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Evolving Computer Science Education Research in Teaching and Learning: A Bibliometric Analysis

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ABSTRACT

This study performed a bibliometric analysis of computer science education (CSE) publications in teaching and learning. The research trend in computer science education was analysed using publications from the Scopus-indexed database between 1970 and 2021. This study aims to summarize this information to assist three groups of stakeholders: educators, researchers and policymakers. Our review goal to document and analyse the trends in CSE research publications for teaching and learning. A total of 800 publications were derived for further assessment based on computer science education in the article title with multiple tools. We used, Microsoft Excel, VOSviewer and Harzing's Publish or Perish were utilized for frequency analysis data visualization and citation metrics and assessment. The study outcomes were documented with standard bibliometric indicators: publication growth, authorship trends, collaboration, prolific authors, national contribution, most active establishments, top-cited articles, preferred journals, intellectual structure and topical trends. Resultantly, CSE research publications have perpetually grown for the past 51 years since 1970 with the United States highlighting the largest study contributor, followed by Germany and the United Kingdom. The ACM SIGCSE Bulletin published the highest number of CSE research publications. The analysis of the cluster on topical trends indicates that curriculum design and implementation (e.g., assessment, broadening participation), elements of teaching and learning (e.g., constructivism, e-learning, game-based learning) and other areas of interest comprise pedagogical approach (e.g., computational thinking, k-12 education, motivation). Based on the research results, we expand on the findings and propose how authors might enhance the CSE function in curriculum design, implementation and shifts could eventually substitute past study clusters.

Keywords:
Computer science; bibliometric analysis; research patterns and trends; VOSviewer; Harzing's publish or perish

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1. Introduction

The evolvement of introductory CSE research has gained much popularity as a curriculum subject with the re-organization and re-structuring of conventional educational institutions [1]. Such development is a vital educational objective [2,3] that transforms the education mode based on various topical and student-centric development and its appropriacy in terms of gender, diversity, accessibility and inclusion to catalyse future educational curriculum pattern shifts [4-6]. The current study primarily elaborated on the research publication status, computer science development pattern in education and holistic combination of CSE. Essentially, curriculum design and implementation should be duly regarded to determine an optimal computer science study area as a curriculum subject. Although computer science education (CSE) research on the curriculum subject, which was initially published in 2004 [7,8], has continuously expanded over the years, its empirical advancement could have been undermined. As such, it is deemed vital to assess recent CSE research activity patterns through bibliometric evaluation.

Although field researchers held contradictory perspectives in terms of scope and future teaching processes, computer science was conceded to be a multi-dimensional discipline with conceptual notions involving the scientific and engineering components [9-11] actualized in algorithmic problem-solving processes with computational, artistic and innovative thinking skills [12]. Meanwhile, computers function as a mechanism to resolve computer science intricacies [13].

The advent of CSE has been documented on a global scale. For example, computer science has existed as a curriculum subject over decades in Cyprus, Poland and Israel [14,15] while the computer science curriculum was recently amended after a period of negligence in other nations [16,17]. Notably, computer science curricula vary across countries in terms of their incorporation and the multiple factors impacting curriculum design and implementation.

The ACM SIGCSE Bulletin initially explained the nature of computer science in the 1989 *Papers of the Twentieth SIGCSE Technical Symposium on Computer Science Education* report. Pedagogically, a global investigation on high-school computer science curricula implementation implied low consistency in curricular interpretation [18,19]. Such diversity is depicted in various curricula terms, such as information technology, information and communication technology, information systems [20], computer science, informatics [21], computer engineering and software engineering [22,23]. Interestingly, preliminary implementations of computer science curricula substantially affected learners' profession-oriented conceptions [24,25]. The essentiality of other computing and computer usage elements, including digital literacy could be associated with the incorporation of a curriculum into computer science disciplines.

This study initially utilized:

i. the Scopus database for bibliometric assessment
ii. mapping to holistically comprehend worldwide CSE research patterns.

Publication growth, authorship pattern, collaboration, prolific authors, national contribution, most active establishments, top-cited articles, preferred journals, intellectual structure and topical trends in CSE were particularly explored between 1970 and 2021 to provide updated information for three groups of stakeholders: educators, researchers and policymakers on how this field has evolved. The following research questions were address in this bibliometric review:

RQ1: What are the document types, volume, growth of publications, collaboration and geographical distribution of publication on CSE?
RQ2: Which are the most influential articles and on CSE?
RQ3: Which journals have emerged as thought preferred in the CSE literature?
RQ4: What is the intellectual structure of CSE knowledge base?
RQ5: What are the topical trends of scholarship on CSE?

2. Methodology

This section describes the procedures used in the identification of studies for the review as well as methods of data analysis.

2.1 Data Sources and Search

Bibliometric analysis was conducted with the Scopus database on November 2021. The Scopus-index was chosen as the data source for searching and extracting papers. The review was confined to publications from "Scopus-indexed journals" because of its wide use to construct databases for systematic reviews and relevance selection for disciplines of study other than medicine and the physical sciences; empirical comparisons have indicated that Scopus provides more extensive coverage of sources than Web of Science [26,27]. The review followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) standards for conducting systematic reviews [28]. PRISMA is frequently used in social science research [29]. The keyword 'computer science education' (CSE) in the article title was employed to identify the relevant articles published in any language. The current study emphasized the article title as the first component to be perceived by readers in demonstrating topics that are significant to the research area and objective [30,31]. The search was refined to publication years between 1970 and 2021 in determining the CSE research publication pattern. Essentially, errata and retracted document types were omitted to deter double or false document counts.

2.2 Information Extraction

We extracted bibliographic information for 800 articles from the Scopus website and stored it in .csv (comma-separated values) file. The year, author name, subject area, document type, source title, keywords, author affiliation, country and language were all saved in the database. Additionally, a duplicate of the .csv file containing the same information was stored for use in descriptive data analysis. Then, we imported the .csv file into VOSviewer to build a map of bibliographic co-occurrences. The software enables users to create co-occurrence maps for various topics, including keywords, journal citation counts and publication titles [32]. Each article underwent bibliometric analysis, including the year of publication, keywords, journal publication citation count and country of publication. Figure 1 presents the study search approach where errata and retracted documents were eliminated to prevent double-counting and false-positive outcomes, respectively. All the documents were subjected to bibliometric evaluation using:

i. Microsoft Excel 2016 for published material frequency and percentage computation and the generation of pertinent charts and graphs
ii. VOSviewer (version 1.6.15) for bibliometric network establishment and visualization
iii. Harzing's Publish and Perish software for citation metric computation.

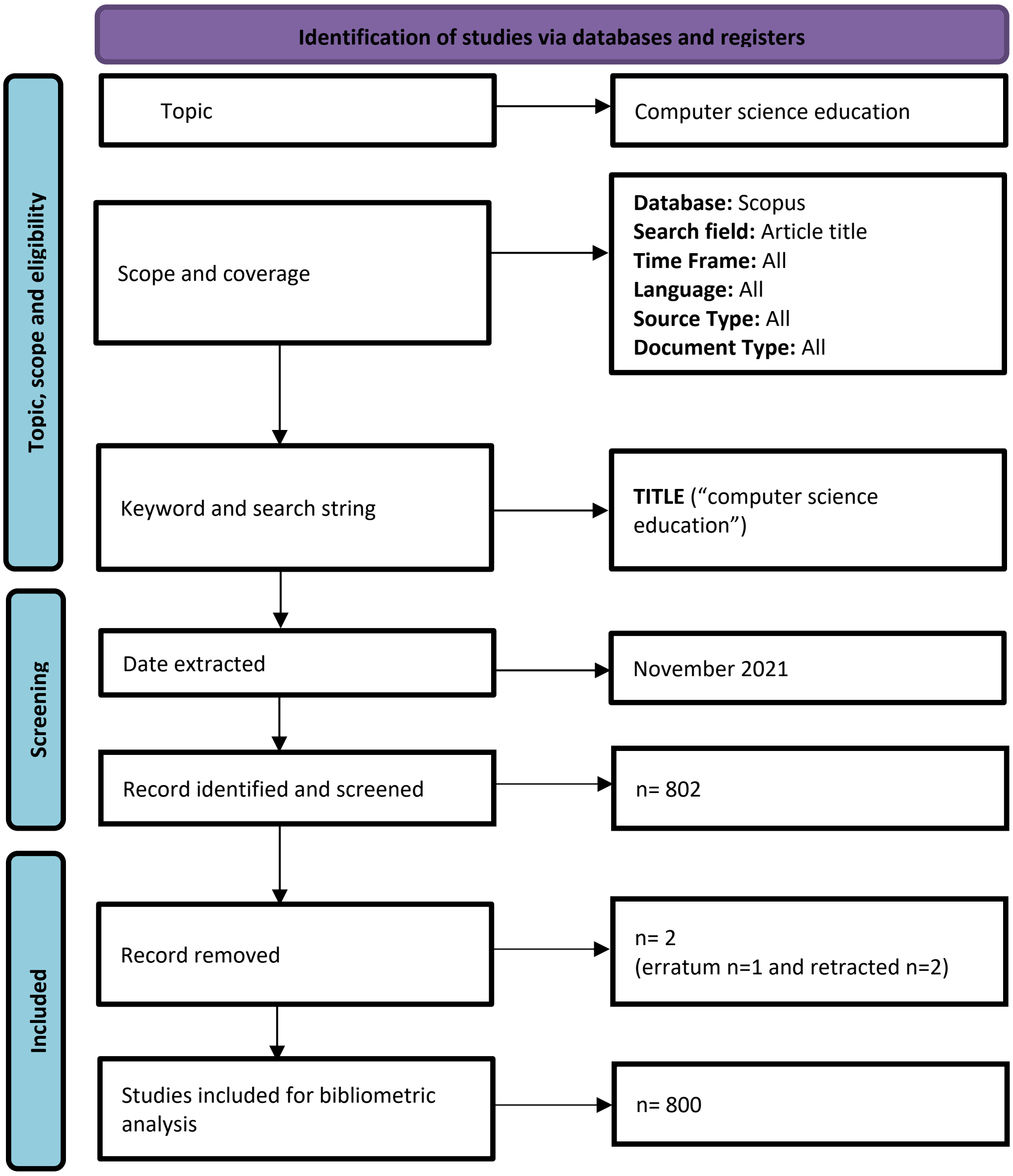

Fig. 1. PRISMA flow diagram of the search strategy

3. Results

This section shows the results of a bibliometric analysis of 800 publications with the title CSE published between 1970 till 2021.

3.1 Description of Retrieved Literature

Overall, 800 documents were selected from the Scopus database in terms of document (conference paper, journal article, conference review, editorial, book chapter, review article, note, short survey and book) and source types. Table 1 outlines the repertoire constitution based on document type. Conference papers demonstrated over half (415, 51.88%) of the total published documents, followed by journal articles (228, 28.50%), conference reviews (102, 12.75%), editorials (20, 2.50%), book chapters (14, 1.75%), review articles (10, 1.25%) and other documents that merely contributed under 1% of the total publication. The elicited documents resulted in a total of 6, 814 citations, 133.61 cites/y and 8.50 cites/paper while the h-index of retrieved documents implied 32.

Most of the extracted articles were published in English (98.14%), followed by German (1.12%), Chinese (0.12%), Russian and other unknown counterparts. Four of the papers were published in dual languages.

Table 1
Types of retrieved documents (1970–2021)

Document Type	Total Publications (TP)	Percentage (%)
Conference Paper	415	51.88
Article	228	28.50
Conference Review	102	12.75
Editorial	20	2.50
Book Chapter	14	1.75
Review	10	1.25
Note	4	0.50
Short Survey	4	0.50
Book	3	0.38
Total	800	100.00

3.2 Growth of Publications

Document analysis in terms of publication year facilitated the researcher's gradual observation of growth trends and study subject popularity [31]. The highest publication was perceived in 2019 with 68 documents while the lowest counterpart was observed in 1990 with no publication. A substantial rise was highlighted in the number of documents during the research duration (see Figure 2).

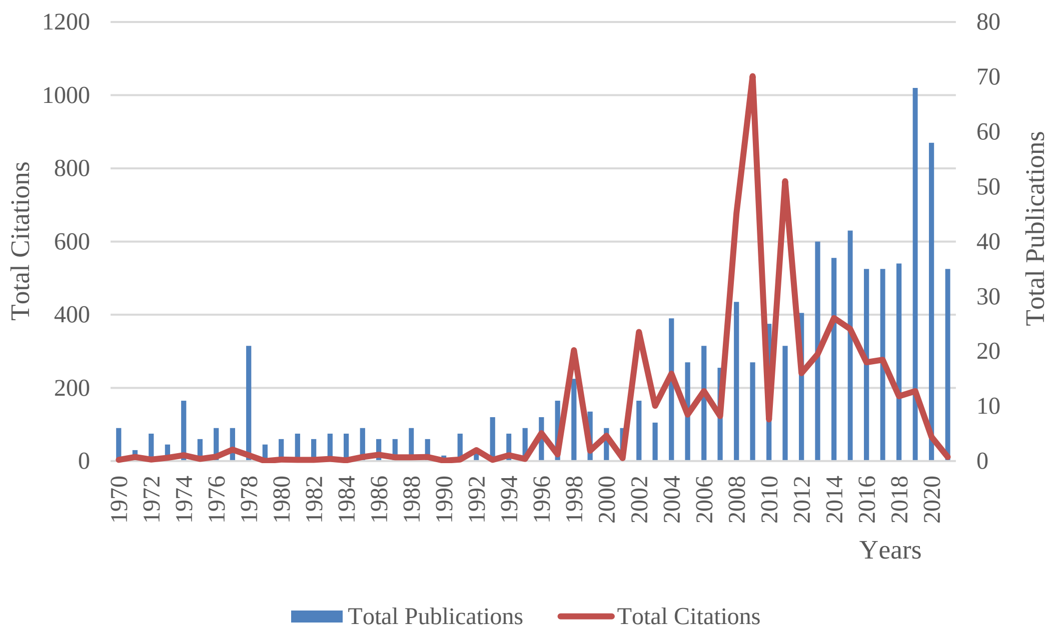

Fig. 2. Growth of CSE publications with 'computer science education' in the title

Table 2 represents the elicited document citation matrix per year. Meanwhile, the number of citations per publication proved highest for the documents published in 2009 (58.44 citations per publication) while no citations were identified for their counterparts in 1979 and 1990.

Table 2
Annual number of publications and citation matrix (1970–2021)

Year	TP	NCP	TC	C/P	C/CP	h	g
1970	6	2	3	0.50	1.50	1	1
1971	2	2	11	5.50	5.50	2	2
1972	5	3	4	0.80	1.33	1	1
1973	3	2	9	3.00	4.50	2	3
1974	11	6	16	1.45	2.67	3	3
1975	4	3	6	1.50	2.00	1	2
1976	6	4	12	2.00	3.00	2	3
1977	6	3	31	5.17	10.33	2	5
1978	21	6	16	0.76	2.67	3	3
1979	3	0	0	0.00	NA	0	0
1980	4	2	4	1.00	2.00	1	2
1981	5	3	3	0.60	1.00	1	1
1982	4	1	3	0.75	3.00	1	1
1983	5	3	6	1.20	2.00	2	2
1984	5	2	2	0.40	1.00	1	1
1985	6	3	11	1.83	3.67	2	3
1986	4	4	17	4.25	4.25	2	4
1987	4	2	10	2.50	5.00	1	3
1988	6	2	10	1.67	5.00	2	3
1989	4	2	11	2.75	5.50	1	3
1990	1	0	1	1.00	NA	0	0
1991	5	2	4	0.80	2.00	1	2
1992	2	1	30	15.00	30.00	1	2
1993	8	2	3	0.38	1.50	1	1
1994	5	2	16	3.20	8.00	2	4
1995	6	2	6	1.00	3.00	2	2
1996	8	4	76	9.50	19.00	4	8
1997	10	5	18	1.64	3.60	2	4
1998	15	8	303	20.20	37.88	5	15
1999	9	5	28	3.11	5.60	3	5
2000	6	6	69	11.50	11.50	3	6
2001	6	2	8	1.33	4.00	1	2
2002	11	7	353	32.09	50.43	4	11
2003	7	4	151	21.57	37.75	4	7
2004	26	20	239	9.19	11.95	8	15
2005	18	13	127	7.06	9.77	7	11
2006	21	13	191	9.10	14.69	8	13
2007	17	12	123	7.24	10.25	7	11
2008	29	20	677	23.34	33.85	9	26
2009	18	15	1052	58.44	70.13	6	18
2010	25	15	114	4.56	7.60	6	10
2011	21	14	765	36.43	54.64	6	21
2012	26	15	240	8.89	16.00	8	15
2013	40	29	292	7.30	10.07	9	16
2014	37	27	391	10.57	14.48	9	19
2015	42	32	361	8.60	11.28	9	18
2016	35	29	270	7.71	9.31	11	15
2017	35	24	277	7.91	11.54	8	16
2018	36	26	177	4.92	6.81	8	12
2019	68	49	191	2.81	3.90	6	9
2020	58	23	66	1.14	2.87	4	6
2021	35	7	11	0.31	1.57	2	2

Notes: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index; NA= not applicable

3.3 Authorship Pattern, Collaboration and Prolific Authors

Essentially, 216 (27.00%) documents denoted single-authored publications, 478 (59.75%) implied multi-authored papers, while the remaining 106 articles (13.25%) reflected conference review documents with no listed authors (see Table 3). As such, the emergence of collaborative studies or the extent of scientific collaborations among CSE scholars represented 59.75%.

Table 3
Number of author(s) per document

Author Count	Total Publications (TP)	Percentage (%)
0a	106	13.25
1	216	27.00
2	179	22.38
3	125	15.63
4	82	10.25
5	39	4.88
6	19	2.38
7	8	1.00
8	8	1.00
9	6	0.75
10	3	0.38
11	4	0.50
12	1	0.13
13	1	0.13
14	1	0.13
17	1	0.13
18	1	0.13
Total	800	100.00

Notes: 0a Conference review document. No author is listed

Authors with minimum document productivity and a total citation of 10 were visualized with the VOSviewer map (see Figure 3) that encompasses 12 circles with each highlighting one author. Several authors might be concealed due to the overlapping of names. Notably, closed circles reflected the active authors of closed research collaboration. A total of 159 authors published CSE-related documents between 1970 and 2021 in line with the study dataset.

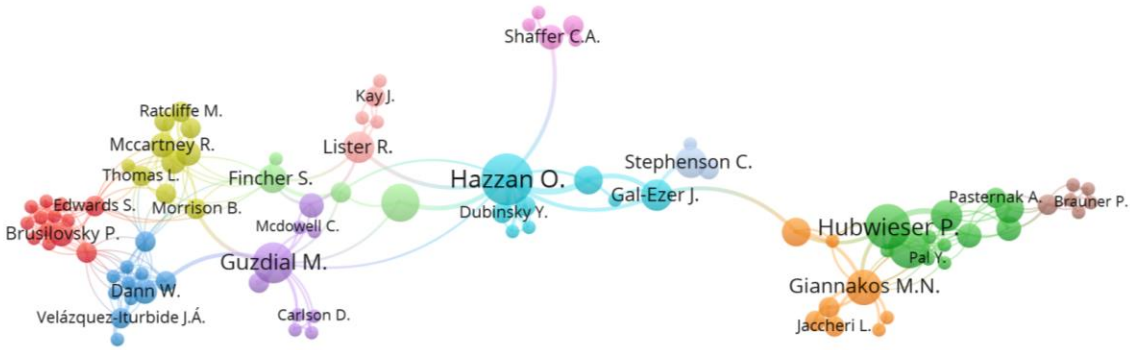

Fig. 3. Network visualization map of co-authorship in CSE research

Table 4 outlines the top 10 most productive authors during the study duration with Ohrndorf [33] from the Israel Institute of Technology representing the highest publication number (13 publications; 133 citations) followed by Zendler [20] from Ludwigsburg University of Education (11 publications; 89 citations).

Table 4
Top 10 most productive authors

Author Name	Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
Hazzan, O.	Israel Institute of Technology	Israel	13	11	133	10.23	12.09	5	11
Zendler, A.	Ludwigsburg University of Education	Germany	11	11	89	8.09	8.09	5	9
Hubwieser, P.	Technical University of Munich	Germany	10	10	245	24.50	24.50	6	10
Repenning, A.	University of Applied Sciences and Arts Northwestern	Switzerland	9	9	180	20.00	20.00	6	9
Diethelm, I.	University of Oldenburg	Germany	8	6	114	14.25	19.00	3	8
Guzdial, M.	University of Michigan	United States	8	5	174	21.75	34.80	5	8
Almstrum, V.L.	The University of Texas, Austin	United States	7	4	28	4.00	7.00	2	5
Ben-Ari, M.	Weizmann Institute of Science	Israel	6	5	310	51.67	62.00	5	6
Giannakos, M.N.	Norwegian University of Science and Technology	Norway	6	6	272	45.33	45.33	6	6
Klaudt, D.	Ludwigsburg University of Education	Germany	6	6	51	8.50	8.50	4	6

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index

3.4 Geographical Distribution of Publications

The extracted articles were authored by scholars from 67 nations showed interest in research on CSE. The geographical distribution of the 800 CSE publications is shown in Figure 4.

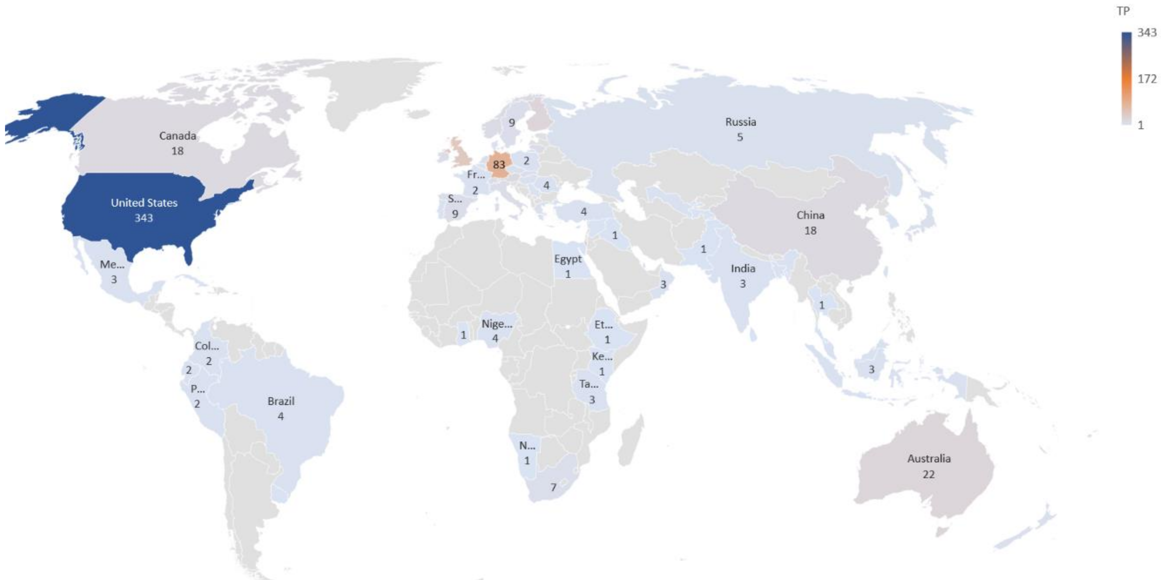

Fig. 4. Geographical distribution of CSE publications, 1970 to 2021. (Notes: TP = total number of publications)

However, only 21% of 67 nation had more than 10 publications as shown in Table 5 and presents the top 14 countries contributing to relevant publications with the United States ranking first (343 papers; 42.88%), followed by Germany (10.38%) and the United Kingdom (5.63%). According to the statistics, there is an increased interest in the United States and Germany to study and better comprehend the growth of CSE base knowledge and a need to do more intense research in Asia and Africa, where the majority of the undeveloped countries are located.

Table 5
Top 14 countries contributed to the publications

Rank	Country	TP	TC	TLS
1	United States	343	3739	63
2	Germany	83	844	39
3	United Kingdom	45	412	40
4	Israel	30	565	23
5	Finland	24	470	13
6	Australia	22	257	37
7	Austria	18	250	5
8	Canada	18	67	4
9	China	18	101	1
10	Norway	14	311	24
11	Switzerland	12	73	0
12	Ireland	11	19	27
13	Italy	11	55	19
14	Lithuania	11	140	21

Notes: TP = total number of publications; TC = total citations; TLS = total link strength

Furthermore, Figure 5 outlines the visualization of global collaboration with the minimum productivity of three documents. Specifically, the map illustrates the distribution of 35 nations in four distinctly-coloured clusters.

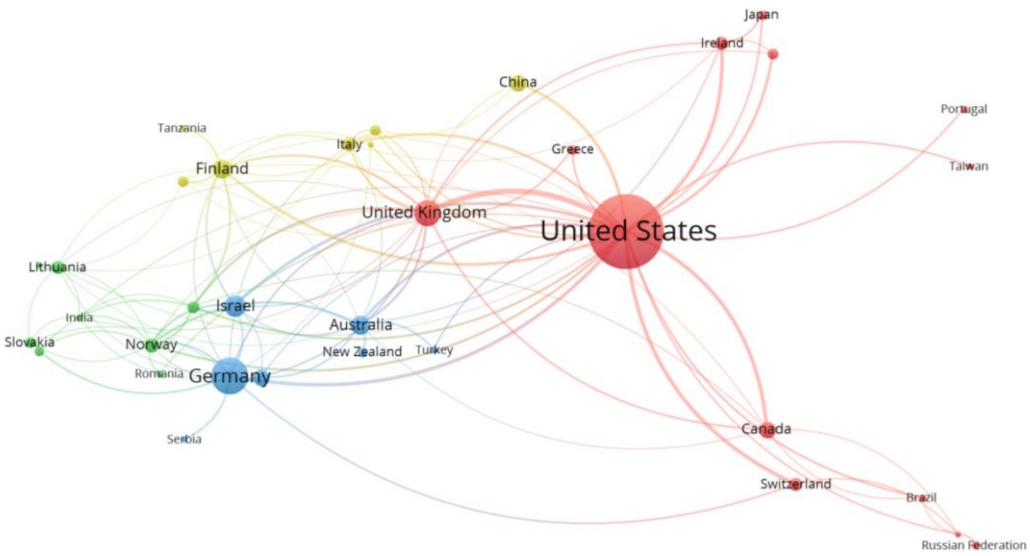

Fig. 5. Network visualization map of international collaboration among countries with minimum productivity of 3 documents

Table 6 highlights the most influential establishments with a minimum of seven publications. The University of Texas, Austin (the United States) ranked first with 15 publications, followed by the Georgia Institute of Technology and Israel Institute of Technology with 14 publications each, 11 American, three German and two Israeli and Finnish establishments along with one Norwegian, Swiss and Lithuanian institution.

Table 6
Most influential institutions with a minimum of seven publications

Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g
The University of Texas at Austin	United States	15	8	332	22.13	41.50	4	15
Georgia Institute of Technology	United States	14	11	207	14.79	18.82	6	14
Israel Institute of Technology	Israel	14	11	133	9.50	12.09	5	11
University of Colorado Boulder	United States	11	9	540	49.09	60.00	6	11
Norwegian University of Science and Technology	Norway	11	9	304	27.64	33.78	7	11
Weizmann Institute of Science	Israel	11	10	389	35.36	38.90	7	11
Technical University of Munich	Germany	10	10	245	24.50	24.50	6	10
Carnegie Mellon University	United States	10	6	93	9.30	15.50	3	9
Virginia Polytechnic Institute and State University	United States	9	8	233	25.89	29.13	7	9
Aalto University	Finland	9	6	363	40.33	60.50	5	9
University of Maryland	United States	8	5	68	8.50	13.60	3	8
University of Oldenburg	Germany	8	6	114	14.25	19.00	3	8
Indiana University Bloomington	United States	8	5	43	5.38	8.60	2	6
Xavier University	United States	8	5	31	3.88	6.20	4	5
University of Eastern Finland	Finland	8	8	44	5.50	5.50	4	6
University of Illinois Urbana-Champaign	United States	7	4	28	4.00	7.00	3	5
University of Applied Sciences and Arts Northwestern	Switzerland	7	7	52	7.43	7.43	5	7
Stanford University	United States	7	5	66	9.43	13.20	4	7
Rose-Hulman Institute of Technology	United States	7	3	90	12.86	30.00	2	7
Paderborn University	Germany	7	5	86	12.29	17.20	3	7
Kaunas University of Technology	Lithuania	7	6	44	6.29	7.33	4	6

Notes: TP = total number of publications; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index

The thickness of the connecting line between any two nations denotes the collaboration strength. Same-coloured countries constitute one cluster. For example:

i. The United States, United Kingdom, Canada, Switzerland, Greece, Ireland, Japan, Portugal, Taiwan, Brazil, Russian Federation, South Africa and Mexico are clustered in red
ii. Norway, Lithuania, Slovakia, Romania, Sweden, India, Czech Republic and Belgium are clustered in green
iii. Germany, Israel, Australia, Austria, New Zealand, Serbia and Turkey are clustered in blue.

3.5 Top Cited Documents

Table 7 presents the top 15 cited articles in CSE. As the most impactful article based on citation per year (81.00 citations/y), the ‘Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation’ document published in the 2009, *Journal of Computer & Education* obtained the highest (972) number of citations. On another note, Papastergiou [34]. was listed as the most productive scholar who has co-authored over half of the highly-cited documents outlined in Table 7, such as the second-most cited article (‘Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community?’) published in the 2011 *ACM Inroads* with 639 citations.

Table 7
Top 15 highly cited articles in CSE research

No.	Authors	Title	Year	Cites	Cites Per Year
1	M. Papastergiou	Digital game-based learning in high school computer science education: Impact on educational effectiveness and student motivation.	2009	972	81.00
2	V. Barr, C. Stephenson	Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community?	2011	639	63.9
3	L. Buechley, M. Eisenberg, J. Catchen, A. Crockett	The LilyPad Arduino: Using computational textiles to investigate engagement, aesthetics and diversity in computer science education	2008	348	26.77
4	T.L. Naps, R. Fleischer, M. McNally, G. Rößling, C. Hundhausen, S. Rodger, V. Almstrum, A. Korhonen, J. Á. Velázquez-Iturbide, W. Dann, L. Malmi	Exploring the role of visualization and engagement in computer science education	2002	271	14.26
5	M. Ben-Ari	Constructivism in computer science education	1998	237	10.30
6	A. Holzinger, M. Kickmeier-Rust, D. Albert	Dynamic media in computer science education; Content complexity and learning performance: Is less more?	2008	110	8.46
7	S.H. Edwards	Rethinking computer science education from a test-first perspective	2003	110	6.11
8	S. Fincher, M. Petre	Computer science education research	2004	95	5.59

9	L. Porter, M. Guzdial, C. McDowell, B. Simon	Success in introductory programming: What works? How pair programming, peer instruction and media computation have improved computer science education	2013	91	11.38
10	A. Repenning, D.C. Webb, K.H. Koh, H. Nickerson, S.B. Miller, C. Brand, I.H.M. Horses, A. Basawapatna, F. Gluck, R. Grover, K. Gutierrez, N. Repenning	Scalable game design: A strategy to bring systemic computer science education to schools through game design and simulation creation	2015	86	14.33
11	M.N. Giannakos, J. Krogstie, N. Chrisochoides	Reviewing the flipped classroom research: Reflections for computer science education	2014	82	11.71
12	A. Yadav, S. Gretter, S. Hambrusch, P. Sands	Expanding computer science education in schools: understanding teacher experiences and challenges	2017	71	17.75
13	P. Hubwieser, M.N. Giannakos, M. Berges, T. Brinda, I. Diethelm, J. Magenheim, Y. Pal, J. Jackova, E. Jasute	A global snapshot of computer science education in K-12 schools	2015	67	11.17
14	J. Pirker, M. Riffnaller-Schiefer, C. Gutl	Motivational active learning - Engaging university students in computer science education	2014	54	7.71
15	M.N. Giannakos, J. Krogstie, N. Chrisochoides	Reviewing the flipped classroom research: Reflections for computer science education	2014	82	11.71

Notes: TP = total number of publications; TC = total citations

3.6 Preferred Journals

Table 8 outlines the top 10 CSE journals. The *ACM SIGCSE Bulletin* and *Annual Conference on Innovation and Technology in Computer Science Education ITiCSE* ranked first and second with 53 and 42 documents, respectively.

Table 8
Top 10 publishing journals on CSE research

Source Title	TP	TC	Publisher	Cite Score	SJR 2020	SNIP 2020
ACM SIGCSE Bulletin	53	122	Association for Computing Machinery, Special Interest Group on Computer Science Education	NA		
Annual Conference on Innovation and Technology in Computer Science Education ITiCSE	42	54	Annual Conference on Innovation and Technology In Computer Science Education ITiCSE	NA		
SIGCSE Bulletin Association for Computing Machinery Special Interest Group on Computer Science Education	34	406	Association for Computing Machinery, Special Interest Group on Computer Science Education	NA		
Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	30	110	Springer Nature	1.8	0.249	0.628
ACM International Conference Proceeding Series	29	103	ACM International Conference Proceeding Series	1.2	0.182	0.296

Proceedings of The Conference on Integrating Technology into Computer Science Education ITiCSE	28	416	Proceedings Of the Conference on Integrating Technology into Computer Science Education ITiCSE	NA		
Computer Science Education	20	265	Taylor & Francis	5.1	0.83	2.644
Communications of the ACM	19	281	ACM	11.3	0.967	4.595
Proceedings Frontiers in Education Conference Fie	15	69	Proceedings - Frontiers in Education Conference, FIE	0.7	0.194	0.428
ACM Inroads	11	657	ACM	1.4	0.194	1.21

Notes: TP = total number of publications; TC = total citations

Meanwhile, Figure 6 illustrates a network visualization map for journal co-citation analysis with a minimum of 20 citations. The *Communications of The ACM* study attained the highest number of connecting lines from other journals, hence implying the journal co-citation with most other counterparts. Notably, the aforementioned journal demonstrated the largest circle size and number of CSE research citations.

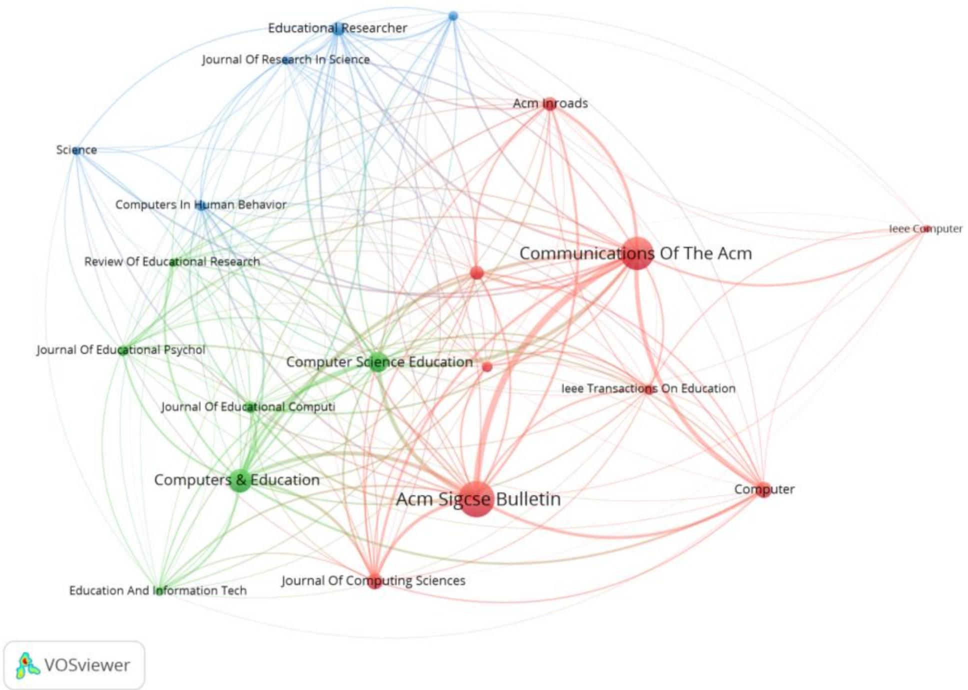

Fig. 6. Network visualization map of co-citation analysis for journals that published documents in CSE with a minimum total of 20 citations. The ACM SIGCSE Bulletin depicted multiple connecting lines with different journals, thus indicating the journal co-citation with computing (red cluster) and educational (green cluster) research counterparts

3.7 Intellectual Structure of the CSE Knowledge Base

Our fourth research question sought to identify prominent authors and the CSE knowledge base is growing 'intellectual structure.' Intellectual structure refers to the schools of thought that constitute the essential research traditions inside a knowledge base [35]. As previously stated, VOSviewer reveals various schools of thought by visualising author association based on co-citation patterns [36]. In VOSviewer, an author co-citation map was generated, displaying the 40 authors with at least 30 co-citations (Figure 7).

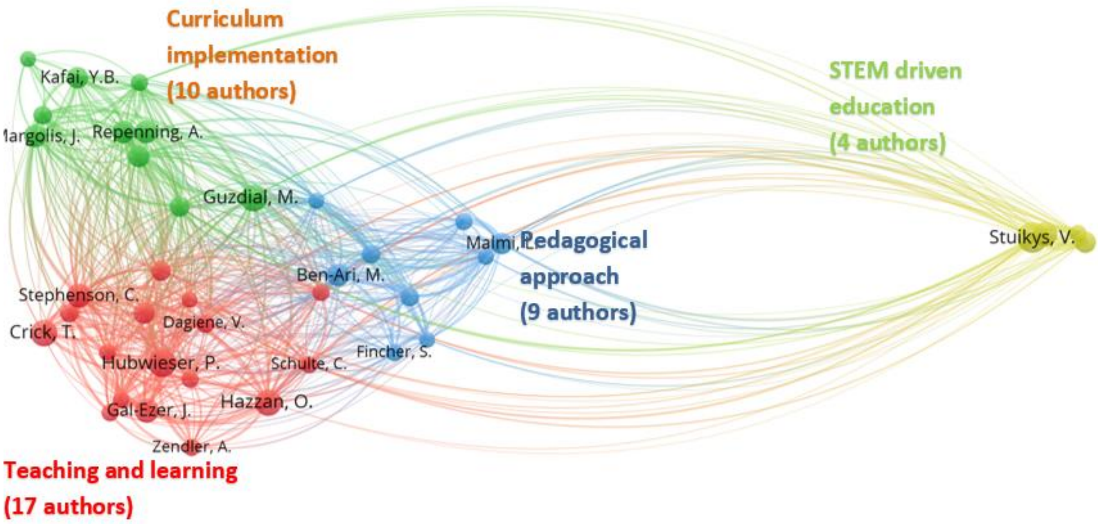

Fig. 7. Schools of Thought in the CSE literature based on author co-citation analysis (15848 in the author network; threshold of 30 co-citations with display of 40 authors in four clusters) (Note: Size of node refers to frequency of co-citations in reference lists of the review documents; proximity refers to frequency with which two authors have been co-cited; colour refers to the clustering of authors based on patterns of co-citation in the review documents)

The co-citation map of authors indicated four clustered yet interconnected schools of thought in CSE. The size of a node represents the author's level of co-citation by other researchers. Thus, Stuikys (108 co-citations), Hubwieser (94), Guzdial (87) and Crick (86) were identified as the most frequently referenced scholars in this literature by co-citation analysis. As aforementioned, co-citation analysis sheds light on author relationships. When a line links two scholars, they have been co-cited by a third scholar. As a result, the large size of the node and dense links originating from Stuikys on the map suggests that he has not only gathered a considerable number of co-citations (i.e., large size of the node) but has also been co-cited with a significant number of other scholars (i.e., numerous links).

The red cluster reflects the term *Teaching and Learning* school of thought. This school's scholars have been focused on defining the and developing a curriculum that contributes to CSE [37,38]. Hubwieser (94 co-citations), Crick (86), Hazzan (81) and Gal-Ezer (72) are vital authors in this school. The central location on the map, establish Hubwieser as the first 'boundary spanning scholar' in this cluster. Boundary spanning scholars play a vital role in the establishment of literature by combining the numerous conceptual streams or schools of thought that cohere into literature [39].

The merging of scholars in this school with those in the red and blue schools shows overlap with CSE methodologies and activities (e.g., type of activities designed for learners, recognition of learners' issues, the method to enhance concept understanding, assessment and testing of learners' projects) [40]. Leading scholars in this blue school in terms of *Pedagogical Approach* are Ben-Ari (59 co-citations), Malmi (53), LIster (45), Simon (45) and Korhonen (36).

The yellow cluster is related to *STEM Driven Education*. Despite being slightly smaller than the *Pedagogical Approach* school, it has more influential researchers and a higher citation effect. Scholars at this school have attempted to comprehend STEM-driven education in computer science. Stuikys (108 co-citations), Burbaite (69), Damasevicius (54) and Bespalova (34) are the prominent scholars in this school, all of whom are based in Kaunas, Lithuania.

Curriculum Implementation is the focus of the red cluster schools of thought regarding the number of scholars. Guzdial (87 co-citations), Repenning (65), Margolin (61), Resnick (61) and Papert (61) are among the most prominent scholars (55). Scholars in this school have focused on thorough curriculum assessments across countries and resources to discover the emergence of common CSE topics and concepts to drive future curriculum creation and research [41]. Curriculum change, whether through curriculum reform or the introduction of new content, presents numerous obstacles and may take several years to complete, particularly when aligning the implemented and intended curriculum [41]. Teachers have often recognized a lack of resources and time as significant barriers to implementing a new curriculum and the complexities of clearly knowing curriculum standards.

3.8 Topical Trends in the Computer Science Education Knowledge Base

The VOSviewer method of mapping author keywords with a minimum of five occurrences depicted computer science education, computer science, education, curriculum, computational thinking, k-12, cs1, gender, diversity and game-based learning to be the most encountered author keywords post-exclusion of the core keywords involving the search query (see Figure 8). Circles within the same colour cluster indicated a similar topic among the publications.

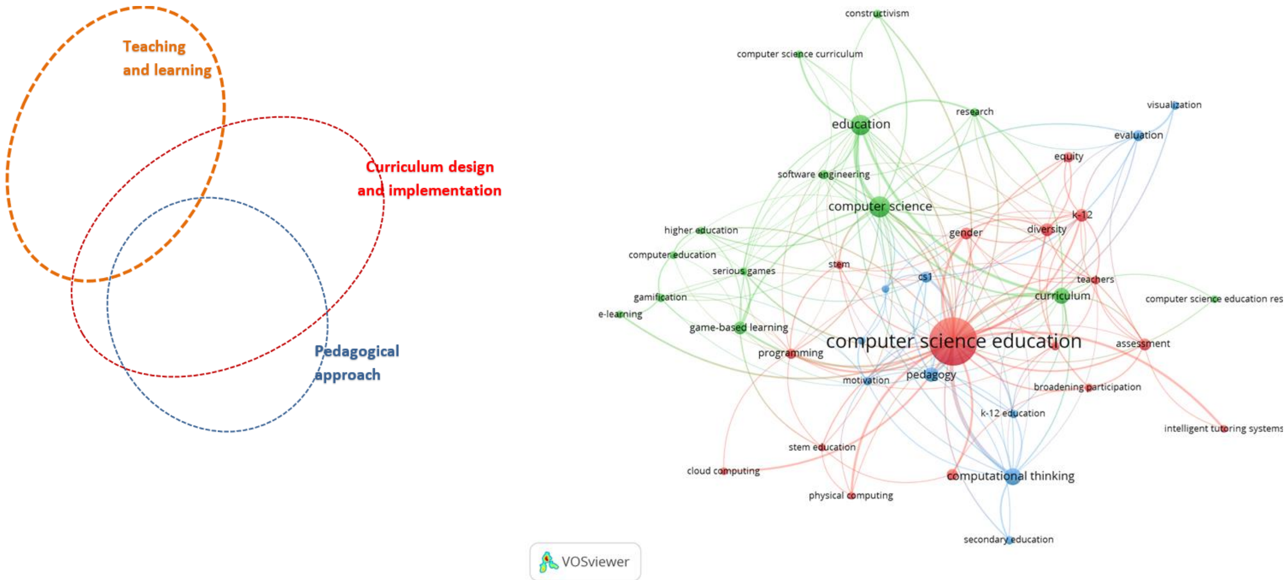

Fig. 8. Network visualization map of the keywords co-occurrence (Note: Unit of analysis = author keywords; counting method = fractional counting; minimum number of occurrences of a keyword = 5; minimum cluster size = 7)

Every publication demonstrated a CSE sub-field. We used keyword co-occurrence analysis to reveal three themes in the CSE knowledge base that scholars were studying. The result of keyword co-occurrence analysis is a network of themes and relationships representing a field's conceptual space. When words frequently appear in documents, it indicates that the thoughts behind those words are strongly related [35]. Keywords involving assessment, broadening participation, cloud computing, computer science education, computing education, diversity, equity, gender and intelligent tutoring system were associated with the topics ‘curriculum design and implementation’ as presented in the red cluster (cluster 1, 16 items). Meanwhile, keywords encompassing computer education, computer science curriculum, constructivism, e-learning, game-based learning and gamification emphasized the primary ‘teaching and learning’ domain within the green cluster (cluster 2, 14 items) while keywords consisting of computational thinking, evaluation, k-12 education, motivation, pedagogy and visualization were related to the ‘pedagogical approach’ in the blue cluster (cluster 3, 10 items).

In Figure 9, the keyword co-occurrence map has a temporal overlay that connects keywords to document dates. Temporal keyword co-occurrence analysis displays a topic's popularity peak [42]. Darker nodes represent topics that were popular earlier in this literature and lighter nodes represent recent literature. This way, the evolution of CSE literature over the last 50 years may be followed using colour/shade analysis. The hot topics of temporal co-word map include computer science education (177 co-occurrences) and computer science (34 co-occurrences). STEM and computer science education are becoming increasingly inextricably linked. Computing education has emerged to facilitate the integration of stem education processes [12]. Coordination in curriculum design and implementation of computer science education can benefit from "programming" and "stem education" collaboration [21], "software engineering" [43] and "gamification" [44].

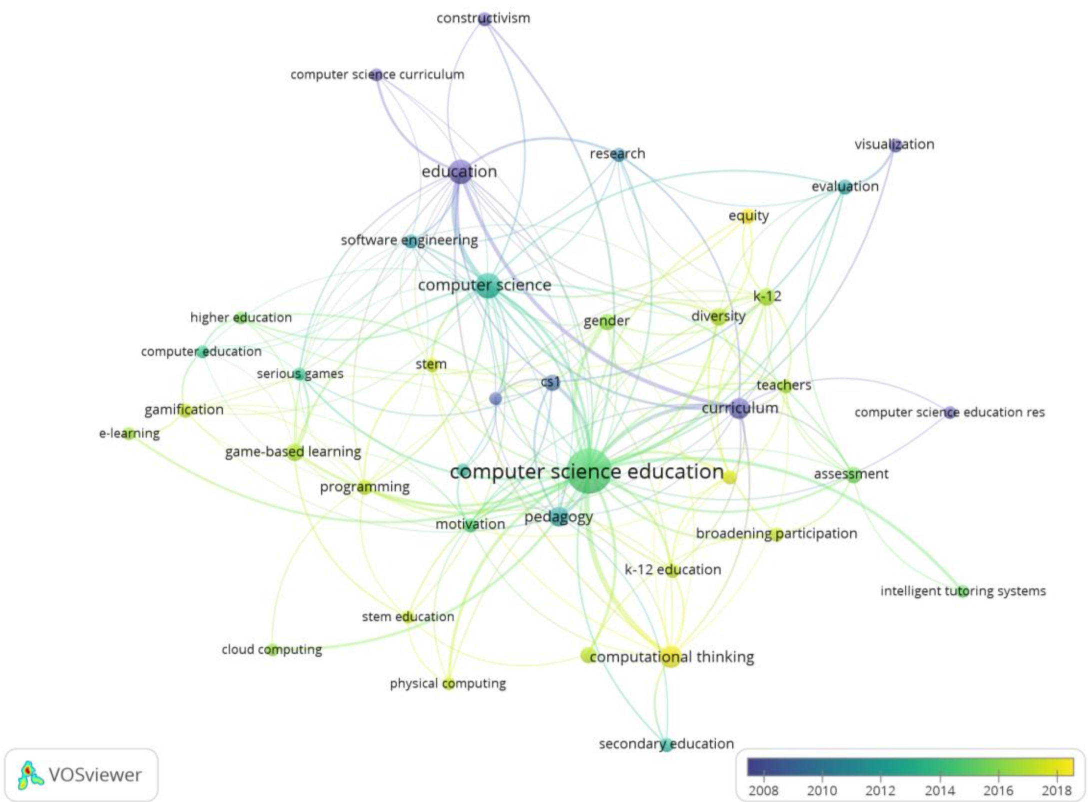

Fig. 9. Temporal overlay visualisation map of the co-occurrence (Note: Unit of analysis = author keywords; counting method: fractional counting; minimum number of occurrences of a keyword = 5; minimum number of cluster size = 7)

4. Discussions

Bibliometric analysis has gained much popularity as one of the most holistic research pattern techniques [45]. In recent years, bibliometric analysis has gained traction as a method for conducting reviews in CSE. A recent study applied bibliometric analysis to examine the keywords used by scholars who published in the proceedings of ICER and ITiCSE working group reports [46]. Similarly, scholars have documented and analysed patterns in the CSE knowledge base using descriptive statistics and citation analysis. The distinction is that this review was conducted using keywords titled computer science education extracted from the Scopus database chosen over the last 50 years instead of databases in the proceedings of ICER and ITiCSE. This section interprets the evolution of CSE research in teaching and learning, explains the review's limitations and suggests future work to further our community's understanding and subfields.

4.1 Interpretation of Evolving Computer Science Education Research in Teaching and Learning

This study justified the initial attempt to highlight the rising trend of annual publications from the 1970s, which stabilized in the late 2003s and perpetuated from 2004 onwards. The Scopus database searched with the defined search query identified 800 publications for evaluation. Such publication rates proved to be extremely low despite the adoption of CSE as a curriculum subject in several nations. Only some articles were published in high-impact journals or conference proceedings following the low research impact with 6, 814 citations. Some documents successfully elicited non-trivial citation numbers in high-impact international journals. The overall performance level paralleled a recent global study review of CSE [47,48].

This trend continues based on the rising number of publications on an annual basis following the study outcomes. Citation-wise, the documents published in 2009 might not be selected as highly-cited articles with high total citations, average citations per publication (per cited publication) and *h* and *g* indices compared to past publications. Furthermore, the research findings depicted a shift in the geographical distribution of CSE research publications with the United States overtaking Germany based on the network visualization maps of global research collaboration due to the presence of active CSE-exploring American establishments. Intriguingly, Germany remained prominent with its topmost prolific authors. For example, Hazzan *et al.,* [49] remained the most productive author who contributed 13 publications and extensively co-authored top-cited articles based on the network visualization map of co-authorship. Papastergiou M. reflected the highest cited CSE document (1972) which appeared in the *Journal of Computers & Education* followed by Zendler [20] and Hubwieser *et al.,* [48] as the second and third-most productive author with 11 and 10 publications, respectively. Thus, Germany was projected as the most influential institution given that the top two and three most productive authors originated from the same nation.

The CSE has become a pertinent issue in curriculum design and change implementation in line with the top 10 highly-cited articles. Speculatively, CSE studies on:

i. curriculum design and implementation
ii. learning and teaching could substitute previously-dominant CSE research clusters parallel to the network visualization map of journal co-citation analysis.

4.2 Limitation

This bibliometric analysis encountered several restrictions. First, the research data were limited to the Scopus database (partial international production sample within this topic) despite the notably large body of knowledge on CSE. As a result, publications from other databases, such as WoS, may have been omitted. Second, our sampling strategy resulted in the omission of conference papers, journal articles, conference reviews, editorials, book chapters, review articles, notes, short surveys and books, as well as keywords associated with the titles of CSE articles published over the last 50 years. Additionally, we limited our data retrieval to the search title word "computer science education". Some CSE articles might have been disregarded if the authors failed to incorporate the study inclusion descriptors in the article titles. While utilising exact search terms may result in a more limited dataset. As a result, the review did not cover the entirety of the CSE literature. Third, the current study data analysed only a subset of the corpus's temporal dimensions ranged between 1970 and November 2021 with new research publications daily. Lastly, the citation count applied to evaluate the research impact could not explicitly reflect each research quality. However, such restrictions are unlikely to affect the patterns and trends revealed in this study.

4.3 Future Work

As our findings indicate, CSE research focuses on curriculum design and implementation, teaching and learning and pedagogical approaches. Future research can deepen our understanding of CSE evolution through quantitative techniques such as authorship and citation analysis and qualitative techniques such as systematic and narrative reviews. Additionally, future studies may incorporate CSE papers from additional databases. Meanwhile, the future study can extend the co-occurrence analysis to a more extensive database, such as the World Wide Web, as the corpus. Finally, the additional investigation should investigate any variations in the usage of terminology between periods (e.g., in five-year). This type of study would uncover newly developed areas, places that had vanished and areas that had evolved into something new. Future research might be particularly intriguing since it would allow us to examine research ideas originating from bridging CSE and other fields, such as pedagogical techniques in the higher education environment, in the CSE knowledge base.

5. Conclusion

This study shows that the US leads Computer Science Education (CSE) research, followed by Germany. The ACM SIGCSE Bulletin dominates CSE publications, demonstrating its importance in global CSE knowledge dissemination. The University of Texas, Austin is a prospective partner for cross-institutional research that could enrich the CSE discipline. Curriculum design and implementation, as well as learning and teaching methods, are future research priorities. These topics align with worldwide education reform trends that emphasize integrating innovative teaching methods and adapting curricula to satisfy the technology sector's demands. Additionally, this study may affect various critical stakeholders. These findings can help funders prioritize research with the greatest potential for innovation and social benefits. This data can help researchers uncover study gaps and collaborate internationally to solve CSE education's complex problems. Finally, identifying CSE research strengths and deficiencies may help policymakers create data-driven policies that promote educational equity, digital literacy and technology workforce strategic development. In conclusion, this study provides a complete review of CSE research, laying the groundwork for future academic collaborations and policy frameworks. This research contributes to the academic community and the broader dialogue on how to shape computer science education to meet the demands of the digital era and Sustainable Development Goal 4: Quality Education, ensuring inclusive and equitable access to high-quality education and lifelong learning opportunities for all.

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