Chen, X., Yu, G., Cheng, G., & Hao, T. (2019). Research topics, author profiles, and collaboration networks in the top-ranked journal on educational technology over the past 40 years: a bibliometric analysis. *Journal of Computers in Education*, *6*(4), 563-585. https://doi.org/10.1007/s40692-019-00149-1

Research topics, author profiles and collaboration networks in a top ranked journal on educational technology over the past 40 years: A bibliometric analysis

Xieling Chen[1], Guoxing Yu[2], Gary Cheng[1], Tianyong Hao[3,*]

[1]Department of Mathematics and Information Technology, The Education University of Hong Kong, Hong Kong SAR

[2]School of Education, University of Bristol, United Kingdom

[3]School of Computer Science, South China Normal University, China

***Corresponding Author**

Tianyong Hao, Ph.D.

Professor

School of Computer Science

South China Normal University

Tianhe district, Guangzhou

Guangdong province, China

Email: haoty@m.scnu.edu.cn

Telephone: +86 15626239317

Abstract

Targeting at analyzing the research status and trend of the educational technology field, this study conducted a bibliometric analysis on research topics, author profiles and collaboration networks using a top ranked journal *Computers & Education* (ISSN: 0360-1315). Using the Web of Sciences database, we retrieved 3,963 articles published by the journal during the period 1978-2018. The annual distribution of articles demonstrates a significant increase in the journal publications, especially since 2005 to 2011. The scientific collaboration between authors, intuitions, and countries/regions has become increasingly close. The scientific collaboration rate between authors from the same institution, and from the same country/region, is relatively higher, compared with those from different ones. Keyword evolution analysis highlights some prevalent topics such as 'interactive learning environment', 'teaching/learning strategies', 'pedagogical issue', and 'improving classroom teaching'. Findings of this study provides a comprehensive overview of the articles on educational technology over the past 40 years.

Keywords: Educational research trend; Scientific collaboration; Bibliometric analysis; Keywords analysis

1. Introduction

Technologies have dramatically changed how we teach and learn (Martin et al., 2011), and technology-assisted learning or education is increasingly important in today's society. Learning and teaching activities are no longer limited to traditional environment (Hsu et al. 2012). The use of digital technologies has expanded to most aspects of education. Accordingly, the study of technology use in education has increasingly become an active research field. For example, Troussas et al. (2019) investigated on how game-based learning and mobile learning can be employed in the context of higher education and further analyzed the pedagogical affordance of their adoption. Aiming at motivating and promoting students' annotations behaviors and reading comprehension performance, respectively, Chen et al. (2019) proposed a web-based collaborative reading annotation system with a combination of gamification mechanisms.

There are review works about educational technology. For example, Chang and Hwang (2018) provided a systematic review of journal articles during the period 1998-2016 to investigate application domains, subjects, adopted learning strategies, and research issues. Tu and Hwang (2018) collected articles that were related to library-associated mobile learning from Scopus database during 2007 to 2016 to conduct a review of the types of sensing or location-based technologies, as well as learning strategies employed in library supported mobile learning. Hsu et al. (2012) reviewed 2,976 articles related to technology-based learning that were published during the period 2000-2009 in five journals with Social Sciences Citation Index (SSCI), namely, Computers & Education, the British Journal of Educational Technology, Educational Technology & Society, Educational Technology Research & Development, and the Journal of Computer Assisted Learning.

Bibliometric analysis is an important tool for the assessment and evaluation of academic research output. It is helpful for the progress of science in a variety of ways

(Martínez et al. 2015; Song et al. 2019), for example, identifying major scientific researchers, laying the academic foundation for the evaluation of new developments, developing bibliometric indexes to evaluate academic output, discovering hot research issues, and drawing insights for future research directions.

Bibliometric analysis has been widely implemented for providing an overview of a research field. For example, Song et al. (2019) conducted a bibliometric analysis of scientific articles relating to classroom dialogue to identify the development trends of articles and citations, recognize prolific journals, authors, and institutions, visualize the geographical distribution of articles in terms of countries/regions, visualize the collaboration among countries/regions, institutions, and authors, and uncover the evolution of top keywords with time. Chen et al. (2019d) explored the status and trend of the research field of event detection in social media based on a bibliometric analysis of academic articles published during 2009-2017. Other similar research with the adoption of bibliometrics include social media enhanced health research (Chen and Hao 2019; Chen et al. 2019c), artificial intelligence on electronic health records (Chen et al. 2018d), text mining in medical research (Hao et al. 2018), natural language processing empowered mobile computing (Chen et al. 2018b), natural language processing in medical research (Chen et al. 2018e), technology enhanced language learning (Chen et al. 2018c), natural language processing research (Chen et al. 2017a), and diabetes research (Chen et al. 2017b).

Bibliometric analysis has also been used to study the changing perspectives, voices and interpretations of theory, findings and practice in a particular journal. For example, Merigó et al. (2019) presented a bibliometric analysis of the articles in the journal Soft Computing to identify the leading trends. Their analysis showed that researchers around the world published regularly in Soft Computing, and the journal is growing significantly during the past years, becoming one of the leading journals in the field. In commemoration of the Anniversary 25th of Knowledge-Based Systems, Cobo et al. (2015) carried out a bibliometric analysis of the scientific article content of the journal during 1991-2014 by depicting the conceptual evolution of the journal, as well as some performance bibliometric indicators based on citations and h-index, and its most cited

authors/articles. *Computers & Education* is a top-ranked journal in the interdisciplinary research relating to computer and education. It has the purpose of increasing knowledge and understanding of ways where technology can enhance or promote education, through the publication of not only research papers but also systematic review papers and meta-analyses, in particular, on the technology use for teaching and learning. For example, Xie et al. (2019) conducted a systematic review of journal articles relating to technology-enhanced adaptive/personalized learning to explore the trends and developments of the research field from 2007 to 2017. Chen et al. (2019b) developed a digital interactive geographic map with global positioning system function to support location-based contextualized English as a foreign language learning. Therefore, a throughout overview of the journal provides insights and understanding of the development and status of the technology in education. By studying a typical journal targeting at both technologies and education, in particular, one with a high impact and wide influence like *Computers & Education*, can help capture the status and development of educational technology.

Regarding the fast-growing interests on education technology, a systematic review of high-quality articles in this field is expected. We thus choose the articles published on *Computers & Education*, which is the most established and prestigious journal with a high academic impact in educational technology field (Zawacki-Richter & Latchem, 2018), for the following two reasons. On the one hand, *Computers & Education* is the only one among the top three EDUCATION & EDUCATIONAL RESEARCH journals in Journal Citation Reports[1] to have a specific concern of the technology use in education. On the other hand, *Computers & Education* holds a wide focus on educational technology, thus receiving interest and attention from a broader education community.

The main aim of this paper is to carry out a thorough bibliometric analysis of the research conducted by *Computers & Education* from 1978 to 2018. In particular, we first present the evolution of the main characteristics (statistics of articles, citations,

[1] https://jcr.clarivate.com/

countries, institutions, and authors) of articles published on *Computers & Education*. Second, we conduct author analysis in terms of article count, H-index, co-authorship visualization, and topical distribution. Third, we visualize the geographic distribution of countries/regions, and identify top institutions and countries/regions by H-index. Finally, we identify top ranked keywords as well as their evolution across time.

This article is organized as follows: Section 2 introduces the dataset and method used. In Section 3, the results are presented. Section 4 provides discussions about some key findings. A final conclusion is drawn in Section 5.

2. Data and methods

2.1 Data preparation

We used Web of Science database to retrieve articles published on the journal *Computers & Education* on 6th July, 2019. Article retrieved were retained if they were: 1) of 'Article' type considering research articles usually present more original research findings (Geng et al. 2017); 2) published during the period 1978-2018. Based on the criteria, 3,963 articles with full bibliographic information as well as annual citations information were collected. We then extracted elements such as title, abstract, year of publishing, authors, authors' institutions and countries/regions for analysis.

In the keywords analysis, author-defined keywords as well as Web of Science Keywords Plus were used. The author-defined keywords were the keywords listed in each article and they were defined by the authors of the articles themselves. Article keywords are commonly used in bibliometric studies for topic detecting for the reason that they usually represent the major research focus of an article (Zhong, Geng, Liu, Gao, & Chen, 2016). Since there were 987 articles without providing keywords information. Thus, we followed the study by Song et al. (2019) to manually add keywords based on title and abstract information. For example, keywords 'automatic submission', 'evolutionary', and 'computer science teaching' were extracted from the title 'Automatic submission in an evolutionary approach to computer science teaching'. To enhance analysis efficiency, we pre-processed the keywords as follows. On the one hand, abbreviations were replaced by corresponding full-names (e.g., 'CALL' to

‘computer assisted language learning’, ‘CAI’ to ‘computer assisted instruction’, ‘CAL’ to ‘computer assisted learning’, ‘CSCL’ to ‘computer supported collaborative learning’, ‘EFL’ to ‘English as a foreign language’, ‘TAM’ to ‘technology acceptance model’, ‘ICT’ to ‘information and communication technology’). On the other hand, keywords with similar semantic meaning were grouped (e.g., ‘computer assisted learning’, ‘computer mediated learning’, and ‘computer enhanced learning’).

2.2 Methods

Methods applied in this study mainly include bibliometric indicators, social network analysis, geographic visualization, topic distribution of authors, keywords analysis, and affinity propagation clustering. Overall, the analysis of major characteristics helps researchers to understand the research status and research trend of this field more comprehensively.

First, to evaluate the performance of authors, institutions, and countries/regions, bibliometric indicators such as article count, citation count, and Hirsch index (H-index) were applied. Article and citation counts were considered as the most popular used indicators, assessing the academic productivity and impact, respectively (Ding, Rousseau, & Dietmar, 2014; Svensson, 2010). H-index was a type of comprehensive indictor for measuring both the academic quality and quantity (Peng et al., 2018). The evaluation of academic performance of authors, institutions, and countries/regions can help identify major actors contributing the most to the *Computers & Education* community.

Second, to visualize the scientific collaboration between prolific authors, a social network analysis (SNA) was conducted by using Gephi (Bastian et al. 2009). SNA uses networks and graph theory to investigate social structures (Otte and Rousseau, 2002), by constructing networked structures using nodes and links. In the constructed network, authors were donated by nodes, while links between them indicated the co-authorship. The productivity of authors and the collaboration times between two authors were visualized by node size and link width. Through the visualization of co-authorship, we can identify groups that were more likely to conduct research in a same area.

Third, to visualize the geographic distribution of the articles, a geographic visualization technique was used. Geographic visualization is a set of tools and techniques for the analysis of geospatial data by ways of interactive visualization. Through the visualization of the geographic distribution of the *Computers & Education* articles, we can more intuitively identify which countries/regions have contributed the most to the *Computers & Education* community.

Fourth, we also visualized the topic distribution of prolific authors based on results from structural topic modeling (STM) method. In STM, there were two tasks, namely, the estimation of document-topic distribution and topic-term distribution. With the document-topic distribution matrix, we constructed a topical proportions matrix of prolific authors, and then visualized the topical distributions by using Cluster Purity Visualizer (Swamy, 2016), javascript packages d3.v3.js[2], and clusterpurityChart.js[3]. Through the comparison of topical distributions of prolific authors, we can identify major authors that were more active in a particular or several area(s).

Last, based on a keyword co-occurrence analysis, a clustering analysis method is implemented to detect the major research themes. The emergence and evolution of frequently used keywords were identified by comparing four periods, i.e., 1978-1987, 1988-1997, 1998-2007, and 2008-2018. With the keyword co-occurrence matric obtained, a keyword correlation matrix was constructed by Ochiai correlation coefficient as Equation (1), in which O_{ij} was the co-occurrence probability of keywords W_i and W_j. A_{ij} was the co-occurrence frequency of the keywords W_i and W_j. A_i and A_j were the frequencies of the keywords W_i and W_j. With the keyword correlation matrix, affinity propagation (AP) clustering was then conducted using an R package *apcluster* (Bodenhofer et al. 2011). AP is a clustering algorithm based on the concept of "message passing" between data points (Frey and Dueck, 2007). Comparing with clustering algorithms like k-means or k-medoids, the major advantage of AP lies in the fact that it does not need to predefine the number of clusters. Through the

[2] https://d3js.org/d3.v3.js
[3] https://bl.ocks.org/nswamy14/raw/e28ec2c438e9e8bd302f/clusterpurityChart.js

clustering of high frequently used keywords, we can identify keywords that were more likely to occur in a same document.

$$O_{ij} = A_{ij}/\sqrt{A_i A_j} \quad (1)$$

3. Results

3.1 Main characteristics of articles

The main characteristics of the articles, as counts of articles, citations, countries, institutions, and authors, published on *Computers & Education* and their evolution over the past 40 years is depicted in **Table 1**. In 1978, only 27 articles are published, while 285 are included in 2013 with a more than 9 times increase. Since then, a slight drop can be seen in the number of articles published on the journal. Among the 3,963 articles, about 37% are published before 2007, while more than 60% are published in the last 12 years.

During the period 1978-2018, the studied articles have been cited 99,247 times in total, with an average citations per article as 25.04. The annual distribution of citation count has shown a significantly upward trend. The year of 2017 gets the most citations as 14,972. Over 92.76% of the citations occurred in the last decade. As for the average number of citations (CC/AC), it has increased stably from 0 to 75.49, reaching a peak in 2017 as 104.7. This indicates that articles published on *Computers & Education* has been gaining increasing attention and becoming more and more influential with time.

The average author count per article (AAP) is found to rise from 1.63 in 1978 to above 3 since 2012. The average institution and country count per article (AIP and ACP) have also risen from 1.11 to 1.77, and 1.04 to 1.29, respectively. The notable increasing trend of the percentages of collaborative articles from perspectives of country/region, institution, and author (CCPR, ICPR, and ACPR) reveals a closer and closer scientific collaboration in terms of authorship in the publication of *Computers & Education*.

Table 1 Major characteristics of the 3,963 articles

Year	AC	>=300	>=100	>=50	H	CC	CC/AC	CCPR	ICPR	ACPR	ACP	AIP	AAP
1978	27	0	0	0	4	0	0.00	3.70	7.41	48.15	1.04	1.11	1.63
1979	41	0	0	0	4	1	0.02	2.44	7.32	26.83	1.02	1.17	1.68
1980	28	0	0	1	3	6	0.21	0.00	7.14	42.86	1.00	1.07	1.57
1981	22	0	0	0	4	11	0.50	4.55	4.55	27.27	1.05	1.05	1.45
1982	51	0	0	0	5	29	0.57	0.00	0.00	41.18	1.00	1.00	1.80
1983	26	0	0	0	3	30	1.15	0.00	0.00	46.15	1.00	1.00	1.77
1984	70	0	0	0	4	40	0.57	0.00	4.29	41.43	1.00	1.09	1.83
1985	28	0	0	0	4	38	1.36	0.00	3.57	42.86	1.00	1.04	1.96
1986	59	0	0	0	5	53	0.90	0.00	0.00	50.85	1.00	1.00	1.63
1987	30	0	0	0	5	48	1.60	0.00	3.33	73.33	1.00	1.07	2.07
1988	74	0	0	0	6	49	0.66	0.00	4.05	54.05	1.00	1.04	1.88
1989	47	0	0	0	4	51	1.09	0.00	10.64	61.70	1.00	1.17	2.21
1990	95	0	0	1	10	86	0.91	0.00	3.16	52.63	1.00	1.03	1.81
1991	74	0	0	0	9	81	1.09	4.05	8.11	50.00	1.04	1.16	1.96
1992	82	0	0	0	7	74	0.90	0.00	6.10	52.44	1.00	1.17	2.04
1993	68	0	0	1	13	92	1.35	0.00	2.94	57.35	1.00	1.06	2.00
1994	71	0	0	1	10	108	1.52	0.00	4.23	60.56	1.00	1.07	2.00
1995	54	0	0	0	12	141	2.61	7.41	12.96	74.07	1.09	1.22	2.54
1996	46	0	0	1	12	124	2.70	2.17	13.04	73.91	1.02	1.28	2.67
1997	41	0	0	3	12	149	3.63	2.44	9.76	78.05	1.02	1.15	2.66
1998	56	0	0	1	15	187	3.34	1.79	12.50	66.07	1.02	1.20	2.02
1999	33	1	2	5	12	219	6.64	3.03	21.21	75.76	1.03	1.21	2.06
2000	43	1	3	9	21	235	5.47	6.98	30.23	79.07	1.07	1.40	2.65
2001	42	1	4	8	20	214	5.10	2.38	30.95	69.05	1.02	1.48	2.57
2002	50	0	1	9	24	219	4.38	4.00	26.00	80.00	1.04	1.30	2.26
2003	46	0	10	15	24	284	6.17	13.04	41.30	78.26	1.17	1.52	2.83
2004	47	0	5	11	26	355	7.55	8.51	36.17	74.47	1.09	1.45	2.40
2005	47	0	5	14	24	618	13.15	10.64	40.43	82.98	1.13	1.57	2.89
2006	55	3	10	18	28	704	12.80	9.09	41.82	80.00	1.09	1.49	2.42
2007	123	3	16	41	45	1149	9.34	7.32	36.59	78.05	1.07	1.48	2.69
2008	226	**5**	25	69	57	1795	7.94	13.72	37.61	80.09	1.15	1.47	2.55
2009	205	2	**33**	72	59	2447	11.94	13.17	39.51	84.88	1.14	1.51	2.89
2010	276	2	**33**	**80**	**62**	3736	13.54	12.68	38.41	77.90	1.13	1.50	2.80
2011	226	0	15	58	54	5382	23.81	15.04	41.15	84.07	1.16	1.58	2.89
2012	234	2	15	46	49	6730	28.76	15.81	44.02	79.49	1.21	1.64	3.03
2013	**285**	2	17	50	50	8468	29.71	18.25	46.67	85.96	1.21	1.67	3.13
2014	214	0	6	24	38	10001	46.73	16.36	46.73	86.92	1.19	1.68	3.22
2015	232	0	2	17	32	12337	53.18	18.53	44.83	87.50	1.21	1.63	3.16
2016	158	0	1	8	25	13791	87.28	18.99	46.84	89.24	1.25	1.65	2.92
2017	143	0	0	1	16	**14972**	**104.70**	**24.48**	52.45	**91.61**	**1.31**	**1.86**	**3.32**
2018	188	0	0	0	8	14193	75.49	23.40	**53.19**	88.83	1.29	1.77	3.23

Abbreviations: >=300, >=100, >=50: article counts with more than 300, 100, or 50 citations; AC: article count; H: H-index; CC: citation count; CC/AC: average citations per article; ACP, AIP, AAP: average number of countries/regions, institutions, or authors per article; CCPR, ICPR, ACPR: percentage of collaborative articles in the levels of country/region, institution, or author.

3.2 Author analysis

There are 8,349 authors participating in the publication of the studied articles. The top 10 prolific and influential authors are described in **Table 2** and **Table 3**. In terms of article count, the top three are all from Taiwan, again indicating its dominant

contribution. *Gwo-Jen Hwang* from *National Taiwan University of Science and Technology* is the most prolific with 28 articles, followed by *Nian-Shing Chen* from *National Sun Yat-Sen University* (21), *Chin-Chung Tsai* from *National Taiwan University of Science and Technology* (20), and *Miguel Nussbaum* from *Pontifical Catholic University of Chile* (20). From the Hirsch index perspective, the top three are *Gwo-Jen Hwang* from *National Taiwan University of Science and Technology* (22), *Chin-Chung Tsai* from *National Taiwan University of Science and Technology* (19), and *Nian-Shing Chen* from *National Sun Yat-Sen University* (16).

Table 2 Top authors ranked by article count

Author	Affiliation	AC
Gwo-Jen Hwang	*National Taiwan University of Science and Technology*	**28**
Nian-Shing Chen	*National Sun Yat-Sen University*	21
Chin-Chung Tsai	*National Taiwan University of Science and Technology*	20
Miguel Nussbaum	*Pontifical Catholic University of Chile*	20
Martin Valcke	*University of Ghent*	16
Johan Van Braak	*University of Ghent*	15
Siu Cheung Kong	*Education University of Hong Kong*	14
Yueh-Min Huang	*National Cheng Kung University*	14
Kuo-En Chang	*National Taiwan Normal University*	13
Ann C. Jones	*The Open University*	12

Abbreviations: AC: article count; H: H-index.

Table 3 Top authors ranked by H-index

Author	Affiliation	H
Gwo-Jen Hwang	*National Taiwan University of Science and Technology*	**22**
Chin-Chung Tsai	*National Taiwan University of Science and Technology*	19
Nian-Shing Chen	*National Sun Yat-sen University*	16
Johan Van Braak	*University of Ghent*	15
Miguel Nussbaum	*Pontifical Catholic University of Chile*	14
Martin Valcke	*University of Ghent*	14
Yueh-Min Huang	*National Cheng Kung University*	12
Kuo-En Chang	*National Taiwan Normal University*	12
Gwo-Jen Hwang	*National University of Tainan*	12
Siu Cheung Kong	*Education University of Hong Kong*	10

Abbreviations: AC: article count; H: H-index.

Co-occurrence analysis of 25 authors with an article count>=10 as a filter was conducted for evaluating collaboration among authors, the result of which is displayed as a network map with 25 nodes and 17 links in **Fig. 1**. Eleven of them are from Taiwan. The most collaborative scholars are *Nian-Shing Chen* from Taiwan and *Martin Valcke* from Belgium, each collaborates with 4 authors. *Kuo-En Chang* from Taiwan and *Yao-*

Ting Sung from Taiwan have the most collaborative articles (11), followed by *Nian-Shing Chen* from Taiwan and *Kinshuk* from Canada (9), *Martin Valcke* from Belgium and *Bram De Wever* from Belgium (8), and *Johan Van Braak* from Belgium and *Jo Tondeur* from Belgium (8).

The topic distribution analysis (**Fig. 2**) demonstrates that *Gwo-Jen Hwang* is more focused on *Context and collaborative learning* and *Experiments and methodologies*, while *Johan Van Braak* is more concerned about *E-learning and policy*. Authors from the same countries/regions tend to show similar topic distribution pattern. For example, *Gwo-Jen Hwang*, *Nian-Shing Chen*, and *Chin-Chung Tsai* are all very active in *Context and collaborative learning*. Taiwan, as well as most of its collaborated institutions, are also very active in *Context and collaborative learning*. *Martin Valcke* and *Johan Van Braak* are more active in *E-learning and policy*. Both two authors are from *University of Ghent*, which is found to be also very active in *E-learning and policy*.

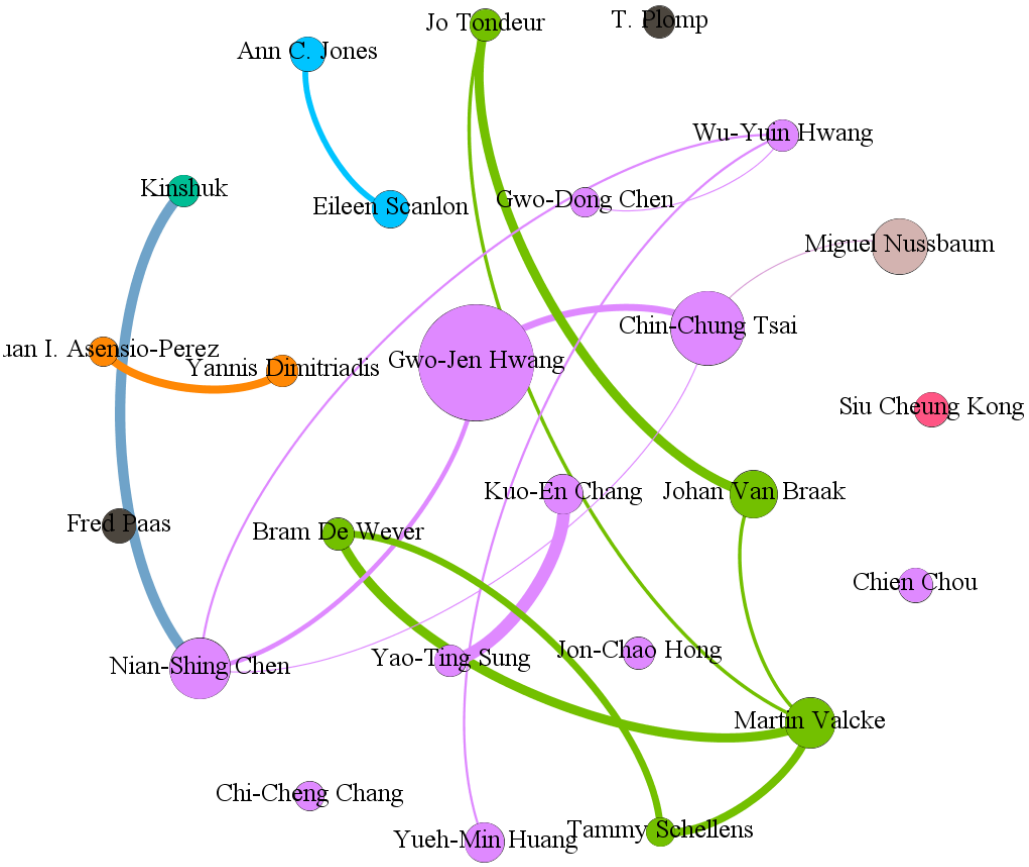

Fig. 1. Collaborative network of authors with an article count >=10

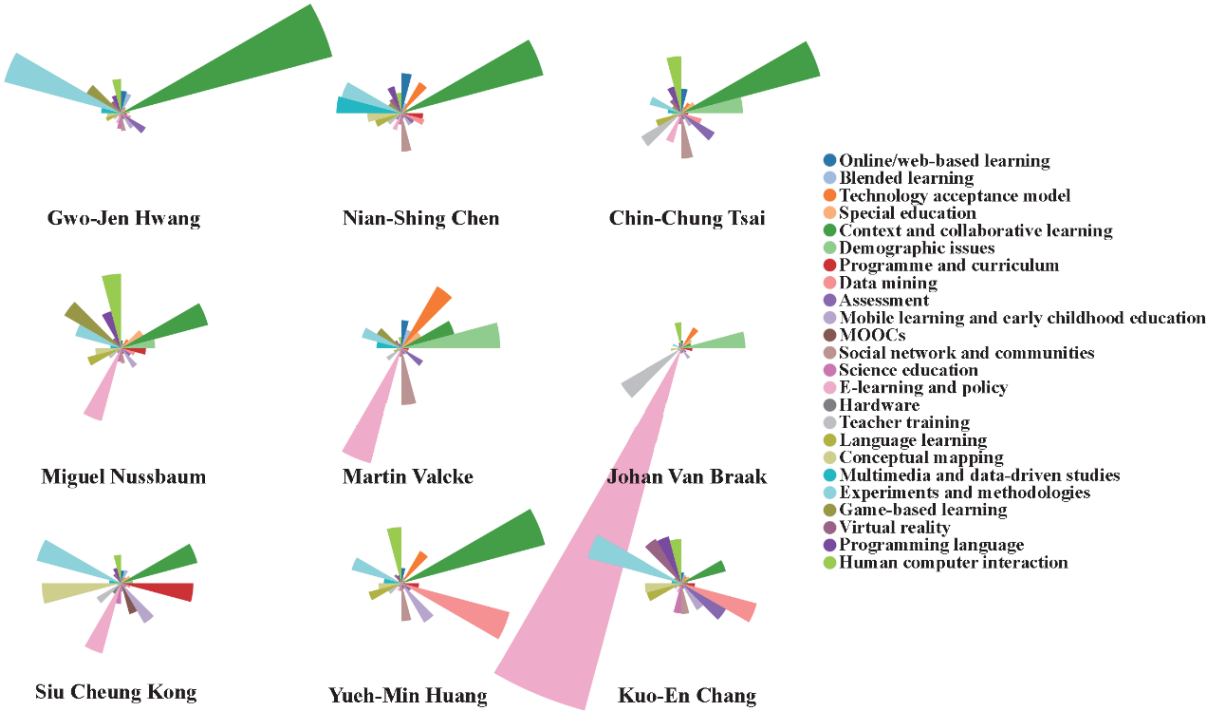

Fig. 2. Topical distribution of prolific authors

3.3 Country/region and institution analysis

A total of 1,751 institutions from 85 countries/regions have participated in the publication of the 3,963 articles published on *Computers & Education*. **Fig. 3** is the visualization of the geographic distribution of prolific countries/regions. The USA has contributed to 858 articles (21.65%), while UK (18.57%) and Taiwan (13.47%) are at the second and third positions. Ranked by H-index, the top 10 countries/regions are depicted in **Table 4**, among which the top 2 are the USA (78) and Taiwan (76). From institution perspective, the top 3 influential ones indicated by H-index are *National Taiwan University of Science and Technology* (39), *National Taiwan Normal University* (29), and *National Central University* (27), all of which are from Taiwan. *Nanyang Technological University* from Singapore also has an H-index value as 27.

Table 4 Top institutions and countries/regions ranked by H-index

C	H	Institution	C	H
USA	78	*National Taiwan University of Science and Technology*	Taiwan	39
Taiwan	76	*National Taiwan Normal University*	Taiwan	29
UK	56	*National Central University*	Taiwan	27
Spain	43	*Nanyang Technological University*	Singapore	27
Netherlands	41	*National University of Tainan*	Taiwan	25

Greece	35	*University of Ghent*	Belgium	24
Australia	34	*The Open University*	UK	23
Turkey	34	*National Cheng Kung University*	Taiwan	23
China	33	*National Sun Yat-sen University*	Taiwan	22
Canada	32	*National Chiao Tung University*	Taiwan	21

Abbreviations: C: Country/region; H: H-index.

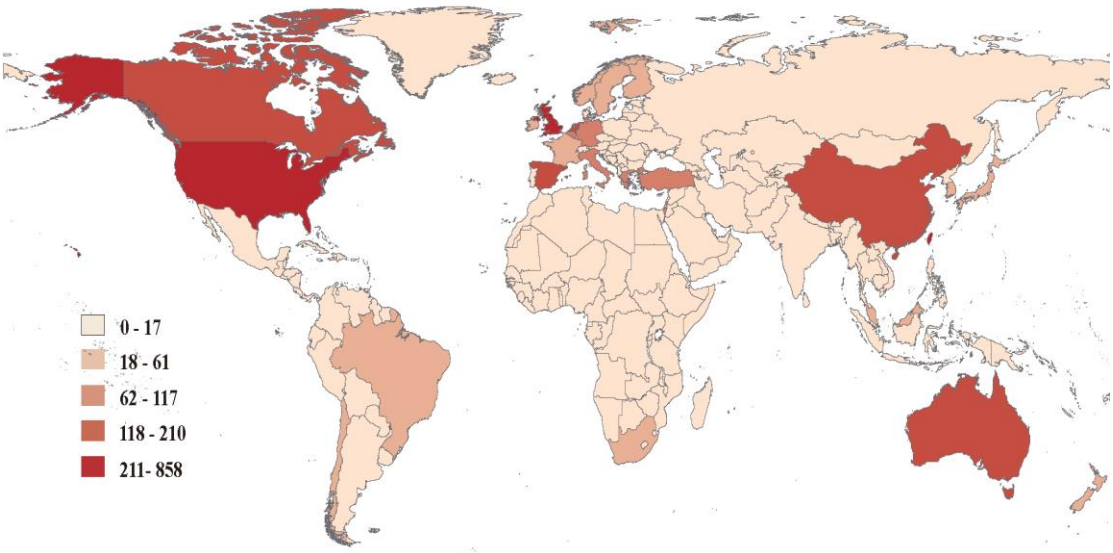

Fig. 3. Geographic distribution of prolific countries/regions

3.4 Keywords analysis

The top 25 frequently used keywords are shown in **Table 5**. The keyword 'interactive learning environment' is ranked first occurring in 615 articles (15.52%), followed by 'teaching/learning strategies' (in 576 articles, 14.53%), 'pedagogical issue' (406 articles, 10.24%). Other very frequent keywords include 'improving classroom teaching' (392), 'student' (376), 'education' (344), 'computer assisted communication' (339), and 'technology' (334). The evaluation of the top keywords in terms of frequency in 4 sub-periods (1978-1987, 1988-1997, 1998-2007, and 2008-2018) has also been integrated in the table. Over the periods, some keywords have shown a growth in frequency, for example, 'student', 'computer assisted communication', 'technology', 'secondary education', and 'motivation'.

Table 5 Top 25 keywords ranked by total frequency for different periods of time

Keywords	1978-2018		1978-1987		1988-1997		1998-2007		2008-2018	
	AC (R)	%	AC (R)	%	AC (R)	%	AC (R)	%	AC (R)	%
interactive learning environment	**615 (1)**	**15.52**	**0.00**	**0.00**	**0.00**	**0.00**	**112 (1)**	**20.66**	**503 (1)**	**21.07**
teaching/learning strategies	**576 (2)**	**14.53**	**0.00**	**0.00**	**0.00**	**0.00**	**91 (2)**	**16.79**	**485 (2)**	**20.32**

pedagogical issue	406 (3)	10.24	0.00	0.00	0.00	0.00	74 (4)	13.65	332 (4)	13.91
improving classroom teaching	392 (4)	9.89	0.00	0.00	0.00	0.00	62 (5)	11.44	330 (5)	13.82
student	**376 (5)**	**9.49**	**1 (109)**	**0.26**	**7 (29)**	**1.07**	**32 (20)**	**5.90**	**336 (3)**	**14.08**
education	344 (6)	8.68	8 (9)	2.09	18 (7)	2.76	33 (16)	6.09	285 (7)	11.94
computer assisted communication	**339 (7)**	**8.55**	**0.00**	**0.00**	**3 (79)**	**0.46**	**78 (3)**	**14.39**	**258 (8)**	**10.81**
technology	**334 (8)**	**8.43**	**1 (109)**	**0.26**	**4 (56)**	**0.61**	**25 (24)**	**4.61**	**304 (6)**	**12.74**
media in education	287 (9)	7.24	0.00	0.00	0.00	0.00	40 (11)	7.38	247 (10)	10.35
performance	270 (10)	6.81	2 (49)	0.52	3 (79)	0.46	17 (36)	3.14	248 (9)	10.39
cooperative/collaborative learning	255 (11)	6.43	0.00	0.00	0.00	0.00	57 (6)	10.52	198 (13)	8.29
environment	233 (12)	5.88	0.00	0.00	3 (79)	0.46	14 (39)	2.58	216 (11)	9.05
post secondary education	232 (13)	5.85	0.00	0.00	0.00	0.00	30 (22)	5.54	202 (12)	8.46
design	226 (14)	5.70	5 (18)	1.31	15 (8)	2.30	10 (53)	1.85	196 (14)	8.21
secondary education	**225 (15)**	**5.68**	**1 (109)**	**0.26**	**2 (121)**	**0.31**	**38 (13)**	**7.01**	**184 (15)**	**7.71**
elementary education	217 (16)	5.48	0.00	0.00	0.00	0.00	33 (16)	6.09	184 (15)	7.71
knowledge	205 (17)	5.17	2 (49)	0.52	8 (23)	1.23	21 (27)	3.87	174 (17)	7.29
model	200 (18)	5.05	2 (49)	0.52	11 (14)	1.69	18 (31)	3.32	169 (18)	7.08
application in subject areas	196 (19)	4.95	0.00	0.00	0.00	0.00	33 (16)	6.09	163 (20)	6.83
human computer interface	193 (20)	4.87	0.00	0.00	0.00	0.00	41 (9)	7.56	152 (22)	6.37
computer	192 (21)	4.84	25 (3)	6.54	49 (1)	7.52	28 (23)	5.17	90 (47)	3.77
instruction	187 (22)	4.72	3 (29)	0.79	13 (11)	1.99	20 (30)	3.69	151 (23)	6.33
classroom	180 (23)	4.54	2 (49)	0.52	6 (36)	0.92	12 (46)	2.21	160 (21)	6.70
motivation	**170 (24)**	**4.29**	**0.00**	**0.00**	**1 (206)**	**0.15**	**4 (99)**	**0.74**	**165 (19)**	**6.91**
distance education and telelearning	169 (25)	4.26	0.00	0.00	0.00	0.00	51 (7)	9.41	118 (34)	4.94

Abbreviations: AC: article count; R: ranking position.

To more directly visualize the usage trend of top keywords, the annual trends of the top 25 research keywords are obtained as shown in **Fig. 4**. Some keywords, such as ‘computer’, ‘design’, and ‘instruction’, have shown a trend with relatively sharp fluctuations. Many keywords have emerged as new popular topics, for example, ‘cooperative/collaborative learning’ emerges in 2001 and continues to gain more attention until 2004, while it experiences a downward trend since then. It is very interesting to find that several teaching-related keywords such as ‘improving classroom teaching’, ‘pedagogical issue’, and ‘teaching/learning strategies’, emerge to be important in 1996, and quickly gained significant attention in the next few years, and till now, they are still important issues in articles published on the journal.

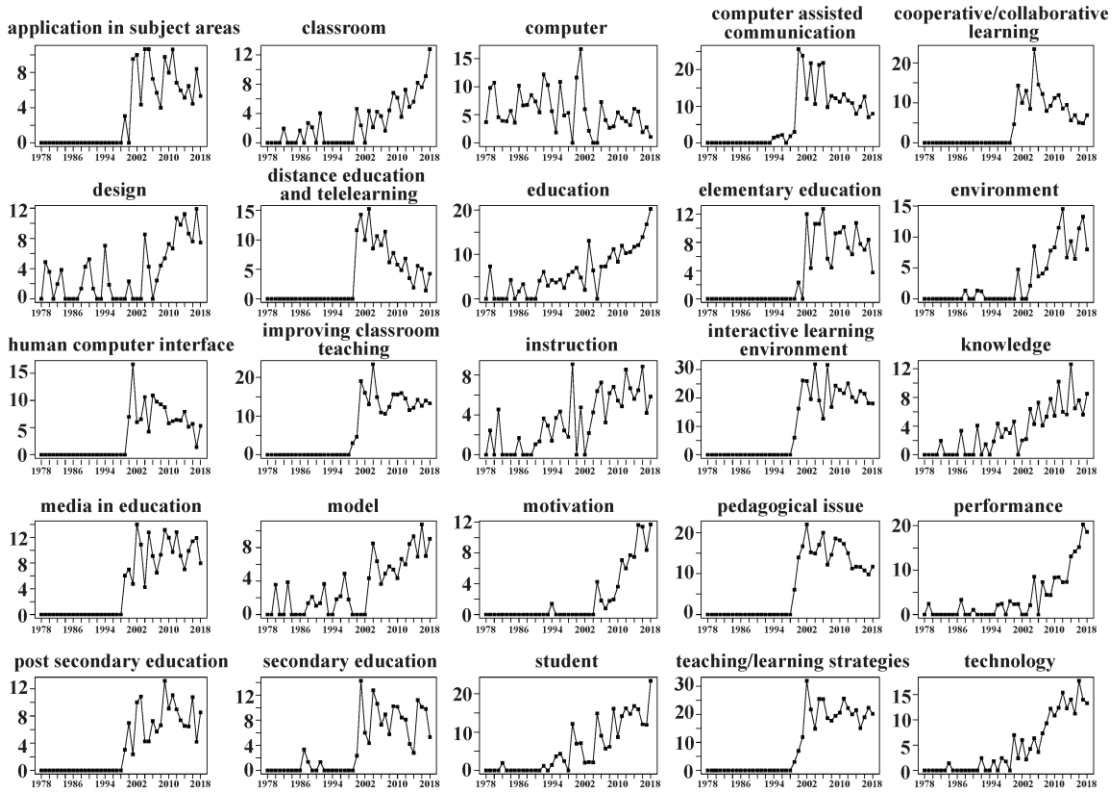

Fig. 4. Annual distribution (proportion) of the top 25 keywords

The AP clustering result of the 25 keywords is presented in **Fig. 5** and **Table 6**, which shows that the 25 keywords has been automatically grouped into 6 clusters. To assign themes to each cluster, we analyze the semantics of keywords as well as reviewing the article content. In this way, 6 major themes are identified as *Computer*, *Computer assisted communication*, *Human computer interface*, *Model*, *Student-focused*, and *Teaching-related*.

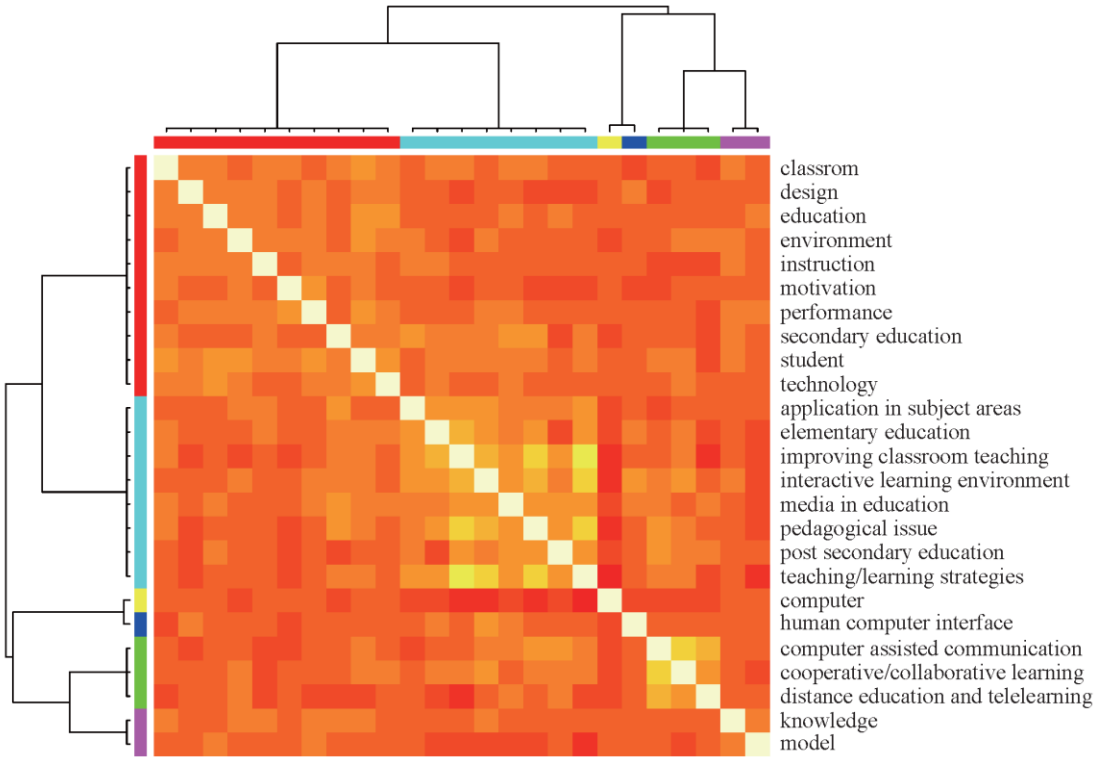

Fig. 5. AP clustering result of the top 25 keywords

Table 6 Potential research themes along with keywords used

	Potential themes	Keywords
1	Computer	**computer**
2	Computer assisted communication	**computer assisted communication**; cooperative/collaborative learning; distance education and telelearning
3	Human computer interface	**human computer interface**
4	Model	**model**; knowledge
5	Student-focused	**student**; classroom; design; education; environment; instruction; motivation; performance; secondary education; technology
6	Teaching-related	application in subject areas elementary education; improving classroom teaching; interactive learning environment; media in education pedagogical issue; post secondary education; **teaching/learning strategies**

4. Discussion

In this paper, we review the 3,963 articles published by *Computers & Education* with the use of bibliometric method. In particular, we present the publication statistical characteristics, identify influential countries/regions and institutions, recognize prolific and influential authors as well as the collaboration among them. In addition, top

keywords used in articles published on *Computers & Education* are analyzed to identify prevalent ones as well as those emerged to be current and future directions.

The articles published on *Computers & Education* has become flourishing over the past decade, in particular, during the period 2006-2013. The citation impact of articles has become increasingly significant, indicates a high-quality and high-impact of its publication. More and more country/region, institution, and author have participated in the research and the scientific collaboration has become more and more common and popular. Our analysis highlights the contribution of *Gwo-Jen Hwang* from *National Taiwan University of Science and Technology* with both the most articles and a highest H-index value. In addition, contributions from Taiwan are quite numerous, with seven out of the 10 most prolific institutions (e.g., *National Taiwan University of Science and Technology*, *National Taiwan Normal University*, and *National Central University*), and several authors (e.g., *Gwo-Jen Hwang*, *Nian-Shing Chen*, and *Chin-Chung Tsai*) ranked the most prolific and influential, demonstrating its significant position in the *Computers & Education*. From the topic distribution of prolific authors as well as the scientific collaboration among them, we can infer that a consistency of topic focus as well as the scientific collaboration between authors from the same institution, even the same country/region, is relatively higher, compared with those from the different ones.

The articles published on *Computers & Education* are diversely distributed and a broad interest from a variety of research perspectives can be noted. Thematic features relating to the articles are explored by the keywords analysis and a few distinguishing ones are illustrated as follows, which is helpful to the understanding of the research focuses and how they developed and evolved.

On the one hand, there are several keywords that are getting increasingly more and more important. First, the keyword ‘student’ has a sharp change in ranking from No. 109 in period 1978-1987 to No. 3 in period 2008-2018. This indicates that there is a growing concern among authors on the role of student in the computer use in education. As indicated by Lowerison et al. (2006), learning is a social and active process, in which the focus shifts from teacher-directed to student-directed learning. Traditional lecturing

has long focused on instructor-based teaching but now has transitioned to that emphasizes students' role in learning (Lai et al. 2018). What a student 'brings' cognitively to the learning environment is very important for the reason that this will determine what and how knowledge is constructed by the learner (Ausubel 1963; Jonassen et al. 2008). Second, the ranking of 'computer assisted communication' and 'technology' have continued to increase. This indicates a growing interest among authors in communication assisted by use of computers, media and technologies. This finding is compatible with that reported by Song et al. (2019) with a focus on review publications relating to classroom dialogue. As suggested by Zawacki-Richter and Latchem (2018), digital tools are cognitive tools and intellectual partners in the knowledge construction process. For example, Stolaki and Economides (2018) conducted a creativity enhancement intervention with participant students of mean age as 18.38, in an information systems course. Third, the keyword 'performance' has become an important area of research especially in the last period. Individual or student learning performance brought by the mediation of technology in the process of learning is a wide concern and core issue for a great number of researchers. For instance, Yang et al. (2018) examined the difference of behavior between high prior knowledge students and low prior knowledge students when interacting with a self-regulated learning environment. They concluded that the gap of learning performance between the two groups was removed after a long-term learning process. Last, but not least, there has been a tendency for research into the technology use in 'secondary education'. For example, Huizenga et al. (2017) examined the practice-based perceptions of teachers who teach with the use of digital games - either playing or creating games - in their classroom, by using semi-structured interviews with 43 secondary education teachers.

On the other hand, there are several keywords that emerge to be new research focuses, indicating a shifting trend of the research on *Computers & Education*. First, 'interactive learning environment' appears in 1998-2007, and occupies at the first place since then. This indicates its popularity among authors in the study of interactive learning. An interactive learning environment is defined as a context which supports learners to interact with a knowledge base to attain clearly defined learning objectives.

It relates to various instructional technology applications and resembles computer managed learning systems and especially the emerging interactive online advisory systems (Martens et al. 1997). For example, Sun et al. (2018) aimed to identify the effects of different combinations of scaffolds and rewards on player gaming behaviors, strategy changes, usage, and interactive effects. Second, several teaching-related keywords emerge and sever as important topics in the latter two periods (1998-2007, 2008-2018), i.e., 'teaching/learning strategies', 'pedagogical issue', and 'improving classroom teaching'. Over the last few decades, the number and variety of technological tools and applications that teachers and students have access to in schools has risen sharply. As the National Council of Teachers of Mathematics indicated, 'Effective teachers optimize the potential of technology to develop students' understanding, stimulate their interest, and increase their proficiency in mathematics' (National Council of Teachers of Mathematics 2015), teachers play a critical role in the determination of how these technology tools are used (McCulloch et al. 2018). For example, Asensio-Pérez et al. (2017) explored the use of a novel integrated learning design environment for supporting teachers' professional development on information and communication technologies and collaborative learning, with the use of a mixed method. Third, there has been a tendency for research into 'cooperative/collaborative learning'. As indicated by Dillenbourg (1999), computer supported collaborative learning research has demonstrated the need to scaffold cooperation to ensure that learners benefit from working together. Collaborative learning can be supported by monitoring and regulating the interaction between learners, which is technology-based, and by providing information about group members' knowledge, emotions, actions, and interactions during collaborative learning (e.g., Molinari et al. 2013; Sangin et al. 2011). In addition, there is growing interest among authors in research of 'media in education'. For example, Chen et al. (2018a) presented findings from a large-scale investigation into new media literacy skills among Singaporean school students, serving to be the basis of formulating media literacy education in pre-university education in Singapore.

Yet, some commonly recognized important issues have not come up as major keywords in your analysis, for example, 'assessment'. Assessment sits at the heart of

the learning process. Timmis et al. (2016) took the findings of the research review, including literature review, briefings and associated discussions, forward by focusing on the risks and challenges of technology enhanced assessment and its potential to influence the wider culture and practice of assessment in education. However, in our analysis, the frequency of 'assessment' is rather lower. This may be due to the fact that we used author-defined keywords and ISI Keywords Plus as analysis units, but 'assessment' may be seldom listed as a keyword in the articles.

5. Conclusions

The analyses in this paper are based on the 3,963 articles published on the journal *Computers & Education* collected from the WOS from 1987 to 2018. Our study highlights a closer collaboration among authors, institutions, and countries/regions in the research, as well as the significant contribution by *Gwo-Jen Hwang*. Further investigation of scientific collaboration of authors from different subjects or disciplinary can be conducted to show more diverse perspectives. The keyword analysis for the articles studied reveals a popular research direction into topics such as 'interactive learning environment', 'teaching/learning strategies', 'pedagogical issue', and 'computer assisted communication'. The findings in current study can provide some directions for future research on technology enhanced education. Future studies are suggested to explore what pedagogical issues are most concerned by the research community through meta-analysis or coding methods, to figure out how to integrate specific technological tools in assisting teaching and learning activities. In addition, how to design interactive learning environment to better suit learners' needs could be further investigated with design-based research. In particular, what kind of technology tools bring about better academic and learning performances in student-centered teaching/learning settings can be further investigated. Also, it would be interesting to look at subject areas that these articles focused on, as to see whether there is a trend on subjects such as 'language learning', 'mathematics', or general skills development

(e.g., critical thinking and collaboration between participants) that come up frequently in the articles.

Focusing on the current research on computer-assisted education, some potential issues or directions may require more attention and effort from scholars. For example, more high-quality research is of need to explore the validity of computer and its relevant technologies or devices in improving teaching or learning performance. Also, more high-quality research on teachers' or learners' attitude towards computer use in the process of teaching or learning. In addition, more research on the validity of various technologies or devices in performance enhancement can be evaluated and compared. The findings from these studies will provide implications or insights in promoting better use of computer technologies in and for teaching and learning.

Acknowledgements

This work was supported by General Research Fund (GRF No. 18601118) of the HKSAR government and National Natural Science Foundation of China (No. 61772146).

Reference

Asensio-Pérez, J. I., Dimitriadis, Y., Pozzi, F., Hernández-Leo, D., Prieto, L. P., Persico, D., & Villagrá-Sobrino, S. L. (2017). Towards teaching as design: exploring the interplay between full-lifecycle learning design tooling and teacher professional development. *Computers & Education*, *114*, 92-116.

Ausubel, D. P. (1963). The psychology of meaningful verbal learning. New York: Grune and Stratton.

Bastian, M., Heymann, S., & Jacomy, M. (2009, March). Gephi: an open source software for exploring and manipulating networks. In *Third international AAAI conference on weblogs and social media*.

Bodenhofer, U., Kothmeier, A., & Hochreiter, S. (2011). APCluster: an R package for affinity propagation clustering. *Bioinformatics*, *27*(17), 2463-2464.

Chang, C. Y., & Hwang, G. J. (2018). Trends of mobile technology-enhanced medical education: a review of journal publications from 1998 to 2016. *International Journal of Mobile Learning and Organisation*, 12(4), 373-393.

Chen, C. M., Li, M. C., & Chen, T. C. (2019a). A web-based collaborative reading annotation system with gamification mechanisms to improve reading performance. *Computers & Education*, 103697.

Chen, D. T., Lin, T. B., Li, J. Y., & Lee, L. (2018a). Establishing the norm of new media literacy of Singaporean students: Implications to policy and pedagogy. *Computers & Education*, *124*, 1-13.

Chen, M. P., Wang, L. C., Zou, D., Lin, S. Y., & Xie, H. (2019b). Effects of caption and gender on junior high students' EFL learning from iMap-enhanced contextualized learning. *Computers & Education*, 103602.

Chen, X., Chen, B., Zhang, C., & Hao, T. (2017a, September). Discovering the recent research in natural language processing field based on a statistical approach. In *International Symposium on Emerging Technologies for Education* (pp. 507-517). Springer, Cham.

Chen, X., Ding, R., Xu, K., Wang, S., Hao, T., & Zhou, Y. (2018b). A bibliometric review of natural language processing empowered mobile computing. *Wireless Communications and Mobile Computing*, *2018*.

Chen, X., Hao, J., Chen, J., Hua, S., & Hao, T. (2018c, August). A bibliometric analysis of the research status of the technology enhanced language learning. In *International Symposium on Emerging Technologies for Education* (pp. 169-179). Springer, Cham.

Chen, X., & Hao, T. (2019). Quantifying and Visualizing the Research Status of Social Media and Health Research Field. In *Social Web and Health Research* (pp. 31-51). Springer, Cham.

Chen, X., Liu, Z., Wei, L., Yan, J., Hao, T., & Ding, R. (2018d). A comparative quantitative study of utilizing artificial intelligence on electronic health records in the USA and China during 2008–2017. *BMC medical informatics and decision making*, *18*(5), 117.

Chen, X., Lun, Y., Yan, J., Hao, T., & Weng, H. (2019c). Discovering thematic change and evolution of utilizing social media for healthcare research. *BMC medical informatics and decision making*, *19*(2), 50.

Chen, X., Wang, S., Tang, Y., & Hao, T. (2019d). A bibliometric analysis of event detection in social media. *Online Information Review*, *43*(1), 29-52.

Chen, X., Weng, H., & Hao, T. (2017b, October). A data-driven approach for discovering the recent research status of diabetes in China. In *International Conference on Health Information Science* (pp. 89-101). Springer, Cham.

Chen, X., Xie, H., Wang, F. L., Liu, Z., Xu, J., & Hao, T. (2018e). A bibliometric analysis of natural language processing in medical research. *BMC medical informatics and decision making*, *18*(1), 14.

Cobo, M. J., Martínez, M. Á., Gutiérrez-Salcedo, M., Fujita, H., & Herrera-Viedma, E. (2015). 25 years at knowledge-based systems: a bibliometric analysis. *Knowledge-based systems*, *80*, 3-13.

Dillenbourg, P. (1999). Introduction what do you Mean by "Collaborative Learning". Teoksessa P. Dillenbourg (toim.), Collaborative Learning: Cognitive and Computational Approaches. *British Library Cataloguing Publication Data*, 1-19.

Ding, Y., Rousseau, R., & Wolfram, D. Measuring Scholarly Impact: Methods and Practice (pp. 285-320). *Cham, Switzerland: Springer*.

Frey, B. J., & Dueck, D. (2007). Clustering by passing messages between data points. *science*, *315*(5814), 972-976.

Geng, Y., Chen, W., Liu, Z., Chiu, A. S., Han, W., Liu, Z., ... & Cui, X. (2017). A bibliometric review: Energy consumption and greenhouse gas emissions in the residential sector. *Journal of cleaner production*, *159*, 301-316.

Hao, T., Chen, X., Li, G., & Yan, J. (2018). A bibliometric analysis of text mining in medical research. *Soft Computing*, *22*(23), 7875-7892.

Hsu, Y. C., Ho, H. N. J., Tsai, C. C., Hwang, G. J., Chu, H. C., Wang, C. Y., & Chen, N. S. (2012). Research trends in technology-based learning from 2000 to 2009: A content analysis of publications in selected journals. *Journal of Educational Technology & Society*, *15*(2), 354-370.

Huizenga, J. C., Ten Dam, G. T. M., Voogt, J. M., & Admiraal, W. F. (2017). Teacher perceptions of the value of game-based learning in secondary education. *Computers & Education*, *110*, 105-115.

Jonassen, D., Spector, M. J., Driscoll, M., Merrill, M. D., van Merrienboer, J., & Driscoll, M. P. (2008). *Handbook of research on educational communications and technology: a project of the association for educational communications and technology*. Routledge.

Lai, H. M., Hsiao, Y. L., & Hsieh, P. J. (2018). The role of motivation, ability, and opportunity in university teachers' continuance use intention for flipped teaching. *Computers & Education*, *124*, 37-50.

Lowerison, G., Sclater, J., Schmid, R. F., & Abrami, P. C. (2006). Student perceived effectiveness of computer technology use in post-secondary classrooms. *Computers & Education*, *47*(4), 465-489.

Martens, R. L., Valcke, M. M. A., & Portier, S. J. (1997). Interactive learning environments to support independent learning: The impact of discernability of embedded support devices. *Computers & Education*, *28*(3), 185-197.

Martin, S., Diaz, G., Sancristobal, E., Gil, R., Castro, M., & Peire, J. (2011). New technology trends in education: Seven years of forecasts and convergence. *Computers & Education*, *57*(3), 1893-1906.

Martínez, M. A., Cobo, M. J., Herrera, M., & Herrera-Viedma, E. (2015). Analyzing the scientific evolution of social work using science mapping. *Research on Social Work Practice*, *25*(2), 257-277.

McCulloch, A. W., Hollebrands, K., Lee, H., Harrison, T., & Mutlu, A. (2018). Factors that influence secondary mathematics teachers' integration of technology in mathematics lessons. *Computers & Education*, *123*, 26-40.

Merigó, J. M., Cobo, M. J., Laengle, S., Rivas, D., & Herrera-Viedma, E. (2019). Twenty years of Soft Computing: a bibliometric overview. *Soft Computing*, *23*(5), 1477-1497.

Molinari, G., Chanel, G., Betrancourt, M., Pun, T., & Bozelle Giroud, C. (2013). Emotion feedback during computer-mediated collaboration: Effects on self-reported emotions and perceived interaction.

National Council of Teachers of Mathematics, 2015, Strategic use of technology in teacher and learning mathematics (2015). (Reston, VA: Author)

Otte, E., & Rousseau, R. (2002). Social network analysis: a powerful strategy, also for the information sciences. *Journal of information Science*, *28*(6), 441-453.

Peng, B., Guo, D., Qiao, H., Yang, Q., Zhang, B., Hayat, T., ... & Ahmad, B. (2018). Bibliometric and visualized analysis of China's coal research 2000–2015. *Journal of cleaner production*, *197*, 1177-1189.

Sangin, M., Molinari, G., Nüssli, M. A., & Dillenbourg, P. (2011). Facilitating peer knowledge modeling: Effects of a knowledge awareness tool on collaborative learning outcomes and processes. *Computers in Human Behavior*, *27*(3), 1059-1067.

Song, Y., Chen, X., Hao, T., Liu, Z., & Lan, Z. (2019). Exploring two decades of research on classroom dialogue by using bibliometric analysis. *Computers & Education*, *137*, 12-31.

Stolaki, A., & Economides, A. A. (2018). The Creativity Challenge Game: An educational intervention for creativity enhancement with the integration of Information and Communication Technologies (ICTs). *Computers & Education*, *123*, 195-211.

Sun, C. T., Chen, L. X., & Chu, H. M. (2018). Associations among scaffold presentation, reward mechanisms and problem-solving behaviors in game play. *Computers & Education*, *119*, 95-111.

Svensson, G. (2010). SSCI and its impact factors: a “prisoner's dilemma”?. *European journal of Marketing*, *44*(1/2), 23-33.

Swamy N. *Cluster Purity Visualizer*. 2016. URL: https://bl.ocks.org/nswamy14/e28ec2c438e9e8bd302f

Timmis, S., Broadfoot, P., Sutherland, R., & Oldfield, A. (2016). Rethinking assessment in a digital age: Opportunities, challenges and risks. *British Educational Research Journal*, *42*(3), 454-476.

Troussas, C., Krouska, A., & Sgouropoulou, C. (2019). Collaboration and fuzzy-modeled personalization for mobile game-based learning in higher education. *Computers & Education*, 103698.

Tu, Y. F., & Hwang, G. J. (2018). The roles of sensing technologies and learning strategies in library-associated mobile learning: a review of 2007-2016 journal publications. *International Journal of Mobile Learning and Organisation*, *12*(1), 42-54.

Xie, H., Chu, H. C., Hwang, G. J., & Wang, C. C. (2019). Trends and development in technology-enhanced adaptive/personalized learning: A systematic review of journal publications from 2007 to 2017. *Computers & Education*, 103599.

Yang, T. C., Chen, M. C., & Chen, S. Y. (2018). The influences of self-regulated learning support and prior knowledge on improving learning performance. *Computers & Education*, *126*, 37-52.

Zawacki-Richter, O., & Latchem, C. (2018). Exploring four decades of research in Computers & Education. *Computers & Education*, *122*, 136-152.

Zhong, S., Geng, Y., Liu, W., Gao, C., & Chen, W. (2016). A bibliometric review on natural resource accounting during 1995–2014. *Journal of cleaner production*, 139, 122-132.