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Development Trends and Analysis of Collaborative Learning in E-Learning Environments 1988-2019

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ABSTRACT

This study applies the bibliometric method to review research in collaborative learning in e-learning and analyzes the trends of research on this topic. Using quantitative tools of science mapping, 8,575 papers in the Scopus database, prior to and including 2019, were reviewed, tracing back to 1988. Retrospective analysis uncovers continuing trends in research by way of topic-related sequence and geographic differences in sub-topics by space; moreover, further analysis is undertaken on the structure of knowledge bases. This reveals that the journals of highest impact include Computers in Human Behavior*,* Computers & Education*, and* Journal of Computer Assisted Learning*, while the most impactful authors are Barolli, Caballé, Chen, Daradoumis, Dimitriadis, Li, Li, Sterbini, Temperini, Tsiatsos, and Xhafa. This paper concludes that the bibliometric method can target a broad range of research; topics related to applied science and emerging technologies are still to be studied. Research topics are cross-border, not limited to geographically close nations.*

KEYWORDS

Bibliometric Method, Collaborative Learning, E-Learning

1. INTRODUCTION

Most past review papers of research on Collaborative Learning in e-Learning have included just a few countries in their sample (Al-Samarraie & Saeed, 2018; Chavez & Romero, 2012; Dado & Bodemer, 2017; Jeong, Hmelo-Silver & Yu, 2014; Schwendimann, De Wever, Hämäläinen, & Cattaneo, 2018). In view of the massive differences in societal transition over time and the widely differing circumstances in the research world of each country, it is not a given that research results are highly mobile, no matter in terms of time or space. Previously, Tang, Tsai and Lin (2014) conducted a co-citation network analysis on 2006-2013 research publications on topics related to computer-supported collaborative learning, exploring relevant sequences; however, no more comprehensive evaluation has been carried out in this field. Thus, this paper employs a search for synonymous keywords frequently used in recent years, expands the time span of the searches to conduct a comprehensive evaluation through time Sequence, geographic Space and knowledge base Structure. Hence, through the application of scientific landscape mapping, the knowledge base related to Collaborative Learning in e-Learning are analyzed to answer the following research questions:

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Question 1: What is the status of research literature volume and its growth in the area of Collaborative Learning in e-Learning? [corresponding to Sequence]
Question 2: What are the geographic origins of research in the area of Collaborative Learning in e-Learning according to volume and distribution? [corresponding to Space]
Question 3: Which journals, authors, and papers have the biggest impact on research in the area of Collaborative Learning in e-Learning? [corresponding to Structure]

The terminology in research topics related to Collaborative Learning in e-Learning in recent years is not exactly the same across the board; for example: Collaborative e-learning (Calle-Alonso et al., 2017; Marie O. Robles, 2017; Salim & Systems, 2017), Computer-supported collaborative learning (Chen, Wang, Kirschner, & Tsai, 2018; Jeong, Hmelo-Silver, & Jo, 2019; Xia & Borge, 2019), Online collaborative learning (Fernández-Ferrer & Cano, 2016; Muuro, Oboko, & Wagacha, 2016; Saqr, Fors, & Tedre, 2018), and so forth, all include the meaning of learners learning together with the aid of digital tools. In this paper, e-CL is used as an abbreviation of this theme. Quantitative tools of scientific landscape mapping (Small, 1999) are used in this paper to search e-CL papers in the Scopus database, prior to and including 2019; and the bibliometric method (Zupic & Čater, 2015) is used for analysis. This study aims to analyze and provide understanding about the global e-CL knowledge base.

2. CONCEPTUAL FRAMEWORK

First, the dimension of Sequence is analyzed on papers already published, through which we can see the growth or diminishing of related research, which can reveal the research publication growth trajectory. (Hallinger, 2018b). Second the Space dimension of already published research results is analyzed, which refers to the geographic distribution status. This is important as current research review papers are mostly focused on results from research in a minority of countries (Al-Samarraie & Saeed, 2018; Chavez & Romero, 2012; Dado & Bodemer, 2017; Jeong et al., 2014; Schwendimann et al., 2018) rather than being representative of all nations around the world. However, there are researchers from more and more countries around the world actively conducting e-CL research, so it is obviously of increasing importance to understand the pulse of related research in diverse nations. Thirdly, the Structure dimension is analyzed, that is the intellectual structure of the subjects comprising this field of research, research topics and the relationship between them (Zupic & Čater, 2015). Researchers in this study make use of research paper sources, authors, titles and keywords in the analysis.

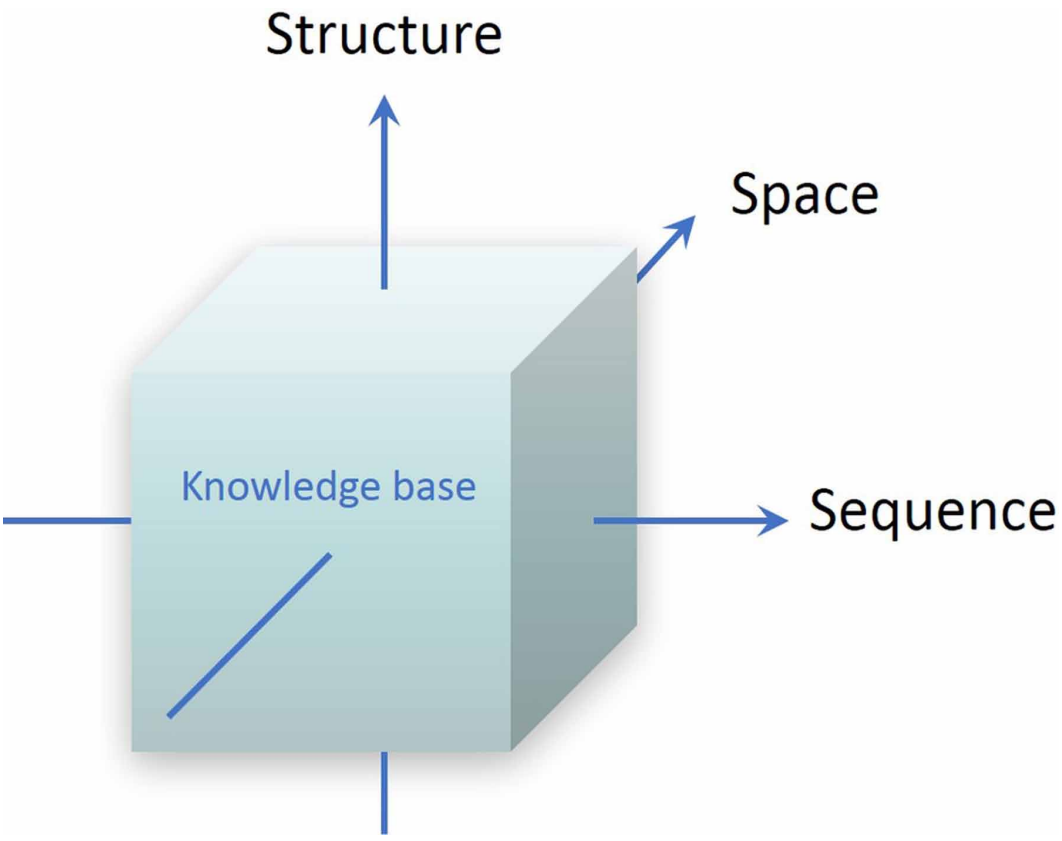
Employing what the authors term as the 3S conceptual framework of Sequence, Space and Structure (Figure 1) described above, this research conducts an analysis of the e-CL knowledge base to answer the three research questions posed in this paper with the purpose of discovering the locus of the knowledge base as well as its scope and boundaries. Formation of the Sequence dimension can reveal trends of past and future research, while the Space dimension can illustrate the research status and differences of each country, whereas which journals, authors and papers have the biggest impact is shown through the Structure dimension. Together, these three dimensions form the conceptual framework of the knowledge base; besides defining its boundaries, they also indicate categories where effort can be directed in future research.

3. RESEARCH TOOLS AND METHODS

3.1 Origin of Search Standards and Definitions

To surface and analyze the status of applying collaborative learning in e-learning, this study takes Scopus as its search base. As the largest citation database of academic literature in the world, the Scopus database encompasses a very broad range of subjects, so can be considered a representative

Figure 1. 3S Conceptual Framework of e-CL Knowledge Base



global index. Using the search terms Collaborat* AND e-Learning OR Online learning as keywords, with no beginning date restrictions through and including 2019, a search of the literature turns up 8,610 entries. The literature types originally included comprise: Article, Book Chapter, Book, Conference Paper, Review, Editorial, Article in Press, and so on. Each type of literature has varying degrees of contribution, but in order to elevate the degree of rigor for analysis of the literature, it was decided to narrow the sample to include only complete publications. This results in 8,575 pieces of data comprising six types of literature being included in the sample for analysis: Article (2,186), Book Chapter (355), Book (37), Conference Paper (5,579), Conference Review (296), and Review (122).

As the data was being organized, it was discovered that when some countries and parts of names were entered into the Scopus database, there were some discrepancies in spelling or expression that resulted in differences. In order to improve accuracy in the succeeding analysis, these discrepancies were resolved by unifying the expressions with the same meaning. For example, among country names, USA and United States were combined; in journal names, Computer and Education and Computer & Education were combined; within keywords, CSCL, Computer Supported Collaborative Learning and Computer-Supported Collaborative Learning were combined, and so forth.

3.2 Data Analysis

The bibliometric method is a supplemental tool for one type of traditional literature review. This analysis can provide researchers with useful information about a field of research, such as: What are the important publications and who are the important authors in this field? What is the geographic structure of this field? What are the trends and directions of research in each country? It can also

provide additional information on the structured literature review. Compared to a summary of the literature, scientific landscape mapping provides a macro perspective. Traditional literature review provides depth, while the bibliometric method can process a range of research literature that numbers in the hundreds, or even thousands.

VOS scientific landscape mapping is one type of tool used in quantitative method design, and uses several data analysis methods, such as simple descriptive statistics to describe the basic time and space characteristics of the literature (such as size, geographic distribution, theme distribution) and knowledge base dynamics (such as time series analysis) (Hallinger, 2018a, 2018b; Hallinger & Bryant, 2013).

In bibliometric research, distance-based maps are maps in which the distance between two items reflects the strength of the relationship between the items. A smaller distance generally indicates a stronger relationship and will gather the items into a cluster. Clusters do not need to exhaustively cover all items in a map; there may be items that do not belong to any cluster. A cluster is a set of items included in a map; items may be grouped into clusters. (Van Eck & Waltman, 2010, 2013, 2017).

4. RESULTS

The results of analyzing the e-CL knowledge base are presented in this section according to the three research questions of this study.

4.1 Volume of Literature and Growth Trajectory

Employing the search criteria described above, 8,575 related pieces of literature are retrieved from the Scopus citation index, from the earliest by Hiltz (1988) in which computer software was used to assist in teaching and collaborative learning in setting up a Virtual Classroom; when this was compared to traditional classroom, totally online and mixed mode, students generally felt that the virtual classroom provided a fine learning experience. The succeeding decade saw only scattered publications in this field; only in 2000 did the trend begin to accelerate. In the three years from 2017 to 2019, a period of explosive growth in this field of research, there were a total of 2,165 papers, accounting for 25% of the total, with the most in 2019, at 779 (Figure 2).

The most frequently appearing author keywords are retrieved from an author keyword co-occurrence analysis applied to the 8,575 papers, the results of which can produce an author keyword map (Figure 3). Filtering out the keywords used in this study's search (collaborat*, e-learning, online learning), common related terms in this field (education, learning), and closely related phrases (distance learning, CSCL, computer-supported collaborative learning), the most commonly used keywords in order of frequency are: mobile learning, blended learning, higher education, Web2.0, collaborative filtering, virtual reality, knowledge management, MOOC, wiki, and learning analytics. The author keyword map uses colors to illustrate the popularity of these keywords over recent years (Figure 3). The commonly appearing keywords Web2.0, knowledge management and wiki seldom appeared prior to 2010, only suddenly soaring in popularity after 2010. Then there was a gradual shift to mobile learning, blended learning, higher education and collaborative filtering. Around 2015, virtual reality, MOOC and learning analytics rose in popularity and it can be seen that these themes appear frequently in the recent years of e-CL literature.

4.2 Geographic Distribution

The contributions from countries all over the world to e-CL research is not evenly distributed; papers from the United States and the United Kingdom account for 25% of the total for countries with over 100 publications each (Figure 4). These 26 countries can be considered the major contributors to this research, accounting for 90% of the total.

Figure 2. Growth Trajectory of e-CL Knowledge Base

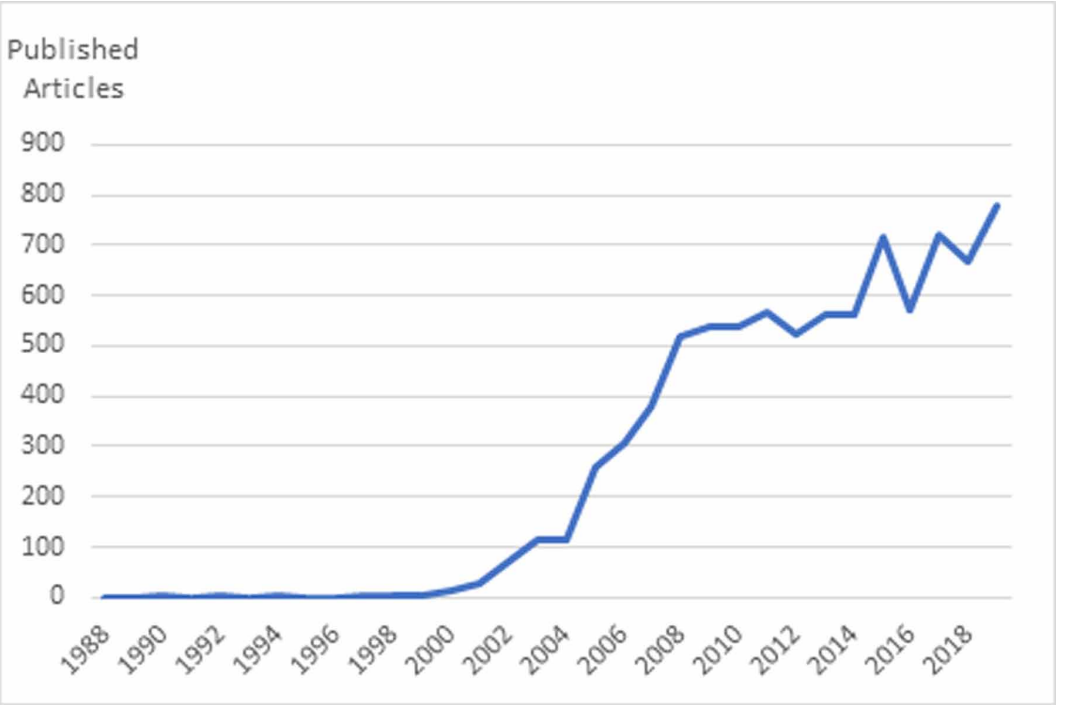
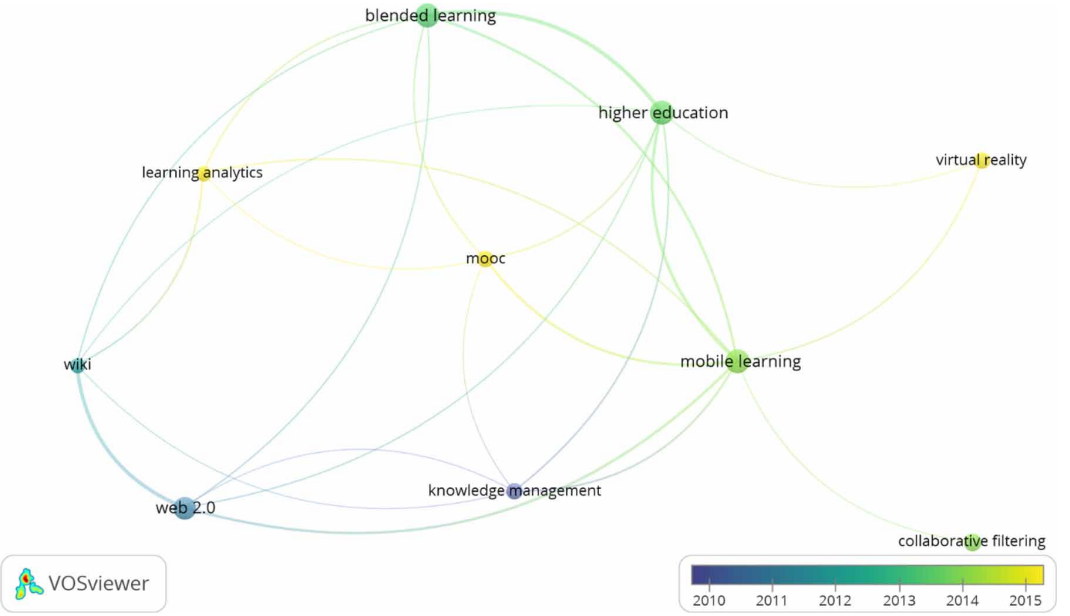


Figure 3. Author Keyword Map of e-CL Knowledge Base



A citation analysis on the literature from these 26 nations, taking into account the frequency and relationship of literature mutually cited, divides them into four clusters (Figure 5), which are shown below:

Cluster 1: China, France, Germany, Hong Kong, India, Malaysia, Norway, Romania, Taiwan
Cluster 2: Australia, Austria, Brazil, Greece, Ireland, Italy, Portugal, Spain
Cluster 3: Canada, Denmark, South Africa, Sweden, United Kingdom, United States
Cluster 4: Japan, Finland, Netherland

It can be clearly seen that these clusters are not formed from geographic proximity; for example, the Scandinavian nations of Norway, Denmark and Finland are found in separate clusters, while geographically distant Finland, Japan and the Netherlands are in the same cluster. Following, within the clusters, co-occurrence analysis was applied to author keyword to find the top 20 keywords in each cluster. After the filtering out the keywords used in this study's search, common related terms in this field and closely related phrases, the author keywords common to all of the clusters are: mobile learning, blended learning, and higher education, which can be seen as the focus of e-CL-related research being carried out all over the world. Moreover, virtual reality and web2.0 are common author keywords to clusters 1, 2 and 3, while learning analytics is common to clusters 2, 3 and 4 and knowledge management is a common author keyword to clusters 1 and 2, illustrating the common topics of research among these clusters. The most frequently appearing author keywords in individual clusters are collaborative filtering, MOOC, learning management system, wiki, and cloud computing in cluster 1; learning design, lifelong learning and assessment in cluster 2; social media and technology in cluster 3; and gamification, Moodle and project-based learning in cluster 4.

Figure 4. Global Distribution of e-CL Literature

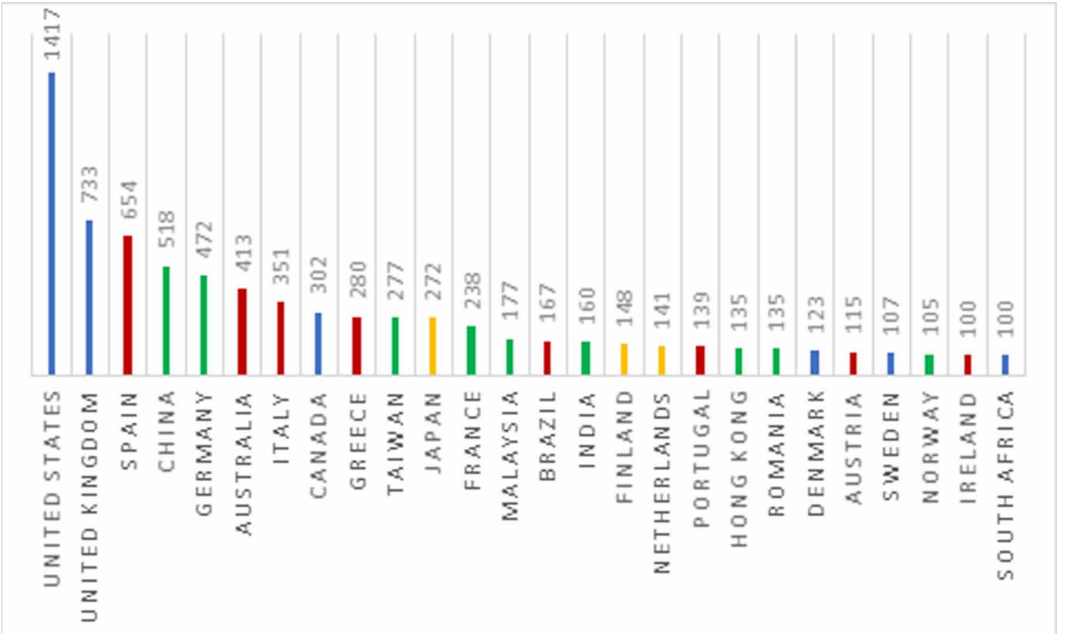
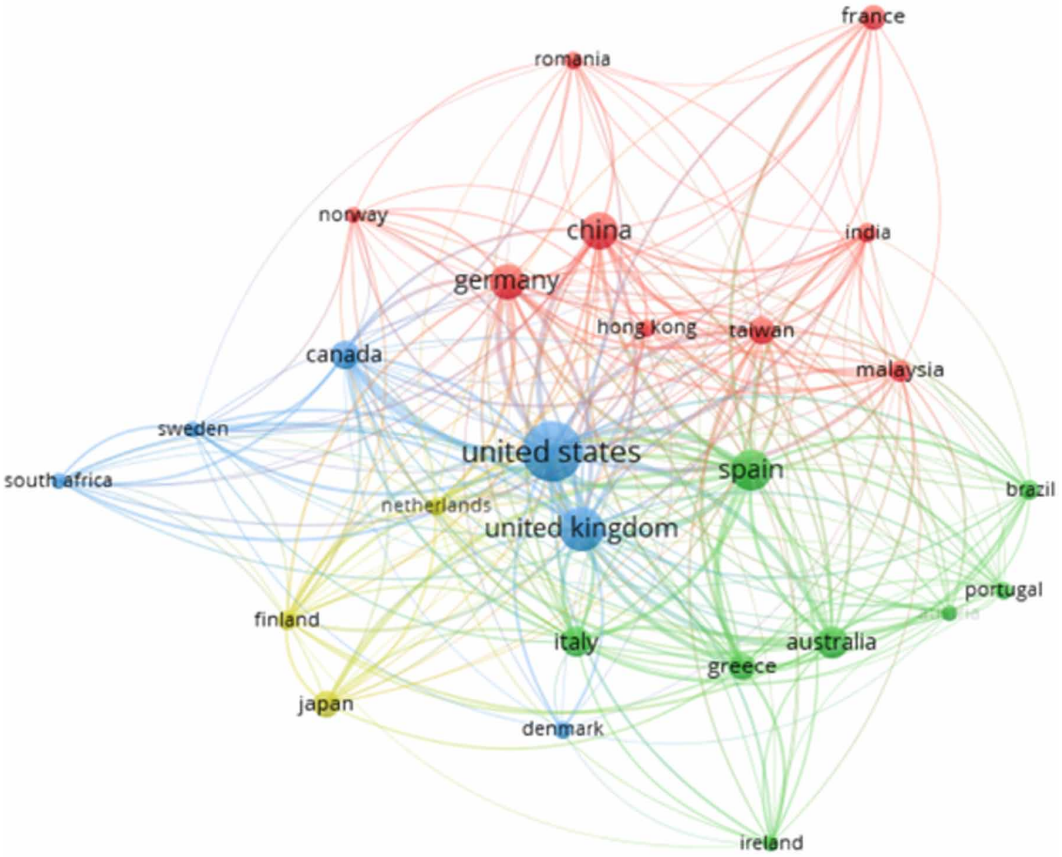


Figure 5. Country Cluster Map of e-CL Knowledge Base



4.3 Influential Journals, Literature and Authors

4.3.1 Journals with Impact

Among all the papers and citations searched in this research, the citation count amounts to a grand total of 83,970; from among these diverse sources, the 20 most frequently occurring publication sources account for at least 355 citations. Computers in Human Behavior heads up a cluster of nine journals, wherein 92 of the e-CL papers are published, cited a total of 5,040 times. Computers & Education heads up a cluster of seven journals, wherein 271 of the e-CL papers are published, cited a total of 7,021 times. Journal of Computer Assisted Learning heads up a cluster of four journals, wherein 54 of the e-CL papers are published, cited a total of 2,489 times. According to published papers and citation frequency, the average citations for papers in the Computers & Education cluster exceeds that in the other two groups by at least 400 citations. The journal in this cluster with the highest number of publications is British Journal of Educational Technology, with 69 papers, far more than those of any journal in the other clusters. From this, it can be known that, in the area of e-CL research, journals in the second cluster have greater impact (Table 1).

Citation data shows that among the 20 journals (Table 2) with the highest correlation of citation frequency, nine of these are not included in the list of those publishing the 8,575 papers in this study, which illustrates that e-CL theory originates from specializations in other fields. Thus, in pushing this exploration deeper through the journal keywords in the three clusters of journals, the researchers found distribution in other related fields.

Table 1. Journal Cluster of the e-CL Knowledge Base

Computers in Human Behavior	Computers & Education	Journal of Computer Assisted Learning
International Journal of Computer-Supported Collaborative Learning	British Journal of Educational Technology	Educational Technology & Society
Educational Technology Research and Development	The Internet and Higher Education	Communications of the ACM
Educational Psychologist	Journal of Asynchronous Learning Networks	MIS Quarterly
Learning and Instruction	Australasian Journal of Educational Technology	
Review of Educational Research	Distance Education	
Educational Researcher		
Journal of the Learning Sciences		
Instructional Science		

Table 2. The 20 Most Important Publications

Publications	Cluster	citations	total link strength
Computers in Human Behavior	1	1384	11769
International Journal of Computer-Supported Collaborative Learning	1	549	4358
Educational Technology Research and Development	1	528	3830
Educational Psychologist	1	466	3719
Learning and Instruction	1	462	4074
Review of Educational Research	1	456	3346
Educational Researcher	1	421	2086
Journal of The Learning Sciences	1	419	2446
Instructional Science	1	355	2944
Computers & Education	2	3571	22563
British Journal of Educational Technology	2	1148	8027
The Internet and Higher Education	2	704	5733
Journal of Asynchronous Learning Networks	2	427	3104
Australasian Journal of Educational Technology	2	407	2946
Distance Education	2	402	2560
Internet and Higher Education	2	362	3229
Journal of Computer Assisted Learning	3	813	6112
Educational Technology & Society	3	706	4554
Communications of The Acm	3	544	1441
Mis Quarterly	3	426	2295

In the nine-journal cluster headed by Computers in Human Behavior, wherein 92 of the e-CL papers are published, there are a total of 354 author keywords. The 10 most highly correlated appear at least four times in papers in this cluster. In the seven-journal cluster headed by Computers & Education, wherein 271 of the e-CL papers are published, the author keywords total 419. The 10 most highly correlated appear at least 13 times in papers in this cluster. In the four-journal cluster headed by Journal of Computer Assisted Learning, wherein 54 of the e-CL papers are published, the total author keywords count is 203. The 10 most highly correlated appear at least two times in papers in this cluster. Among the three clusters, aside from the keywords of collaborative learning and e-learning, higher education and mobile learning are commonly occurring keywords in cluster 1 and cluster 3 (Table 3), illustrating that higher education and mobile learning are important themes in the e-CL field of research.

Table 3. Keywords of the Three Clusters in e-CL Knowledge Base

Computers in Human Behavior	Computers & Education	Journal of Computer Assisted Learning
social networks	interactive learning environments	collaborative filtering
***higher education**	computer-mediated communication	recommender systems
***mobile learning**	teaching/learning strategies	*higher education
learning analytics	learning communities	*mobile learning
social media	pedagogical issues	ubiquitous learning

Note: *indicates keywords that are duplicated in different clusters

4.3.2 Literature with Impact

The 8,575 publications in this study are also analyzed for the 20 most frequently cited, as the most important papers in the e-CL field; each is cited at least 197 times, as shown in the following table. Among them, 10 are published in the Computers & Education journal, including the five most frequently cited papers, which illustrates the importance of this journal in the e-CL field (Table 4).

The 8,575 publications from the Scopus database studied in this research have a total of 27 research field correlations. Those accounting for over 1% of the related publications belong to the nine research fields of Computer Science; Social Sciences; Engineering; Mathematics, Business, Management and Accounting; Decision Sciences; Medicine; Arts and Humanities; and Psychology (Table 5). Among them, most are in Computer Science, followed by Social Sciences. Computer Science, Engineering, Mathematics, which, along with Arts and Humanities, are part of the STEAM disciplines, illustrating that e-CL research in STEAM fields is very popular; however, there is relatively little research in Technology.

4.3.3 Authors with Impact

Among the 8,575 papers analyzed in this research, there are 17,903 authors. The top 20 cited authors each published at least 15 papers related to e-CL. Analysis of the correlation between authors' mutual citations and co-authoring results in forming the author clusters of: [Xhafa, Caballé, and Barolli], [Li, Li and Chen], [Daradoumis, Tsiatsos and Dimitriadis] and [Temperini and Sterbini]. Being clustered together shows that there is significant correlation between them regarding co-authoring or mutual citations, indicating that their areas of research are closely related. Although nine authors – Gillet, Kim, Okamoto, Rummel, Trausan-Matu, Wang J., Wang X., Zhang J. and Zhang X. – collectively published more e-CL research papers than others, little correlation is found between them in regard to citations or collaborative publication.

Table 4. Top 20 Important Publications in e-CL Knowledge Base

Publication	Citations	Title	Contributions / Focus in e-CL	Source
Cheung R. (2013)	254	Predicting user acceptance of collaborative technologies: An extension of the technology acceptance model for e-learning	The ability to share information in the collaborative learning environment is found to influence intention and behavior toward the Google Applications platform.	Computers & Education
Mikropoulos T.A. (2011)	286	Educational virtual environments: A ten-year review of empirical research (1999–2009)	This study is a ten-year critical review of empirical research on the educational applications of Virtual Reality. Findings show that collaboration and social negotiation are not only limited to the participants of an EVE, but exist between participants and avatars, offering a new dimension to computer assisted learning.	Computers & Education
Jones C. (2010)	387	Net generation or Digital Natives: Is there a distinct new generation entering university?	This study found that new technology was often used in ways that did not fully correspond with the expectations that arise from the Net generation and Digital Natives theses. The authors find that the generation is not homogenous in its use and appreciation of new technologies and that there are significant variations amongst students that lie within the Net generation age band.	Computers & Education
Macfadyen L.P. (2010)	437	Mining LMS data to develop an "early warning system" for educators: A proof of concept	This paper confirms and extends how higher education institutions could harness the predictive power of Learning Management System (LMS) data to develop reporting tools that identify at-risk students and allow for more timely pedagogical interventions. A growing body of research on teaching and learning in higher education emphasizes the adoption of learner-centered pedagogical approaches and the critical importance of encouraging student–student interaction/collaboration, promoting active learning, providing prompt and detailed feedback, and stressing the need for time on task, whilst also respecting the diverse modes of learning.	Computers & Education
Paechter M. (2010)	271	Students' expectations of, and experiences in e-learning: Their relation to learning achievements and course satisfaction	This study investigates how different facets of students' expectations and experiences are related to perceived learning achievements and course satisfaction and relevance. Students' achievement goals were the best predictors for success and ranked higher than other course characteristics. Furthermore, self-regulated and collaborative learning were related to learning achievements.	Computers & Education
Frohberg D. (2009)	223	Mobile Learning projects – a critical analysis of the state of the art	This paper provides a critical analysis of Mobile Learning projects published before the end of 2007. Discussion of the MOOP (Mattilaand Fordell 2005) project explains how the system is explicitly designed as a tool to support cooperative learning in school classes. The purpose of the system is to bring different observations from nearby surroundings into the classroom. The learners can create photos, videos and voice annotations with a GPS location tag, exchange them and work with them, collaboratively generating their own knowledge.	Journal of Computer Assisted Learning

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Table 4. Continued

Publication	Citations	Title	Contributions / Focus in e-CL	Source
Hoic-Bozic N. (2009)	198	A Blended Learning Approach to Course Design and Implementation	This paper describes the use of the blended e-learning model, which is based on a mixture of collaborative learning, problem-based learning and independent learning. Supporting collaborative and project-oriented activities promotes students' motivation for learning and establishes learning as an active and interactive process. A survey conducted in the end of the course showed that students were satisfied with the pedagogical approach, and their academic achievements were also better than expected. Particularly important is that the dropout rate was greatly diminished, which could be related to students' satisfaction with the support they received from the instructor and the system.	IEEE Transactions on Education
De Lucia A. (2009)	242	Development and evaluation of a virtual campus on Second Life: The case of Second DMI	The study conducted an experiment involving university students aiming at evaluating Second Life synchronous distance lectures in the virtual campus learning environment. The evaluation has been conducted considering that, in a 3D multi-user virtual environment, learning is strongly related to the user perception of belonging to a learning community, as well as to the perception of awareness, presence and communication. The results of the evaluation are very positive.	Computers & Education
So H.-J. (2008)	438	Student perceptions of collaborative learning, social presence and satisfaction in a blended learning environment: Relationships and critical factors	The purpose of this study was to examine the relationships of the students' perceived levels of collaborative learning, social presence and overall satisfaction in a blended learning environment. The analysis of quantitative data indicated that student perceptions of collaborative learning have statistically positive relationships with perceptions of social presence and satisfaction. This means that students who perceived high levels of collaborative learning tended to be more satisfied with their distance course than those who perceived low levels of collaborative learning. Similarly, students with high perceptions of collaborative learning perceived high levels of social presence as well.	Computers & Education
Monahan T. (2008)	197	Virtual reality for collaborative e-learning	This article presents research in this area and the resulting development of CLEV-R, a Collaborative Learning Environment with Virtual Reality. The mobile version of CLEV-R provides access to course announcements, communication with other users and the ability to download course notes through an interactive 3D environment.	Computers & Education
Motiwalla L.F. (2007)	495	Mobile learning: A framework and evaluation	This project explores the extension of e-learning into wireless/handheld computing devices with the help of a mobile learning framework. A prototype application was developed to link wireless/handheld devices to three course websites. The results from this exploratory study provide a better understanding on the role of mobile technology in higher education.	Computers & Education

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Table 4. Continued

Publication	Citations	Title	Contributions / Focus in e-CL	Source
De Laat M. (2007)	218	Investigating patterns of interaction in networked learning and computer-supported collaborative learning: A role for Social Network Analysis	The focus of this study is to explore the advances that Social Network Analysis can bring, in combination with other methods, when studying Networked Learning/Computer-Supported Collaborative Learning (NL/CSCL). The study presents a general overview of how SNA is applied in NL/CSCL research and illustrates how this research method can be integrated with existing studies on NL/CSCL as a way to synthesize and extend our understanding of teaching and learning processes in this context.	International Journal of Computer-Supported Collaborative Learning
Kamel Boulos M.N. (2006)	667	Wikis, blogs and podcasts: a new generation of Web-based tools for virtual collaborative clinical practice and education	This study discusses how effectively deployed wikis, blogs and podcasts could offer a way to enhance students', clinicians' and patients' learning experiences, and deepen levels of learners' engagement and collaboration within digital learning environments. Of particular importance is research into novel integrative applications, to serve as the "glue" to bind the different forms of Web-based collaboration tools synergistically in order to provide a coherent learning experience.	BMC Medical Education
Hernańdez-Leo D. (2006)	214	COLLAGE: A collaborative Learning Design editor based on patterns	This paper introduces Collage, a high-level IMS-LD compliant authoring tool that is specialized for CSCL (Computer-Supported Collaborative Learning). Nowadays CSCL is a key trend in e-learning since it highlights the importance of social interactions as an essential element of learning. An example of a Learning Design (LD) that can be created using Collage is illustrated in the paper. Preliminary evaluation results show that teachers with experience in CL but without LD knowledge, can successfully design real collaborative learning experiences using Collage.	Journal of Educational Technology & Society
Ruiz J.G. (2006)	880	The Impact of E-Learning in Medical Education	The authors provide an introduction to e-learning and its role in medical education by outlining key terms, the components of e-learning, the evidence for its effectiveness, faculty development needs for implementation, evaluation strategies for e-learning and its technology, and how e-learning might be considered evidence of academic scholarship. Innovations in e-learning technologies point toward a revolution in education, allowing learning to be individualized (adaptive learning), enhancing learners' interactions with others (collaborative learning), and transforming the role of the teacher.	Academic Medicine
Paavola S. (2005)	278	The Knowledge Creation Metaphor – An Emergent Epistemological Approach to Learning	This paper reviews three approaches to knowledge-creation, i.e., Bereiter's knowledge-building, Engestr□m's expansive learning, and Nonaka and Takeuchi's organizational knowledge-creation. It gives a concise analysis of the trialogical character of the knowledge-creation approach and illustrate how the third metaphor may be applied at the school level.	Science & Education

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Table 4. Continued

Publication	Citations	Title	Contributions / Focus in e-CL	Source
Sadiq S.W. (2005)	209	Specification and validation of process constraints for flexible workflows	This paper presents a foundation set of constraints for flexible workflow specification. These constraints are intended to provide an appropriate balance between flexibility and control. The constraint specification framework is based on the concept of "pockets of flexibility" which allows ad hoc changes and/or building of workflows for highly flexible processes. The workflow concepts have been used to support non-coordinative (collaborative) processes. speaks of ad hoc workflows, where the process cannot be completely defined prior to execution. It also discusses the coordination of collaboration intensive processes.	Information Systems
Chen C.-M. (2005)	307	Personalized e-learning system using Item Response Theory	To determine an appropriate level of difficulty parameter for the course materials, this study proposes a collaborative voting approach for adjusting course material difficulty. Experiment results show that applying Item Response Theory to Web-based learning can achieve personalized learning and help learners to learn more effectively and efficiently. In the proposed system, the difficulty of the course material can be dynamically tuned using the proposed collaborative voting approach after learners offer feedback.	Computers & Education
Sharples M. (2002)	215	The Design and Implementation of a Mobile Learning Resource	This article describes the theory-informed design, implementation and evaluation of a handheld learning device. It is intended to support children to capture everyday events such as images, notes and sounds, to relate them to web-based learning resources, and to organize these into a visual knowledge map. Learning is a continual conversation: with the external world and its artefacts, with oneself, and also with other learners and teachers. The most successful learning comes when the learner is in control of the activity, able to test ideas by performing experiments, asking questions, collaborating with other people, seeking out new knowledge, and planning new actions.	Personal and Ubiquitous Computing
David Merrill M. (2002)	691	First principles of instruction	This paper identifies prescriptive principles that are common to the various theories of instruction. Representative instructional design theories include: Star Legacy by the Vanderbilt Learning Technology Center, 4-Mat by McCarthy, instructional episodes by Andre, multiple approaches to understanding by Gardner, collaborative problem solving by Nelson, constructivist learning environments by Jonassen, and learning by doing by Schank. It is concluded that, although they use a wide variety of terms, these theories and models do include fundamentally similar principles.	Educational Technology Research and Development

Table 5. Important Research Fields in e-CL

Research Field	No. of Papers	Percentage of Total Papers
Computer Science	**6,347**	42.08%
Social Sciences	**4,106**	27.22%
Engineering	1,747	11.59%
Mathematics	945	6.27%
Business, Management and Accounting	374	2.48%
Decision Sciences	363	2.41%
Medicine	272	1.81%
Arts and Humanities	173	1.15%
Psychology	150	1%

From among those mentioned above who have published at least 15 papers in this field and have the highest number of citations in this field, the top 20 authors are divided into four clusters based on the similarity of their publications. Using Author as the search filter, author keyword co-occurrence analysis is carried out once again using VOS software on all publications in this field for each cluster of authors. Once the keywords of collaborative learning and e-learning set for this research are removed, the result of the analysis is a list of the five most commonly occurring keywords for each cluster of authors, from which the research topics receiving most attention by each author cluster can be seen (Table 6).

5. DISCUSSION AND CONCLUSION

5.1 Research Findings

The major findings from the bibliometric analysis of the 8,575 publications on the e-CL theme in this research are: (1) the focus on e-CL-related research continues to grow; (2) research related to e-CL is not evenly distributed geographically in terms of volume of publications and the geographic distribution is not clustered according to proximity; (3) the journals with the most impact in e-CL research are: Computers in Human Behavior, Computers & Education and Journal of Computer Assisted Learning; (4) the most impactful authors in e-CL research are: Barolli, Caballé, Chen,

Table 6. Keywords of Four Author Clusters in the e-CL Knowledge Base

Xhafa F., Caballé S., Barolli L.	Li X., Li Y., Chen W.	Daradoumis T., Tsiatsos T., Dimitriadis Y.	Temperini M., Sterbini A.
e-assessment	blended learning	affective feedback	adaptive e-learning
emotion awareness	collaboration	emotion	assessment
information security	collaborative filtering	emotion awareness	reputation system
trustworthiness	collaborative virtual maintenance	orchestration	student modeling
virtualized collaborative sessions	semantic wiki		zone of proximal development

Daradoumis, Dimitriadis, Li, Li, Sterbini, Temperini, Tsiatsos and Xhafa; (5) 10 of the 20 papers with the highest impact in e-CL research are published in Computers & Education, including those with the top five number of citations.

5.2 Research Limitations

The citation values for the papers found in the search of this study vary slightly, which may be due to a linear impact on a small portion of the data or that when the paper was entered into the Scopus database, explanation of some data was not provided. For example, regarding the country of origin for publications, 351 of them are marked as Undefined, which results in slight discrepancies in data calculation. As these slight discrepancies do not affect the analysis of trends in this research, no deeper analysis of them is addressed in this study.

5.3 Conclusion

5.3.1 e-CL Research is Currently Primarily Targeted on Tertiary Education

Through author keyword analysis it is found that Higher Education appears very often in this whole knowledge base and is a high frequency keyword in each of the clusters of nations, which illustrates that e-CL research is developing vigorously in higher education, while much less in K-12. In terms of journals with impact in e-CL research, publications related to higher education are mostly published in the nine-journal cluster headed by Computers in Human Behavior and the four-journal cluster headed by Journal of Computer Assisted Learning.

5.3.2 e-CL Research is Extensively Applied in Specific Subjects, not to Minor Subjects

Through the source journal analysis of the 8,575 publications, it can be seen that journals in the fields of Sciences, Engineering, Mathematics, Business, Management and Accounting all contain e-CL research, illustrating that the research topic of e-CL is being extensively discussed in all fields. Combined, source journals in the Computer Science and Social Sciences fields account for 70% of the total. However, as some e-CL topics are essentially a combination of topics from these two fields, it cannot simply be inferred that e-CL is investigated most in Computer Science or Social Sciences subject applications.

5.3.3 e-CL Research Actively Integrates New Technology Applications

In the analysis of Author keyword in this Knowledge base, it is found that mobile learning, web2.0, virtual learning, MOOC and wiki appeared many times, indicating that these technologies are commonly combined in today's e-CL research. Moreover, this type of research is concentrated in the cluster of China, France, Germany, Hong Kong, India, Malaysia, Norway, Romania, and Taiwan. Among them, virtual learning and MOOC are research topics that have emerged in recent years.

5.3.4 Research Topic Borders

Citation analysis shows that there are cluster relationships among nations which are not simply formed based on geographic proximity. Through author keyword co-occurrence analysis, using the 'country' factor, it can be seen that national borders are blurred in this research topic, while the 'journal' factor exhibits a much stronger distinction. The keywords of the most prolific authors show little overlap between author clusters. These findings illustrate that regions of neighboring countries do not necessarily have similar research topic trends and research topics are frequently cross-border, but the topical focus of researchers and journals is much more long-term and stable.

Employing the 3S conceptual framework of Sequence, Space and Structure to analyze the e-CL knowledge base, it can be seen from the Sequence dimension that research in the e-CL field continues to draw much attention. Hot keywords after 2015 are virtual reality, MOOC, and learning analytics; however, the Sequence dimension also reveals that keywords continue to be hot for approximately 3-5

years. So, the 2018-2019 literature also commonly includes the following keywords: gamification, active learning, engagement, deep learning, interactive learning environments, flipped classroom, and augmented reality. Although the current usage frequency of these themes in the knowledge bank in not yet considered significant, the changes in Sequence indicate that these themes have much potential for future development in the e-CL field. The speed of Internet development has virtually broken through the limitations of geographic space; analysis of the Space dimension reveals the research trends that each nation is partial to, providing researchers with literature sources for consideration in regard to topics of interest. Moreover, analysis of the Structure dimension within the e-CL field reveals topics of interest in high impact journals, research contributions of important literature and most frequently cited authors in the e-CL field, which provides explicit research references for e-CL researchers regarding topics attracting attention in these disciplines.

Conflicts of Interest

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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