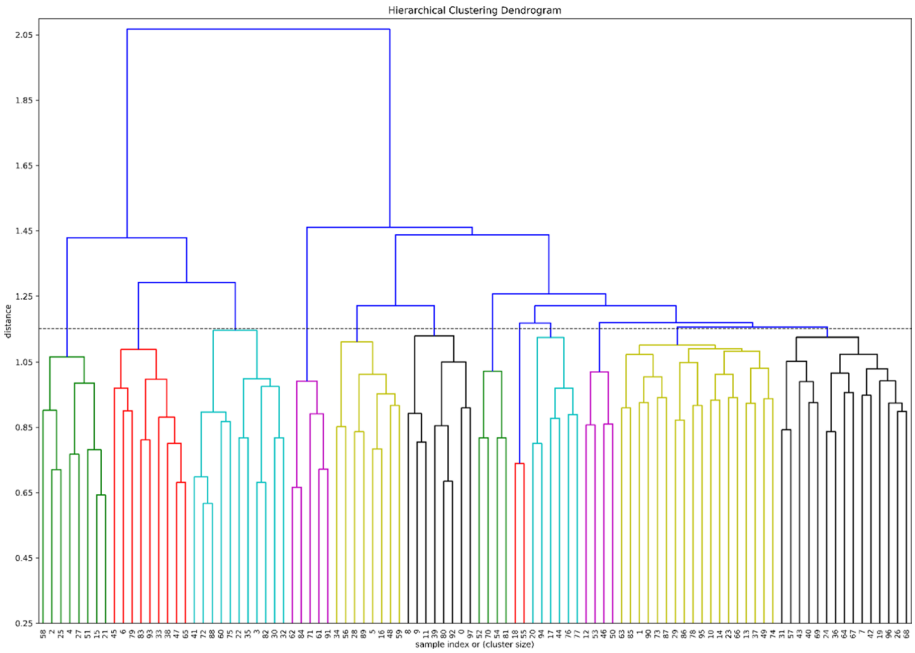


Fig. 7 Hierarchical clustering analysis for the keywords, 1999–2008

Appendix 2

See Fig. 8.

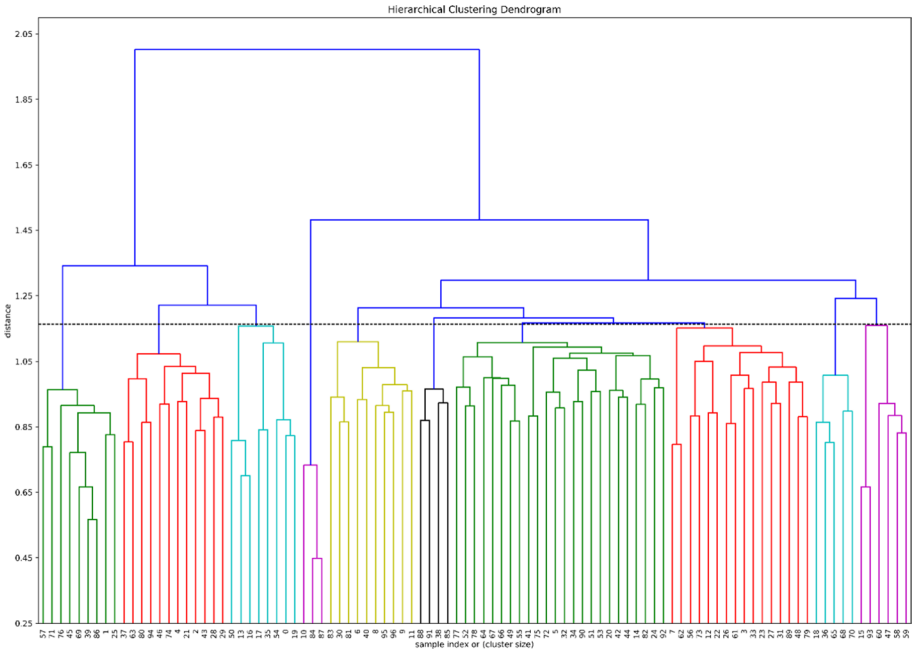


Fig. 8 Hierarchical clustering analysis for the keywords, 2009–2018

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