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Examining the Trend of Research on Computational Thinking: A Bibliometric Analysis

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ABSTRACT

This study presents a bibliometric analysis of top papers published in the research of computational thinking (CT) between 2006 and 2020, retrieved from the Scopus database. Based on the keywords used, which are related to computational thinking in the article title, the study retrieved 1422 documents for further analysis using various tools. Microsoft Excel was used to conduct frequency analysis, VOSviewer for data visualization, and Harzing's Publish or Perish for citation metrics and analysis. This study reports the results using ordinary bibliometric indicators such as the growth of publications, authorship patterns, collaboration, and prolific authors, country contribution, most active institutions, preferred journals, top-cited articles, top subject area, and top keywords analysis. The findings shows there is a continuous growth of publications on computational thinking research for 14 years since 2006. United States of America was the largest contributor to computational thinking research, followed by the People's Republic of China. In terms of publication, the ACM International Conference Proceeding Series published the most number of publications related to computational thinking research. Through VOSviewer software, the findings depict co-authorship and bibliographic couplings of authors and their affiliated institutions and countries, co-citations of journals, and co-occurrence of an author-specified keyword

Keywords: Bibliometric, Computational thinking, Harzing's Publish or Perish, VOSviewer

INTRODUCTION

Talks on computational thinking (CT) as a vital skill for the future have grown tremendously. The future generations must develop the skill to succeed in today's technological society (ISTE and CSTA 2011; ISTE 2016; NRC 2010; The Royal Society 2012). CT is one of the essential elements in building creativity and intelligence among human capital to meet the challenges of the 21st century (The College Board 2017), and a vital skill in the era of industrial revolution 4.0 (IR 4.0) (Chong and Wong 2019). The definition of CT has undergone some debate and re-examination, with no clear consensus on the actual definition of CT (So et. al 2020). According to Wing (2006, p. 33), is "solving problems, designing systems, and understanding human behaviors, by drawing on the concepts fundamental to computer science". Wing then refined her definition of CT, that is an approach to problem solving by using basic concepts for computing (Wing 2008). Later, Grover and Pea (2013) and CTSA (2011) described the term CT as a data collection, data analysis, data representation, problem decomposition, abstraction, algorithms and procedures, automation, simulation and parallelization. Aho (2012) defines CT as problem-solving techniques including algorithm design that is used to solve common problems in computing, which involves three key elements namely algorithms, abstraction, and automation (Wing 2006; Yadav et. al 2011; Yadav et. al 2017). Since then, the term CT has evolved with a variety of interpretations, for instance Özmutlu et al. (2021) define CT as problem solving, designing and interpreting new systems by thinking like a computer. Meanwhile, Allsop (2019) defines CT as an advanced metacognitive skill that goes beyond the context of problem solving.

Studies related to CT has increased extremely since 2006 after Wing formally popularized the term into the scientific community, even though the term of CT originally came from Seymour Papert in 1980 through LOGO programming. Since then, CT topic has been found published in Scopus and many studies related to CT have been conducted in various fields and concepts such as the factors contributing to the implementations of CT and the impacts and evolutions of CT on related fields such as bibliometrics analysis. Bibliometrics is a sophisticated and versatile technique that produces many different types of information useful for integration at different scenario technique steps (Stelzer et. al 2015), and provides valuable tools for describing scientific activity in the past and for orienting future research (Schoepflin & Glänzel 2001). Bibliometrics is built on the database of large scholarly articles. When bibliometrics is applied to a particular field of technology the results will include intellectual structure, current research topics and publication organizations, authors, and countries (Ma et. al 2014; Vogel & Güttel 2013). This will allow the identification and description of a network of patterns resulting from scientific knowledge being formed (Ali et. al 2020).

There are several past studies conducted to look at the patterns and growth of CT using bibliometric analysis. For example, Chen et. al (2018) conducted a bibliometric analysis on CT related kinds of literature from Web of Science (WoS) database from 1900 to 2018. They analysed the development status, developing trend, and hot subjects of computational thinking research. The findings show that CT was first time mentioned in 1979 but studies began to emerge officially in 2009. The top 5 keywords with high occurrence were "computational thinking", "education", "K-12", "programming", and "early", while "computational literacy", "competition", and "mobile programming" were the most frequently occurring themes.

Roig-Vila and Moreno-Isac (2020) also conducted a bibliometric analysis study focusing on research of CT-related papers for 39 years (1979-2018) based on the WoS database. The data analysis of the study covered aspects such as year and country of publication, source of the documentary in which it was published, author of the document, characteristics of the study participants, type of document, research methodology used and platform or programming language with successful computational thinking. Their study found that the field of CT studies is continuously increasing from year to year until 2018, Furthermore, Roig-Vila and Moreno-Isac (2020) also suggested some aspects of improvement that should be considered for future bibliometric analysis studies such as the impact index of the author's work or the funding of the study. Their study found that the field of CT studies is continuously increasing until 2018, variously merged and applied. The increasing number of CT-related publication, according to Cano and Delgado (2015), is correlated with programming subject – a CT skill deemed vital in the future.

Saqr et. al (2021) conducted a study using Scopus database for articles published between the period 2006 to 2019. They found 1784 documents related to the topic. but data representing the documents each year were not shown in their article. Their study analyses data with regards to main themes of research, international collaborations, influential authors, seminal publications, and how authors and publications have influenced one another.

The current study, despite the same publication period focused in Roig-Vila and Moreno-Isac (2020), and Saqr et. al (2021), aims to provide a better understanding of the global trends in the CT research as reported in the Scopus-indexed journal articles. Specifically, this study explores the growth of publications, authorship pattern, collaboration, prolific authors, country contribution, most active institutions, preferred journals, top-cited articles, top subject area, and top keywords analysis in the field of CT from 2006 to 2020.

INSERTING CONTENT ELEMENTS

A bibliometric analysis was performed using Scopus database as a basis to extract published works on CT as of May 2021. The search term 'computational thinking' contained in the article title was used to search for relevant articles published in any language related to research on CT. This study focuses on the title of the articles because it is the first element that readers will perceive (Annesley 2010; Bavdekar 2016; Rossi & Brand 2020). It represents the relevant topic that is significant with the research area and the aim of the study. A refined search for the publishing year from 2006 to 2020 was used to identify the recent trend in CT research, with erratum and retracted document types excluded to avoid double or false counting of documents. Therefore, the PRISMA protocol by Moher et. al (2009) was adopted to provide a robust and comprehensive framework in this study (**Figure 1**). In addition, PRISMA's search for the right term could be promptly executed with extensive scientific literature database searches related to CT. Figure 1 shows the search strategy employed for this study and all documents targeted for bibliometric analysis. There were three software tools used in this study namely: (1) Microsoft Excel 2016 to calculate the frequencies and percentage of the published materials and to generate the relevant charts and graphs; (2) VOSviewer (version 1.6.15) to create and visualize the bibliometric networks; and (3) Harzing's Publish and Perish software to calculate the citations metrics.

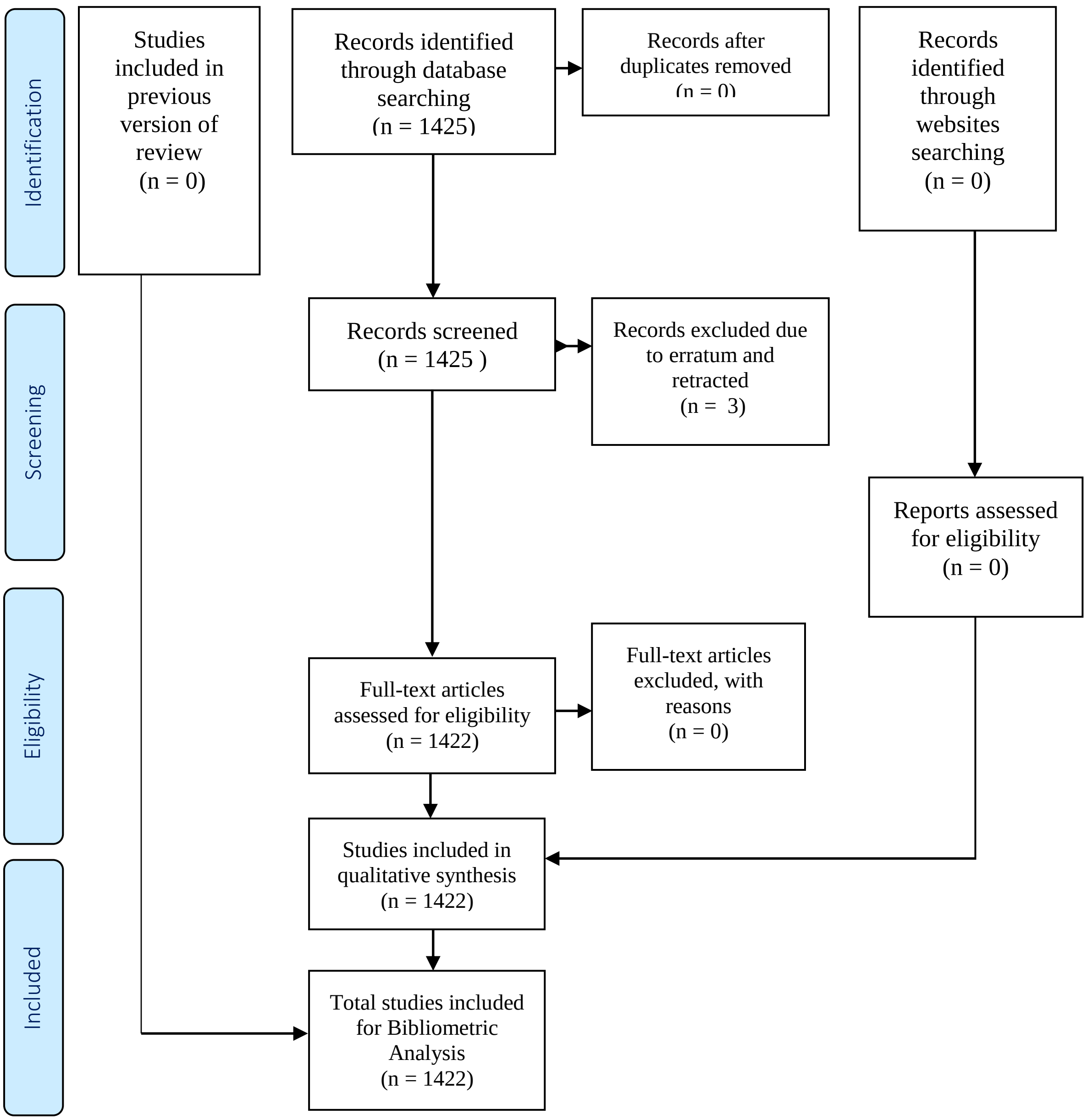

Figure 1: PRISMA 2020 Flow Diagram.

Source: Matthew J. Page, Joanne E. McKenzie, Parick M. Bossuyt, Isabelle Boutron, Tammy C. Hoffmann, Cynthia D. Mulrow, Larissa Shamseerf, Jennifer M. Tetzlaff, Elie A. Akli, Sue E. Brennan, Roger Chou, Julie Glanville, Jeremy M. Grimshaw, Asbjørn Hróbjartsson, Manoj M.

Lalu, Tianjing Li, Elizabeth W. Loder, Evan Mayo-Wilson, Steve McDonald, Luke A. McGuinness, Lesley A. Stewart, James Thomas, Andrea C. Tricco, Vivian A. Welch, Penny Whiting, David Moher. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. International Journal of Surgery, 88, 105906.

RESULTS

Description of Retrieved Literature

This section will present the results and analysis of 1422 articles published in the Scopus journal database in terms of the document type and source type, growth of publications, authorship pattern, collaboration, prolific authors, geographical distribution of publications, preferred journals, and top cited documents. **Table 1** summarizes the constitution of the repertoire depending on the type of document. Conference paper accounted for (934, 65.68%) more than original articles (402, 28.27%), followed by book chapter (34, 2.39%), review (17, 1.20%), and other document types that each only contributed less than 1% of the total publications.

Table 1.
Document Type (2006 – 2020)

Document Type	Total Publications (TP)	Percentage (%)
Conference Paper	934	65.68
Article	402	28.27
Book Chapter	34	2.39
Review	17	1.20
Editorial	12	0.84
Conference Review	6	0.42
Note	5	0.35
Book	4	0.28
Letter	4	0.28
Short Survey	4	0.28
Total	**1422**	**100.00**

Meanwhile, Table 2 summarizes the constitution of the collection depending on the type of source. The top publications for source type was conference proceeding (756, 55.90%), followed by journal (456, 33.70%), book series (94, 6.96%), book (35, 2.63%), and trade journal (11, 0.81%).

Table 2.
Source Type (2006 – 2020)

Source Type	Total Publications (TP)	Percentage (%)
Conference Proceeding	828	58.23

Journal	453	31.86
Book Series	94	6.61
Book	36	2.53
Trade Journal	11	0.77
Total	**1422**	**100.00**

Table 3 shows the citation matrices from the retrieved documents, a total of 16272 citations, 1084.80 cites/y, and 11.44 cites/paper. The h-index of the retrieved documents was 53.

Table 3.
Citations Metrics

Metrics	**Data**
Publication years	2006-2020
Citation years	14 (2006-2020)
Papers	1422
Citations	16272
Citations/year	1084.80
Citations/paper	11.44
Citations/author	8436.85
Papers/author	614.62
h-index	53
g-index	109

Table 4 indicates that the major language used in the retrieved document was English (94.23%), followed by Spanish and Chinese with 1.98%. Other languages found (<1%) include Italian, Portuguese, Turkish, German, Japanese, Arabic, and Korean. About 15 of the documents were published in dual languages.

Table 4.
Languages

Language	**Total Publications (TP)***	**Percentage (%)**
English	1340	94.23
Spanish	27	1.98

Chinese	27	1.98
Italian	10	0.73
Portuguese	9	0.59
Turkish	3	0.22
German	2	0.15
Japanese	2	0.15
Arabic	1	0.07
Korean	1	0.07
	1422	100.00

*15 document published in dual languages

The VOSviewer technique which maps the author keywords with 25 being the minimum occurrences, shows that problem solving, programming, computer science education, K-12, teacher professional development, computing education, robotics, coding, scratch, and curriculum were the most encountered author keywords after the exclusion of the core keywords related to the search query (**Figure 2**). Circles in the same color cluster suggest a similar topic among the publications. Each represents a subfield of computational thinking research. Specifically, as shown in the red cluster (cluster 1, 30 items), keywords such as evaluation, abstraction, self-efficacy, computing education, robotics, creativity, algorithm, etc., are related to the topic "problem solving". In the green cluster (cluster 2, 50 items), keywords such as programming, computer science education, K-12, teacher training curriculum design, etc., are focused on the main domain of "computational thinking". Next, in blue (cluster 3, 16 items), are keywords like teacher education, coding, teachers' professional development, programming education, etc., that are associated with "K-12 education". Next, in yellow (cluster 4, 22 items), are keywords like primary school, curriculum, mathematics, computer science, pedagogy, teaching, etc., that are associated with "education". In the purple cluster (cluster 5, 23 items), keywords such as gender, primary school, elementary education, etc., are related to the topic "assessment". Next, in cyan (cluster 6, 14 items), are keywords like collaborative learning, coding, stem education, etc., that are associated with "game-based learning". Last, in brown (cluster 7, 23 items), the keywords like constructionism, teacher professional development, game design, etc., are associated with "scratch".

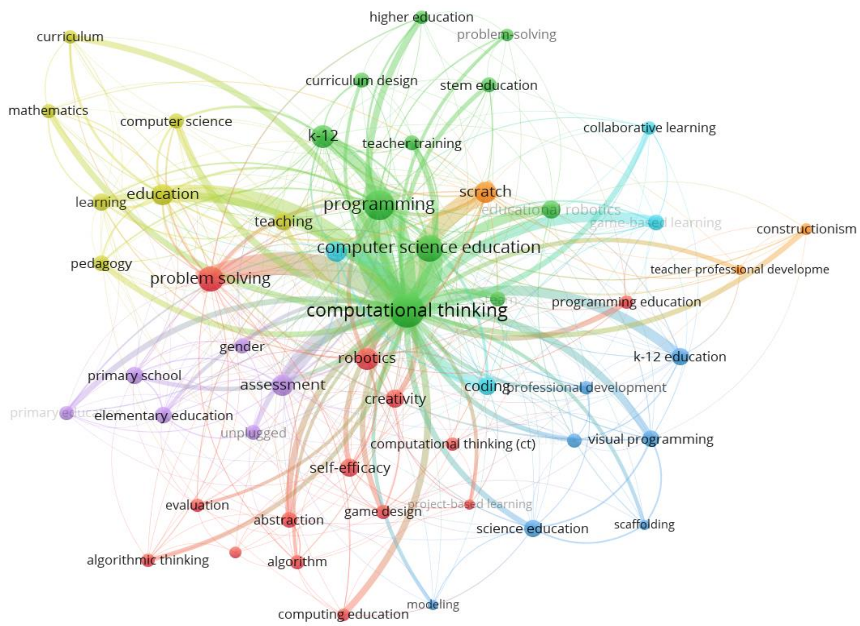

Figure 2: Network visualisation map of the author keywords. Unit of analysis = author keywords; Counting method: Full counting; Minimum number of occurrences of a keyword = 25; Minimum cluster size = 10.

<u>Growth of publications</u>

This section demonstrates the analysis of publications concerning CT. According Ahmi and Mohammad (2019a), document examination based on the year of publication can help the researcher to see the growth patterns and popularity of the study subject over time. The citation matrix per year for retrieved documents is shown in **Table 5.** The increasing number of publications between 2006 and 2020 shows a growing interest in the subject. Since 2006 until 2013, the number of publication grow significantly year by years. Then, the numbers had grown rapidly from 222 documents in 2018 up to 321 documents in 2019. However, in 2020 there has been a slightly increase in the number of publications regarding CT with 338 documents. It is expected that the number in 2021 will surpass the total number published in 2019 and 2020 as the data collected in this study was until December 2020. **Figure 3** depicts the growth trend of CT publications and citations per cited work spread across the 14 years. Although a declining trend of citations per article cited was evident in later years, such a decline is not surprising given that the term CT has expanded over time. Thus, in general, the publications and citations in CT reveal a robust growth trend. The number of citations per publication was highest for documents published in 2006 (1103 citations per publication), while the lowest was for those published in 2020 (1.13 citations per publication) due to the short time that has elapsed since publications.

Table 5.

Year of Publication

Year	TP	NCP	TC	C/P	C/CP	*h*	*g*
2006	2	2	2206	1103.00	1103.00	1	2
2007	3	2	56	18.67	28.00	2	3
2008	9	8	701	77.89	87.63	6	9
2009	21	20	431	20.52	21.55	10	20
2010	18	17	505	28.06	29.71	11	18
2011	31	27	1309	42.23	48.48	13	31
2012	21	21	491	23.38	23.38	7	21
2013	40	35	1457	36.43	41.63	14	38
2014	62	47	1381	22.27	29.38	15	37
2015	71	57	742	10.45	13.02	14	25
2016	104	89	1719	16.53	19.31	19	39
2017	160	121	1732	12.93	14.31	21	37
2018	222	162	1107	5.51	6.83	15	24
2019	321	165	684	2.13	4.15	12	15
2020	338	109	438	1.13	3.27	8	12
Total	**1422**	**882**	**15316**	**11.34**	**17.39**	**52**	**106**

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.

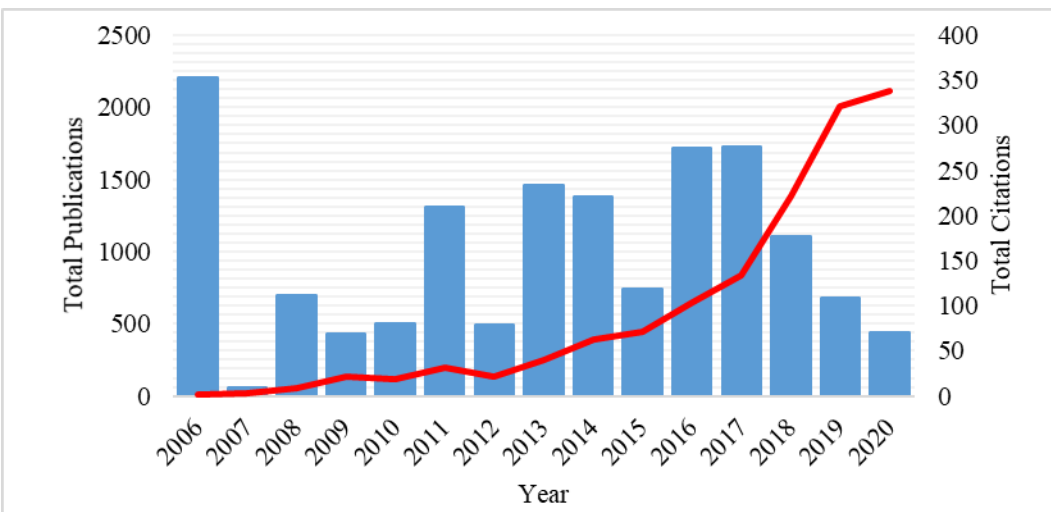

Figure 3. *Total Publications and Citations by Year*

Authorship Pattern, Collaboration, Prolific Authors.

A total of 203 (14.28%) documents were single-authored publications while the remaining documents (1211; 85.16%) were multi-authored publications, and eight document (0.56%) were no author publications (**Table 6**). Therefore, the prevalence of team research or the degree of research collaboration among CT researchers was 85.16%. Authors with minimum productivity of 3 documents, a minimum total citation of 3, and with fractional counting method mode were visualized using the VOSviewer technique presented in **Figure 4**. The map includes 63 circles, each representing one author. Some names might not be seen due to overlapping. Closed circles indicate active authors of close research collaboration. Based on our dataset, 2872 authors published articles on CT from 2006 to 2020. **Table 7** lists the top 15 most productive authors during the research period. The most productive author with the highest number of publications was Biswas G (22 publications; 412 citations), followed by Basu S (19 publications; 426 citations). Both of them were from United States but different affiliations.

Table 6.
Number of Author(s) per document

Author Count	Total Publications (TP)	Percentage (%)
1	203	14.28
2	395	27.78
3	348	24.47
4	228	14.28
5	116	27.78
6	59	24.47
7	29	16.03
8	10	8.16
9	10	4.15
10	7	2.04
11	2	0.70
12	1	0.70
13	2	0.49
20	1	0.14
21	1	0.07
27	1	0.14
34	1	0.07
0*	8	0.56
Total	**1422**	**100.00**

*Review document. No author is listed.

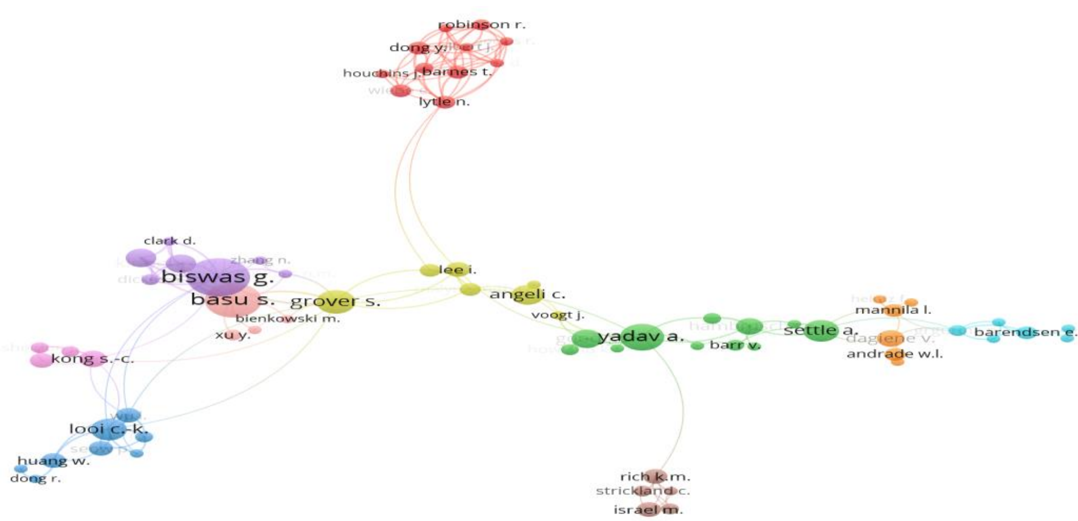

Figure 4. *Network visualisation map of coauthorship in computational thinking research. Note: Unit of analysis = Authors; Counting method: Fractional counting; Minimum number of citations of a document = 3*

Table 7.
Most Productive Authors

Author's Name	**Affiliation**	**Country**	**TP**	**NCP**	**TC**	**C/P**	**C/CP**	***h***	***g***
Biswas, G.	Vanderbilt University	United States	22	17	412	18.73	24.24	8	20
Basu, S.	SRI International	United States	19	18	426	22.42	23.67	7	19
Repenning, A.	Hochschule für Technik	Switzerland	17	17	463	27.24	27.24	11	17
Fronza, I.	Free University of Bozen-Bolzano	Italy	16	13	109	6.81	8.38	6	10
Robles, G.	Universidad Rey Juan Carlos	Spain	14	13	216	15.43	16.62	8	14
Yadav, A.	Michigan State University	United States	14	11	616	44.00	56.00	8	14
Wilensky, U.	Northwestern University	United States	13	10	422	32.46	42.20	7	13
García-Peñalvo, F.J.	Universidad de Salamanca	Spain	12	11	152	12.67	13.82	6	12
Grover, S.	Stanford University	United States	12	8	810	67.50	101.25	5	12
Cardella, M.E.	National Science Foundation	United States	11	10	61	5.55	6.10	5	7
Ehsan, H.	Purdue University	United States	11	9	56	5.09	6.22	5	7
Román-González, M.	Universidad Nacional de Educacion a Distancia	Spain	11	10	281	25.55	28.10	5	11
Kong, S.C.	The Education University of Hong Kong	China	10	5	46	4.60	9.20	3	6
Settle, A.	DePaul University	United States	10	10	255	25.50	25.50	7	10
Weintrop, D.	University of Maryland	United States	10	8	369	36.90	46.13	5	10

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.

Geographical distribution of publications

Researchers from 42 different countries contributed to the publication of retrieved documents. The top 20 countries that contributed to the publications are listed in **Table 8**. United States of America ranked first with a total of 473 (34.96%) documents followed by China with 101 (7.46%), Spain (98, 7.24%), Brazil (61, 4.51%), and Italy (57, 4.21%).

Visualization of collaboration among countries with minimum productivity of 5 documents is shown in **Figure 5**. The map shows 42 countries distributed in nine different clusters, each with a different color. For example, countries with cyan color such as Singapore, Malaysia, Indonesia, and Japan exist in one cluster while Spain, Mexico, Brazil, Portugal, and Chile are clustered in red. The most influential institutions with a minimum of 5 publications are summarized in **Table 9**. The most active institutions in the field are in the USA. Purdue University at Indiana was the most productive institution and ranked first with a total of 34 publications. This was followed by Spain (Universidad de Salamanca), seven institutions in USA, two institutions in Singapore and Spain, one institution in Taiwan as well as Italy.

Table 8.
Top 20 Countries contributed to the publications

Country	**TP**	**NCP**	**TC**	**C/P**	**C/CP**	***h***	***g***
United States	473	360	11055	23.42	30.71	44	98
China	101	53	322	3.19	6.08	7	15
Spain	98	76	845	8.62	11.12	15	26
Brazil	61	33	232	3.80	7.03	8	13
Italy	57	40	354	6.21	8.85	9	17
Taiwan	52	22	149	2.87	6.77	6	11
United Kingdom	48	39	486	10.13	12.46	11	21
South Korea	37	23	95	2.57	4.13	6	8
Germany	35	23	136	3.89	5.91	7	10
Turkey	35	23	226	6.46	9.83	7	14
Indonesia	29	10	16	0.55	1.60	2	3
Malaysia	29	12	67	2.31	5.58	5	7
Australia	28	17	212	7.57	12.47	6	14
Denmark	26	16	69	2.65	4.31	5	7
Hong Kong	26	15	94	3.62	6.27	5	9
Greece	25	17	270	10.80	15.88	5	16
Canada	22	19	257	11.68	13.53	8	15
Finland	22	13	201	9.14	15.46	3	14
Mexico	21	14	75	3.57	5.36	5	8
Netherlands	21	15	408	19.43	27.20	8	20

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.

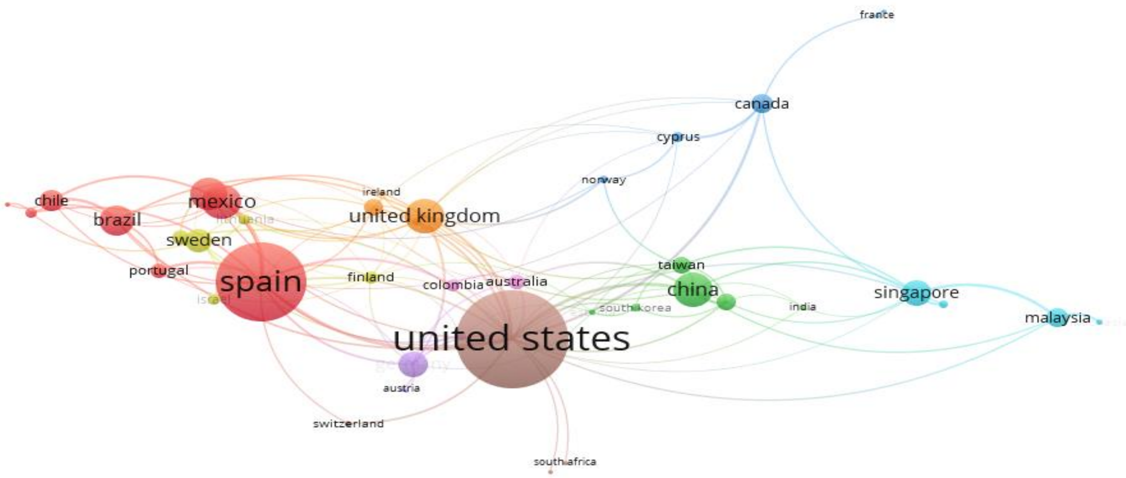

Figure 5. *Network visualisation map of international collaboration among countries with minimum productivity of 1 document.*

Table 9.
Most influential institutions with minimum of five publications

Affiliation	Country	TP	NCP	TC	C/P	C/CP	*h*	*g*
Purdue University	United States	34	26	475	13.97	18.27	9	21
Universidad de Salamanca	Spain	30	25	242	8.07	9.68	7	14
University of Colorado Boulder	United States	26	25	510	19.62	20.40	12	22
Michigan State University	United States	22	15	436	19.82	29.07	9	20
Vanderbilt University	United States	20	16	389	19.45	24.31	7	19
Universidad Rey Juan Carlos	Spain	20	17	246	12.30	14.47	10	15
Free University of Bozen-Bolzano	Italy	18	13	109	15.57	15.57	6	10
Universidad Nacional de Educacion a Distancia	Spain	18	17	364	20.22	21.41	9	18
University of Maryland	United States	17	11	71	4.18	6.45	4	8
National Taiwan Normal University	Taiwan	17	6	91	5.35	15.17	3	9
Nanyang Technological University	Singapore	15	7	458	30.53	65.43	4	15
SRI International	United States	15	13	166	11.07	12.77	6	12

Northwestern University	United States	15	11	430	28.67	39.09	7	15
National Institute of Education	Singapore	14	7	458	32.71	65.43	4	14
Clemson University	United States	14	9	95	6.79	10.56	5	9

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.

Preferred Journals.

A list of the top 10 journals on CT research is shown in **Table 10**. *ACM International Conference Proceeding Series* ranked first with 105 documents, followed by the *Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics* at second place with 48 documents. **Figure 6** is a network visualization map for co-citation analysis for journals with minimum citations of 20. *Communication of the ACM* journal received the highest number of linking lines from other journals, indicating that this journal was being co-cited with most other journals. Furthermore, this journal has the largest spherical size scale compared to others, revealing that there is the highest number of citations in CT research.

Table 10.
Top 10 journals on CT research

Source Title	**TP**	**TC**	**Publisher**	**Cite Score**	**SJR 2019**	**SNIP 2019**
ACM International Conference Proceeding Series	105	441	Association for Computing Machinery	N/A	N/A	N/A
Lecture Notes In Computer Science Including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics	48	172	Springer Nature	1.9	0.427	0.776
Annual Conference On Innovation And Technology In Computer Science Education Iticse	45	219	Association for Computing Machinery	N/A	N/A	N/A
Proceedings Frontiers In Education Conference Fie	43	297	Institute of Electrical and Electronics Engineers Inc.	0.9	0.322	0.708
ASEE Annual Conference And Exposition Conference Proceedings	42	118	American Society for Engineering Education	N/A	N/A	N/A

Proceedings Of International Conference On Computational Thinking Education	36	13	The Education University of Hong Kong	N/A	N/A	N/A
Ceur Workshop Proceedings	21	19	CEUR-WS	0.6	0.177	0.293
Informatics In Education	20	146	Institute of Mathematics and Informatics	3.9	0.539	1.565
Communications Of The ACM	18	3004	Association for Computing Machinery	9.8	1.204	4.097
Computer Supported Collaborative Learning Conference Cscl	18	2	International Society of the Learning Sciences (ISLS)	N/A	N/A	N/A
Proceedings Of International Conference Of The Learning Sciences Icls	18	54	International Society of the Learning Sciences (ISLS)	0.7	0.176	0.319
Journal Of Science Education And Technology	16	532	Springer	5.2	1.17	2.315
Computational Thinking In The Stem Disciplines Foundations And Research Highlights	16	89	Springer International Publishing	N/A	N/A	N/A
Interactive Learning Environments	16	78	Routledge	4.9	1.226	1.665
Journal Of Educational Computing Research	15	88	SAGE Publications Inc.	3.4	0.877	1.313
Education And Information Technologies	14	395	Springer	3.6	0.782	1.527
IEEE Global Engineering Education Conference Educon	14	101	IEEE Computer Society	N/A	N/A	N/A
Journal Of Physics Conference Series	14	5	IOP Publishing Ltd	0.7	0.227	0.574
Advances In Intelligent Systems And Computing	13	12	Springer	0.9	0.184	0.429
Computers And Education	13	727	Elsevier Ltd	12.7	3.047	4.28
IFIP Advances In Information And Communication Technology	12	5	Springer Science and Business Media Deutschland GmbH	0.9	0.209	0.422
Computers In Human	11	820	Elsevier Ltd	12.1	2.173	3.079

Behavior

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

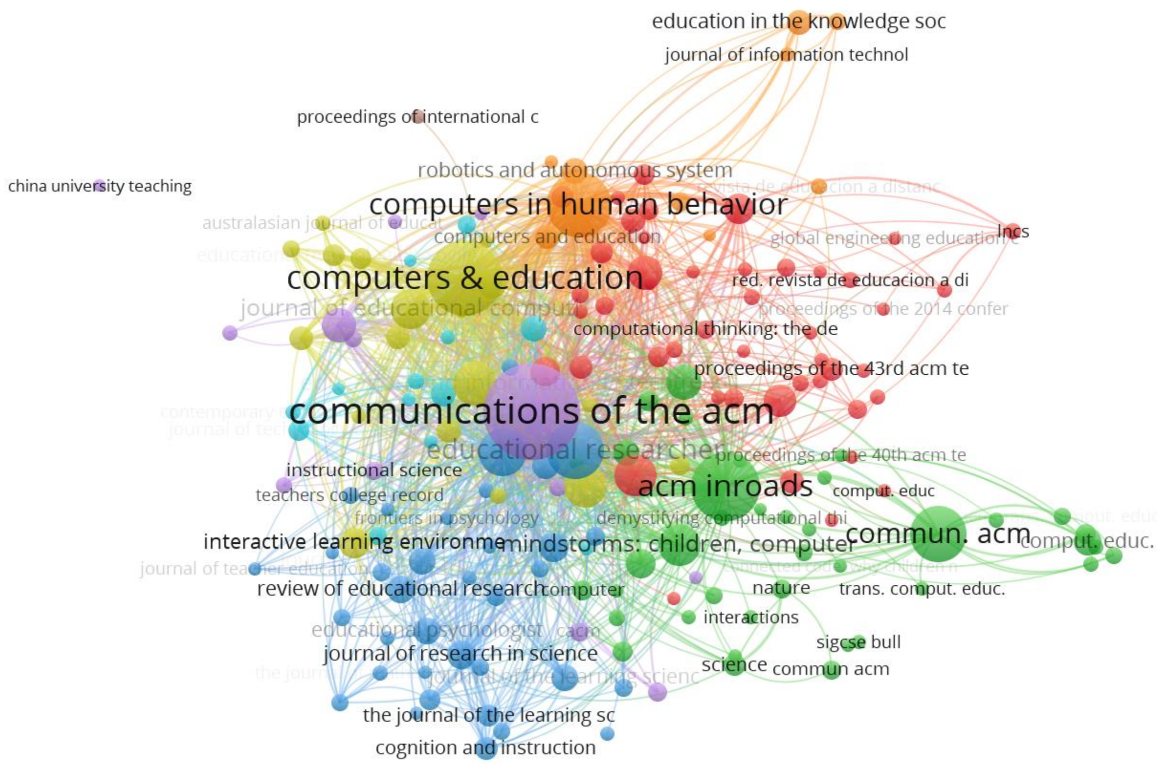

Figure 6. *Network visualisation map of co-citations analysis for journals that published documents in CT with minimum number of citations of a document = 20. Journals related to computers and education (dark yellow cluster) and computers in human behavior (orange cluster).*

<u>The Most Cited Documents.</u>

According to Tsay (2009), the more citations achieved by an article the more influential the article. **Table 11** presents the top 20 most cited articles in the field of computational thinking between 2006 and 2020. The review that received the highest citation, “Computational thinking” was published in the Communications of the ACM journal in 2006. It received a total of 2473 citations and was the most impactful article based on the citation per year (164.87 citations/y). Wing (2006) has been listed as the most productive author and authored highly cited articles. Besides, Wing (2008) has the most cited article with a total of 547 citations. The article is titled “Computational thinking and thinking about computing” published in Philosophical Transactions of the Royal Society A journal in 2008.

Table 11.
Top 20 most cited articles in CT research

No.	Authors	Title	Year	Cites	Cites per Year
1	J.M. Wing	Computational thinking	2006	2473	164.87
2	S. Grover, R. Pea	Computational Thinking in K-12: A Review of the State of the Field	2013	746	93.25
3	J.M. Wing	Computational thinking and thinking about computing	2008	547	42.08
4	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	532	53.2
5	S.Y. Lye, J.H.L. Koh	Review on teaching and learning of computational thinking through programming: What is next for K-12?	2014	389	55.57
6	D. Weintrop, E. Beheshti, M. Horn, K. Orton, K. Jona, L. Trouille, U. Wilensky	Defining Computational Thinking for Mathematics and Science Classrooms	2016	303	60.6
7	M.U. Bers, L. Flannery, E.R. Kazakoff, A. Sullivan	Computational thinking and tinkering: Exploration of an early childhood robotics curriculum	2014	292	41.71
8	I. Lee, F. Martin, J. Denner, B. Coulter, W. Allan, J. Erickson, J. Malyn-Smith, L. Werner	Computational thinking for youth in practice	2011	260	26
9	P. Sengupta, J.S. Kinnebrew, S. Basu, G. Biswas, D. Clark	Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework	2013	203	25.38
10	M. Guzdial	Education: Paving the way for computational thinking	2008	171	13.15
11	V.J. Shute, C. Sun, J. Asbell-Clarke	Demystifying computational thinking	2017	158	39.5
12	L. Werner, J. Denner, S. Campe, D.C. Kawamoto	The fairy performance assessment: Measuring computational thinking in middle school	2012	154	17.11
13	M. Román-	Which cognitive abilities underlie	2017	147	36.75

	González, J.C. Pérez-González, & C. Jiménez-Fernández	computational thinking? Criterion validity of the Computational Thinking Test			
14	A. Yadav, C. Mayfield, N. Zhou, S. Hambrusch, J.T. Korb	Computational thinking in elementary and secondary teacher education	2014	145	20.71
15	S. Atmatzidou, S. Demetriadis	Advancing students' computational thinking skills through educational robotics: A study on age and gender relevant differences	2016	141	28.2
16	A. Repenning, D. Webb, A. Ioannidou	Scalable game design and the development of a checklist for getting computational thinking into public schools	2010	138	12.55
17	J. Voogt, P. Fisser, J. Good, P. Mishra, A. Yadav	Computational thinking in compulsory education: Towards an agenda for research and practice	2015	127	21.17
18	P.J. Denning	The profession of IT: Beyond computational thinking	2009	125	10.42
19	A.V. Aho	Computation and computational thinking	2012	116	12.89
20	P.J. Denning	Remaining trouble spots with computational thinking	2017	100	25

<u>Subject area</u>

Table 12 presents the subject areas related to CT. It could be seen that CT has been quite a popular term to be studied and published in various fields in science and social science areas. the top ten subject areas are computer science, social science, engineering, mathematics, business, management and accounting, psychology, decision sciences, physics and astronomy, arts and humanities, biochemistry, genetics and molecular biology. Computer science and social sciences areas dominated the publications in CT with 40.53% (TP=986) and 31.81% (TP=774) respectively.

Table 12.
Subject Area

Subject Area	**Total Publications (TP)**	**Percentage (%)**
Computer Science	986	40.53
Social Sciences	774	31.81
Engineering	266	10.93
Mathematics	119	4.89
Business, Management and Accounting	68	2.79
Psychology	46	1.89
Decision Sciences	43	1.77

Physics and Astronomy	30	1.23
Arts and Humanities	23	0.95
Biochemistry, Genetics and Molecular Biology	13	0.53
Energy	11	0.45
Materials Science	11	0.45
Agricultural and Biological Sciences	10	0.41
Environmental Science	10	0.41
Medicine	7	0.29
Multidisciplinary	5	0.21
Chemistry	4	0.16
Economics, Econometrics and Finance	2	0.08
Chemical Engineering	1	0.04
Earth and Planetary Sciences	1	0.04
Health Professions	1	0.04
Immunology and Microbiology	1	0.04
Neuroscience	1	0.04

Keywords analysis

Table 13 lists the top keywords that are used along with the “computational thinking” keywords, which occurred more than 200 times in the articles studied. The top three keywords used are “computational thinking” (1022 articles), “computational thinkings” (844 articles), and “students” (458 articles) which are mostly related to school or computer science. Only one keyword may relate best to social science, namely “problem solving”.

Table 13.
Top Keywords

Author Keywords	**Total Publications (TP)**	**Percentage (%)**
Computational Thinking	1022	22.96
Computational Thinkings	844	18.96
Students	458	10.29
Teaching	270	6.07
Curricula	221	4.97
Education Computing	220	4.94
Education	209	4.70
Engineering Education	188	4.22
Computer Programming	149	3.35
Problem Solving	136	3.06
Programming	93	2.09
E-learning	91	2.04
Computer Science	89	2.00
Computer Science Education	89	2.00
Computation Theory	72	1.62
Robotics	72	1.62

Computational Methods	66	1.48
Mathematical Programming	57	1.28
STEM	55	1.24
Scratch	50	1.12

DISCUSSION

Bibliometric study has grown in popularity as a method for demonstrating the trend of studies (Ahmi and Nasir 2019b). To date, a few bibliometric studies on CT research have been conducted since 2018. Chen et. al (2018) were the first to conduct a bibliometric study on CT, combined with systematic review on aspects such as development status, developing trend, and hot subjects of CT research from the year 1900 to 2018. However, these researchers only demonstrated highly cited literature and clustering label. In contrast, Roig-Vila and Moreno-Isac (2020) showed bibliometric findings about researchers publishing the most articles which is more than three articles, and the methodology in CT studies that is often used by researchers. However, this study focuses on recent publications on CT research from 2006 to 2020 retrieved from Scopus database. 1422 documents found from the Scopus database using the refined search query.

Previous data indicated that CT research demonstrates an impressive, dramatically increasing trend as reflected by the increased number of publications from year to year beginning from the 2009 to 2017 (Chen et. al 2018). In fact, the growth of CT-related publications accelerated between 2013 and 2019 with 87% of titles published, and reached 430 articles in 2019 with an annual percentage growth rate of 61.2% (Saqr et. al 2021). This study indicates that the trend is continuing, as evidenced by the year-on-year increase in the number of documents. In terms of citation, the articles published in 2007 (**Table 5**) were the least cited to be selected as the highly cited articles, higher total citations, average citations per publication (per cited publication), as well as h and g indexes compared to publications in 2008 an above. This is because two out of three articles published in 2007 relate to computation system modelling (Leff & Rayfield 2007; Priami 2007), and one article (Henderson et. al 2007) presents discussion session about fundamental ideas and concepts underlying computational thinking for curriculum reform building. Therefore, there is not much information can be taken from the article published in 2007 to be used as a citation. It is because of the number of papers published in that year.

With regards to the geographical distribution of CT research, this study displays the findings similar to prior bibliometric studies (Chen et. al 2018; Roig-Vila & Moreno-Isac 2020; Saqr et. al 2021). The current study also finds majority of the publications to be originated from academic institutions as shown in the network visualization maps of international collaboration among countries (**Figure 5**), and prominent with the topmost prolific authors. Biswas G was the most productive author in CT research with contributing 22 publications. Meanwhile, the second most productive author was Basu S, with 19 publications. Since the top two most productive authors come from the same country, it can be concluded that the most influential institution in CT research was in the USA, namely the Purdue University at Indiana. However, these findings contradict the one reported in the previous bibliometric studies (Saqr et al., 2021).

In the present study, CT has become a relevant issue in educations and human behavior, as reflected by the top 20 highly cited articles. This has not been reflected in the earlier studies by Chen et. al (2018), Roig-Vila and Moreno-Isac (2020), and Saqr et. al (2021). It thus can be speculated that CT research related to education and human behavior, as well as computers, may in many years in the future take over the other clusters that have dominated CT research earlier, as illustrated by the network visualization map of the co-citation analysis for journals (**Figure 6**).

There are some limitations to this bibliometric study. First, the data presented are limited to the Scopus database, that is, a portion of the global production sample on this topic, and that the scientific literature on CT is expected to be much larger. Second, the data in this study only cover studies from 2006 to 2020, and almost every day there are new studies involving CT published. Third, some papers on CT may have been excluded if the authors do not include this study participation descriptors in the article title. Fourth, the amount of citations used in assessing the impact of the study may not directly reflect the quality of each study.

CONCLUSION

As a summary, the United States was the largest contributor to CT research, followed by the China. The ACM International Conference Proceeding Series remained as the main source of publication related to CT research. The Purdue University at Indiana, is expected to be a good candidate for collaborative research in this field. The results of this study might contribute to the body of knowledge by providing comprehensive trend analysis of the studies related to CT, published in the Scopus database from the year 2006 to 2020. CT-related topics have grown extensively since 2006 and will grow rapidly in the future as a result of the impact fourth industrial revolution reforms that changed not only people work life but also their personal life. This can be seen in the CT’s strong in the fields like computer science, educational technology, and social science disciplines. Thus, aspects related to the industrial revolution 4.0 (IR 4.0) and Technical and Vocational Education and Training (TVET) could be some of the potential research areas for computational thinking.

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