Trends and development in research on computational thinking

Mehmet Tekdal

Received: 8 March 2021 / Accepted: 1 June 2021 / Published online: 28 June 2021
© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2021

Abstract
As computational thinking (CT) has gained more attention as a research topic in the recent decade, a paper to identify trends and development in CT research would be timely and critical to understand the current research landscape and to guide future research endeavors. In this context, this study revealed the change in research trends in the field of CT in the last twelve years with the method of bibliometric mapping analysis. The relevant literature was searched in the SCOPUS database and 321 journal articles were identified. The VOSviewer software was used for analysis of the retrieved dataset. The findings of the study showed that (1) the research on computational thinking is an emerging area that has grown exponentially since the 2013s, (2) the literature in this area has been produced as a result of national and international collaboration of researchers in several institutions and countries, mostly in the United States, (3) the CT research is predominantly published in journals specializing in educational technology and feeds from information generated in education, computing, and social sciences, (4) research topics contributing to the CT literature are grouped under three themes: Integrating CT into Science, Technology, Engineering, and Math (STEM) education, experimental studies on assessing CT skills, and discussing on definition of CT and CT skills, and (5) the CT has the general nature of an emerging discipline that is not yet mature, and will continue to evolve in the future. Overall, this work provides the current state of the art in this field and a research direction for future research. It is hoped that this study will accelerate the research in the field, guide new studies and contribute to the development of the field.

Keywords Computational thinking · Educational computing · Bibliometric analysis · Science mapping · Vosviewer

Mehmet Tekdal
mtekdal@cu.edu.tr

1 Faculty of Education, Department of Computer Education & Instructional Technology, University of Çukurova, 01330 Saricam, Adana, Turkey
1 Introduction

Although the concept of Computational Thinking (CT) was first used by Seymour Papert in 1980 (Papert, 1980) and again in 1996 (Papert, 1996), the idea of developing students’ thinking skills via computer science concepts did not find interest in the academic community for many years until it was brought to the forefront in 2006 in Jeannette Wing’s article published in Communications of the ACM magazine (Wing, 2006). In this article, she noted that CT represents a universally feasible attitude and skill that not only computer scientists but also anyone will be willing to learn and use.

Then, in 2011, Wing et al. revisited the topic again to further clarify and described CT as “Computational thinking is the thought processes involved in formulating problems and their solutions so that the solutions are represented in a form that can be effectively carried out by an information-processing agent” (Wing, 2011). Here, an information-processing agent can be a human, a computer, or a combination of both. After this date, many researchers started to stress that it is important to integrate CT into the curriculum as a 21st-century literacy at all educational levels from kindergarten to university (Barr et al., 2011; Mohaghegh & McCauley, 2016; Voogt et al., 2015; Yadav et al., 2011). But later, to be more descriptive, she described computational thinking (with feedback from Al Aho at Columbia University, Jan Cuny at the National Science Foundation, and Larry Snyder at the University of Washington) as follows: “Computational thinking is the thought processes involved in formulating a problem and expressing its solution(s) in such a way that a computer–human or machine-can effectively carry out” (Wing, 2017).

CT includes various thinking skills, including abstraction and parsing, iterative thinking, problem reduction and transformation, error prevention and preservation, and intuitive reasoning necessary to solve universal complex problems not limited to software problems. Therefore, CT represents a universal twenty-first century skill set that not only computer scientists but everyone from different disciplines should learn (So et al., 2020). In this context, CT has developed beyond computer science in many different disciplines, such as life sciences (Rubinstein & Chor, 2014), mathematics (Benakli et al., 2017; Weintrop et al., 2016; Wilkerson-Jerde, 2014), music (Bell & Bell, 2018), robotics (Durak et al., 2019; Atmatzidou & Demetriadis, 2016), science in general (Basu et al., 2017), sciences and arts (Sáez-López et al., 2016), journalism and writing (Wolz et al., 2010, 2011), and physics (Yin et al., 2019).

Alternatively, the increasing interest in integrating CT into the STEM (Science, Technology, Engineering, and Math) education significantly contributed to the creation of CT literature (Tang et al., 2020). In this context, the content produced focused on the integration of CT into STEM education (Barana et al., 2019; Gadaindis et al., 2018; Garneli & Chorianopoulos, 2018; Lee et al., 2014; Malyn-Smith & Lee, 2012; Pei et al., 2018; Sun et al., 2020; Sung et al., 2017; Swaid, 2015) and the assessment of CT skills (Chen et al., 2017; Garneli & Chorianopoulos, 2019; Korkmaz et al., 2017; Sáez-López et al., 2016; Shell &
Soh, 2013; Werner et al., 2012). These studies have created an important set of publications that help us to recognize the nature of CT, CT integration in STEM classes, and the characteristics of students’ performance in CT applications.

Since 2006, increased attention to CT has contributed to the maturation of CT research. In this context, many publications on CT have been published in recent years (Hsu et al., 2018). However, there are few studies in the literature that are similar to our study. Of these, the study by Chen et al. (2018) is the one most closely related to our research. The authors used a sample of 395 journal articles on CT research included in ISI Web of Science from 1979 to 2018. The bibliometric analysis method is adopted and Cite Space, the visual knowledge analysis tool, is used to conduct an analysis of data. They reported aspects such as development, trend, and hot topics of CT research. Results showed (1) The subject of CT was first mentioned in 1979 and the studies on this subject showed a slow growth between 1979 and 2008. The CT study started to emerge in 2009 and from 2014 has entered a large-scale and rapid development phase. The top three countries with the most contributing researchers to the field of CT are the USA, China and Spain. (2) The top 5 keywords with high co-occurrence frequency are computational thinking, education, k 12, programming, and scratch. The hot research topics in CT are coding, game-based learning, programming and programming languages, k-12 education, and computing. (3) The most significant knowledge base clusters of CT are computational literacy, contest, and mobile programming. (4) While the initial stage of research focused more on CT definitions in K-12 and higher education, the focus has recently shifted to tackling more practical questions about how to develop and evaluate IT skills.

Another bibliometric research to analyze the scientific literature on the implementation of CT in the field of education was conducted by Roig-Vila and Moreno-Isac (2020). The sample of this review has been composed of 189 documents, published in the main collections of the Web of Science database from 2008 to 2018. Their objective was to conduct a bibliographic study on CT and, thus, offer an international vision of how the scientific production of this subject is evolving in the educational field. A systematic review is conducted where the variables of the year of publication, countries with the most production, the most productive authors in this field, and documentary sources with the largest number of publications have been taken into account. Results showed that (1) it is a continuously growing field of study, (2), the United States has the largest number (66 publications), followed by China (36), Spain (21) and Canada and United Kingdom (8), (3) the journals with the most publications on computational thinking are Informatics and Education and Red.Revista de Educación aDistancia, with 7 publications each, (4) this field of study has been approached from the two main research methods—quantitative and qualitative—and the most investigated educational stage is primary education.

As mentioned above, since the 2000s, CT has continued to grow in popularity in many research areas, particularly education, computing, engineering and social sciences. However, there is a lack of bibliometric or scientometric analysis that measures and analyses scientific literature to inform trends, and also, how it has been applied and what has been achieved in this research area. In fact, we
find a few systematic reviews or content analysis studies include CT through programming in education (Fagerlund et al., 2020; Tikva & Tambouris, 2020), digital tools used for the developing CT in primary education (Kordaki et al., 2017), CT in education (Roig-Vila & Moreno-Isac, 2020), assessing CT (Tang et al., 2020a, b; Martins-Pacheco et al., 2019), learning CT through Scratch in K-9 (Zhang & Nouri, 2019), computational thinking in higher education (Lyon & Magana, 2020; Agbo et al., 2019), review studies on computational thinking (Ilic et al., 2018), and content analysis of CT (Tang et al., 2020a, b). As CT has gained more attention as a research topic in the recent decade, a research paper to identify trends and development in CT research would be timely and critical to understand the current research landscape and to guide future research endeavors. However, there has been no comprehensive study examining the state of research on CT as a whole using bibliometric analysis techniques. Therefore, the current study analyzes the scientific literature on CT using data indexed in the Scopus database from 2008 to 2020 (June, 30). In this context, the following research questions (RQs) have been investigated in this study:

RQ1. What are the trends in the literature of CT research?
RQ2. What are the most prolific and collaborating authors and countries researching on CT?
RQ3. What are the most popular scientific journals publishing articles on CT?
RQ4. What are the most studied subject areas in the CT literature?
RQ5. What are the most used authors' keywords and terms in the abstract on CT research?
RQ6. What is the most cited/co-cited authors, references, and journals on CT research?

2 Method

Bibliometric data analysis provides a way to understand the intensity of current research on a topic and the different areas of research explored by researchers. In this study, a bibliometric data analysis method was used to create a network map of the research literature on computational thinking. Research data were retrieved from publications indexed in the Scopus database (https://www.scopus.com). On June 30, 2020, Web of Science (WoS) core collection (including Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), Arts & Humanities Citation Index (AHCI), and Emerging Sources Citation Index (ESCI)) (https://apps.webofknowledge.com) and Scopus databases were scanned with the same search query. As a result of the search, while the WoS Core Collection database yielded 260, Scopus database returned 321 records. Scopus database has been selected as the data source of this research since it contains more publications on computational thinking and also because of its wide coverage of educational and social science publications (Hallinger & Kovačević, 2019; Mongeon & Paul-Hus, 2016).

To select as many relevant records as possible from the database, the search query has been limited to the "title" field of the documents. In addition, to get
only peer-reviewed documents in English, the dataset is filtered by document type as "Article" and language as "English". Finally, the search query has been limited to papers created from 2008 to 2020-time span. Based on these criteria the following query has been created: TITLE ("computational thinking") AND DOCTYPE (ar) AND PUBYEAR > 2007 AND PUBYEAR < 2021 AND (LIMIT-TO (LANGUAGE, "English"))). This query is used to retrieve a dataset of this research from the Scopus database.

In addition, to determine the current trends in publications and citations by years, frequency counts of documents and citations were used. Furthermore, to identify the most influential publications, journals, and leading countries, institutions, and authors, ranked techniques were used to order frequencies of documents and citations. The VOSViewer software version 1.6.9 was used for the bibliometric analysis of the data. This software is commonly used for the creation and visualization of bibliometric networks. It also includes data mining techniques required to create and visualize networks of important terms derived from a scientific literature (Van Eck & Waltman, 2014). The VOSViewer software was used to analyze and visualize the abstract and author keywords, and also relationship and collaboration between authors, institutions, countries, and publications in the dataset.

Finally, before starting the analysis, a control process was conducted to determine whether there were any erroneous records in the dataset. As a result of the in-depth examination of the dataset, it was determined that the name of the author or the content of the reference was different in the citations made by different authors to the same publication of an author. For example, in some references, "Wing J.M." spelled as” Wing J." or "Communications of the ACM" as "Comm. ACM"., etc. To correct these inconsistencies in the dataset, two (authors and references) VOSviewer thesaurus files, a text file that can be used to perform data cleaning, were created to merge terms.

3 Results and discussion

3.1 Trends in the CT literature

Trends in publications and citations are an important indicator in determining developments in a discipline, field or topic. Between 2008 and 2020 (June, 30), 321 articles were published on CT and these publications were cited 4528 times. The distribution of the number of publications and citations by years is shown in Fig. 1.

Figure 1 reveals that there has been a slight rise in the number of publications and citations of CT research from 2008 to 2013. Although an increased trend has been observed since 2014, the interest in the field has increased rapidly since 2015. Note that the reason for the decrease in the distribution of publications and citations in 2020 is only due to the use of the data of the first 6 months of this year. Collectively, there has been an increasing trend in both publications and citations within the scope of CT research since 2013.

Content courtesy of Springer Nature, terms of use apply. Rights reserved.
3.2 The most prolific and collaborating authors and countries

Total 321 articles published by 776 authors from 46 countries around the world. The mean number of authors per article is 2.42, pointing out a trend towards multi-author contributions to this domain of research. A list of the most productive and influential authors ranked with the number of articles is given in Table 1. As seen from Table 1, with both the highest number of publications and citations, Yadav, A. (8 articles, 354 citations) is the most productive author who research on CT, followed by Basu, S. (6 articles, 246 citations), Wilensky, U. (5 articles, 258 citations), and Román-González, M. (5 articles, 139 citations).

Authors from many countries have published papers on CT. However, in terms of the number of articles published, Yadav, A. from Michigan State University and Basu, S. from SRI International, both from the United States, are the two most productive authors with 8 and 6 contributions, respectively. In terms of the citations, again, researchers from the United States share the top ranks. Yadav, A. from Michigan State University, is in first place with 354 citations, followed by Bers, M.U., from Tufts University, and Malyn-Smith, J., from the Education Development Center.

A co-authorship analysis was conducted to determine the signs of scientific cooperation between authors conducting research on CT. Analysis conducted with 115 out of 776 authors with a minimum of two articles in the dataset. Results showed that there was a scientific collaboration between 99 of 115 authors. This means that the proportion of authors working collaboratively within the scope of CT research is 86.09%. However, this collaboration is not between a group of
Table 1: Top authors leading the research on computational thinking

<table>
<thead>
<tr>
<th>Author</th>
<th># of Articles</th>
<th># of Citations</th>
<th>Country</th>
<th>Institution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yadav, A</td>
<td>8</td>
<td>354</td>
<td>United States</td>
<td>Michigan State University</td>
</tr>
<tr>
<td>Basu, S</td>
<td>6</td>
<td>246</td>
<td>United States</td>
<td>SRI International</td>
</tr>
<tr>
<td>Wilensky, U</td>
<td>5</td>
<td>258</td>
<td>United States</td>
<td>Northwestern University</td>
</tr>
<tr>
<td>Román-González, M</td>
<td>5</td>
<td>139</td>
<td>Spain</td>
<td>Universidad Nacional de Educación a Distancia (UNED)</td>
</tr>
<tr>
<td>Korkmaz, Ö</td>
<td>5</td>
<td>47</td>
<td>Turkey</td>
<td>Amasya University</td>
</tr>
<tr>
<td>Lee, Y</td>
<td>5</td>
<td>11</td>
<td>South Korea</td>
<td>Kangnam University</td>
</tr>
<tr>
<td>Bers, M.U</td>
<td>4</td>
<td>300</td>
<td>United States</td>
<td>Tufts University</td>
</tr>
<tr>
<td>Malyn-Smith J</td>
<td>4</td>
<td>286</td>
<td>United States</td>
<td>Education Development Center</td>
</tr>
<tr>
<td>Lee, I</td>
<td>4</td>
<td>269</td>
<td>United States</td>
<td>Massachusetts Institute of Technology</td>
</tr>
<tr>
<td>Biswas, G</td>
<td>4</td>
<td>227</td>
<td>United States</td>
<td>Vanderbilt University</td>
</tr>
<tr>
<td>Dagiene, V</td>
<td>4</td>
<td>81</td>
<td>Lithuania</td>
<td>Vilnius University</td>
</tr>
<tr>
<td>Fronza, I</td>
<td>4</td>
<td>45</td>
<td>Italy</td>
<td>Libera Università di Bolzano</td>
</tr>
<tr>
<td>Moreno-León J</td>
<td>4</td>
<td>40</td>
<td>Spain</td>
<td>Universidad Rey Juan Carlos</td>
</tr>
<tr>
<td>Robles G</td>
<td>4</td>
<td>40</td>
<td>Spain</td>
<td>Universidad Rey Juan Carlos</td>
</tr>
</tbody>
</table>

The table is ranked by the number of articles. The highest citations are shown in bold.

all authors, but between separate groups of authors. The largest of these groups consists of 20 authors, while the others are groups of 2 to 5 authors. The network map of research collaboration between these twenty authors is presented in Fig. 2.

The results of the analysis show that the authors cooperating on CT research are gathered in five different clusters. When the size of the connection nodes in the

Fig. 2: The network map of the collaboration between authors researching on computational thinking

Content courtesy of Springer Nature, terms of use apply. Rights reserved.
network is examined, it is seen that a leading researcher is present in each network cluster and provides connection with other researchers. For example, Yadav, A. (Red Cluster), Basu, S. (Yellow Cluster), and Biswas, G. (Blue Cluster) with total link strength 15, 12, and 12, respectively. In other words, these three researchers are the ones who produced the most articles in collaboration with other researchers. Although clusters are far from each other, Grover, S. and Voogt, J. are interestingly seen to play a key role in establishing the connection between the researchers in Green–Blue and Green–Red clusters, respectively.

The total link strength attribute indicates the total strength of the co-authorship links of a given researcher with other researchers (Van Eck & Waltman, 2013). Finally, correlation analysis was conducted to test whether there is a correlation between the number of articles and total link strength of the authors. There was a significant positive correlation between the number of articles and total link strength ($r=0.535$, $p<0.5$). So, we reasonably conclude that the results confirm that the contribution of more productive authors is also effective in the formation of international cooperation networks. This is evident from the number of articles produced by the leading authors and the strength of the link they establish with other authors. For example, the number of articles and total link strengths of some of the leading authors are: Yadav, A. (8, 11), Basu, S. (6, 15), Román-González, M. (5, 11), and Wilensky, U. (5, 6).

A list of countries, ranked by the number of articles, with 5 or more studies is given in Table 2. Researchers from 46 countries around the world have contributed to the CT literature. This means that various researchers worldwide have conducted CT research. However, the United State is the leader in this field with 121 (33%) documents and 3407 (66%) citations in these studies. This finding may be the result of the country’s technological and academic superiority in this field. Other countries

<table>
<thead>
<tr>
<th>Country</th>
<th># of Articles</th>
<th># of Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>121</td>
<td>3407</td>
</tr>
<tr>
<td>South Korea</td>
<td>28</td>
<td>30</td>
</tr>
<tr>
<td>Spain</td>
<td>23</td>
<td>200</td>
</tr>
<tr>
<td>Turkey</td>
<td>22</td>
<td>110</td>
</tr>
<tr>
<td>China</td>
<td>18</td>
<td>101</td>
</tr>
<tr>
<td>Italy</td>
<td>13</td>
<td>57</td>
</tr>
<tr>
<td>Taiwan</td>
<td>11</td>
<td>51</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>10</td>
<td>170</td>
</tr>
<tr>
<td>Canada</td>
<td>9</td>
<td>99</td>
</tr>
<tr>
<td>Greece</td>
<td>9</td>
<td>156</td>
</tr>
<tr>
<td>Malaysia</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>Brazil</td>
<td>7</td>
<td>40</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Indonesia</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Lithuania</td>
<td>5</td>
<td>81</td>
</tr>
<tr>
<td>Sweden</td>
<td>5</td>
<td>13</td>
</tr>
</tbody>
</table>

The table is ranked by the number of articles. The highest citations are shown in bold.
who contribute most to the field with a minimum number of 10 publications are South Korea (28 Articles, 30 Citations), Spain (23 Articles, 200 Citations), Turkey (22 Articles, 110 Citations), China (18 Articles, 101 Citations), Italy (13 Articles, 57 Citations), Taiwan (11 Articles, 51 Citations), and United Kingdom (10 Articles, 170 Citations).

Another co-authorship analysis was repeated with the countries option to create a network map showing scientific cooperation between the countries. The collaboration between 30 out of 49 countries with a minimum number of two or more publications is presented in Fig. 3. Note that only 23 out of 30 (76.67%) countries, collaborating with each other, are shown on the network map consisting of five clusters that each one is composed of four to six countries. It can be seen from the network map that the United States is at the center of the research on CT and the most cooperating country with other countries in this arena with total link strength 22, followed by Spain, United Kingdom, and China with total link strengths 9, 8, and 7, respectively. However, this collaboration is stronger with countries in the same cluster (Green), such as South Korea, Turkey, China, and Hong Kong. When countries in other clusters (Red, Blue and Purple) are analyzed, the cooperation between countries in distant geography is remarkable. For example, in the Red Cluster we see the cooperation of European and Southern American countries. Alternatively, Denmark, Sweden, Argentina and Peru, which are in the Yellow Cluster, are distant from other clusters, so they show weak cooperation.

Overall, international research collaboration between researchers can be considered as an important indicator of high quality research (Kim, 2006). According to the

---

Fig. 3 The network map of the collaboration between countries researching on computational thinking
results of this study, there is a scientific cooperation on CT research between 86.39% of authors and 76.67% of countries with at least two documents. The increase in communication opportunities, and the spreading of joint projects to encourage new technologies among countries may have implications on this high level of cooperation between countries.

3.3 The most efficient institutions

The list of institutions contributing to the development of research on CT with publishing at least 5 articles, ranked by number of publications, is given in Table 3. The institutions that have reached the highest number of publications on CT research are Michigan State University and Purdue University, both from the United States, respectively. They are followed by Universidad Nacional de Educacion a Distancia from Spain and Jeju National University from South Korea.

3.4 Most influential journals

According to the data obtained in this study, 321 articles on CT research have been published in 139 journals. The top 20 journals ranked by the number of articles are presented in Table 4. In general, studies on CT have been published in a wide range of journals covering many fields, such as educational technology, computer science, informatics, science, mathematics and engineering. Accordingly, it can be said that CT is in the focus of many disciplines. However, it should not be overlooked that publications are mostly concentrated in journals in educational technology and educational related research categories. For example, Informatics in Education, Journal of Science Education and Technology, Interactive Learning Environments, Computers and Education, and Education and Information Technologies are ranked in the top five most influential journals in Table 4.

<table>
<thead>
<tr>
<th>Institutions</th>
<th># of Articles</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michigan State University</td>
<td>9</td>
<td>United States</td>
</tr>
<tr>
<td>Purdue University</td>
<td>8</td>
<td>United States</td>
</tr>
<tr>
<td>Universidad Nacional de Educacion a Distancia</td>
<td>7</td>
<td>Spain</td>
</tr>
<tr>
<td>Jeju National University</td>
<td>7</td>
<td>South Korea</td>
</tr>
<tr>
<td>Northwestern University</td>
<td>6</td>
<td>United States</td>
</tr>
<tr>
<td>Vilnius universitetas</td>
<td>6</td>
<td>Lithuania</td>
</tr>
<tr>
<td>Amasya Universitesi</td>
<td>6</td>
<td>Turkey</td>
</tr>
<tr>
<td>SRI International</td>
<td>5</td>
<td>United States</td>
</tr>
<tr>
<td>Universidad Rey Juan Carlos</td>
<td>5</td>
<td>Spain</td>
</tr>
<tr>
<td>University of Maryland</td>
<td>5</td>
<td>United States</td>
</tr>
</tbody>
</table>

© Springer

Content courtesy of Springer Nature, terms of use apply. Rights reserved.
Table 4 Most influential journals ranked by the number of articles

<table>
<thead>
<tr>
<th>Journals</th>
<th># of Articles</th>
<th># of Citations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Informatics in Education</td>
<td>17</td>
<td>85</td>
</tr>
<tr>
<td>Journal of Science Education and Technology</td>
<td>15</td>
<td>296</td>
</tr>
<tr>
<td>Interactive Learning Environments</td>
<td>14</td>
<td>35</td>
</tr>
<tr>
<td>Computers and Education</td>
<td>13</td>
<td>455</td>
</tr>
<tr>
<td>Education and Information Technologies</td>
<td>12</td>
<td>289</td>
</tr>
<tr>
<td>TechTrends</td>
<td>11</td>
<td>129</td>
</tr>
<tr>
<td>Computers in Human Behavior</td>
<td>8</td>
<td>210</td>
</tr>
<tr>
<td>International Journal of Child-Computer Interaction</td>
<td>8</td>
<td>61</td>
</tr>
<tr>
<td>Mondo Digitale</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>ACM Inroads</td>
<td>7</td>
<td>716</td>
</tr>
<tr>
<td>Communications of the ACM</td>
<td>7</td>
<td>248</td>
</tr>
<tr>
<td>ACM Transactions on Computing Education</td>
<td>7</td>
<td>223</td>
</tr>
<tr>
<td>Journal of Educational Computing Research</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Eurasia Journal of Mathematics, Science and Technology Education</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Asia-Pacific Education Researcher</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>SIGCSE Bulletin Inroads</td>
<td>4</td>
<td>96</td>
</tr>
<tr>
<td>Computer Applications in Engineering Education</td>
<td>4</td>
<td>23</td>
</tr>
<tr>
<td>Revista Iberoamericana de Tecnologias del Aprendizaje</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>IEEE Access</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Journal of Digital Learning in Teacher Education</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

The table is ranked by the number of articles. The highest citations are shown in bold.

3.5 The most studied subject areas

The subject area distribution of the articles in the database is shown in Fig. 4. Although research on CT has been conducted mostly in the field of Social Sciences (35.9%), then Computer Science (31.4%) and Engineering (12.1%), it is seen that CT research covers a wide range of subjects and attracts researchers from different disciplines. In line with the results, it can be concluded that the CT subject is a multidisciplinary research area.

3.6 The most used author keywords in articles

The keywords chosen by the author allow us to determine what relationships exist between a research field and others close to this field. Also, the frequency of keywords helps identify the main topics studied in articles in this field. A co-occurrence analysis was selected from the menu of the VOSviewer software to create a network map of the most used author keywords based on bibliographic data to reveal the general themes of CT research. The author keywords option selected and the minimum number of occurrences of a keyword was set to 5. Also, to make the map clearer, "computational thinking" keyword has been removed from the list. The created
map showing the distribution of 33 keywords meeting this criterion is presented in Fig. 5. In the map, the size of nodes shows the frequency of keywords occurrence, the curved links between the nodes represent their co-occurrences in the same documents, and the number of co-occurrences of the two keywords increases as the distance between them decreases.

As seen from Fig. 5, the most used author keywords were “Programming” (50), “Robotics” (27), “Scratch” (19), “STEM” (26), “Problem solving”, (24) and “Coding” (21). When the strength of the link between keywords is examined, it is seen that “Programming” and “Problem solving” keywords are ranked in the first two places with total link strength 116 and 62, respectively. Furthermore, it is worth noting that there is a strong link between “Programming” and “Computer Science Education”, and they are also close to each other.

Upon closer examination of Fig. 5, the main topics studied in the field of CT are gathered under four clusters. As mentioned above, programming is the most studied topic under CT research belonging to the Red Cluster with problem solving, algorithm, abstraction, and constructionism in computer science, computing, primary and teacher education. Studies grouped under the Blue Cluster are mostly related to scratch, assessment, and visual programming in elementary, K12, science, and engineering education. Finally, while the studies in the Green Cluster focus on robotics, coding, STEM, and game-based learning in elementary
and secondary education, it is seen that the studies in the Yellow Cluster mostly focus on integrating CT in mathematics education.

In the light of the results obtained in this study, the question of how CT is applied and what has been achieved? was also investigated. As seen in Fig. 5, the frequency of the most repeated author keywords in the publications examined in this study shows the global picture of CT research that gives us the answer to this question. Based on the number of co-occurrences of author keywords, while CT has been mostly applied to programming activities, it has been widely used in different subjects, including STEM, computer science, education, science, mathematics, engineering, and computing. Robotics, game-based learning, constructionism, self-efficacy and unplugged activities are also hot topics in which CT applied. This evidence shows that CT is no longer just an independent field of teaching, but also a field that can be applied to different disciplines or daily life. Scratch was the most popular programming language which the educators used for designing CT learning activities followed by other visual programming languages. In addition, CT applied in the education settings for students from primary to k-12 level and in teacher education courses. Thus, students have been trained with skills of CT, independent thinking, and problem solving from childhood. The implementation of CT in such a wide framework has had outputs, and this has been widely recognized by academics and educators. This situation makes a significant contribution to the field.
3.7 The most used terms in abstracts

The abstract part of an article reflects the essence of the whole article. The terms in the abstract section of the collected documents can provide insights into main topics and research trends in the field of CT. Therefore, the frequency of the terms in the abstract section can be used to determine general themes. To reveal the general themes of CT research from the most used terms in the abstract section of articles, "Create a map from text data" analysis was selected from the VOSviewer menu. Then "Read data from bibliographic database files" selected. After abstract and binary counting options selected and then the minimum number of occurrences of a term set to 10, the number of most relevant terms computed as 94. The created map is presented in Fig. 6.

The size of a node on the map shows the frequency of the term occurring in abstracts, i.e. larger nodes represent higher occurrence frequency. The proximity between nodes represents stronger relatedness and the thickness of the curved line connecting them, on the other hand, shows the magnitude of passing together in the same document. Different colors show clusters of terms. As shown in Fig. 6, terms in abstract were classified into 3 distinct clusters. While the Blue Cluster consists of only 14 terms, the Red Cluster consists of 41 and the Green Cluster 39. The most used terms in the abstracts are "Practice" (73), "Science" (53), "Computer science" (48), "Computational thinking skill" (46), and "Effect" (45), respectively.

Based on the related terms in each cluster, it can be seen that topical foci of research on the field of CT are gathered under three themes. Through in-depth
analysis of the terms in each cluster, we can roughly describe the research hot spots in CT studies.

First, there is an interest in integrating CT into STEM education, because of frequently repeated terms, such as "practice", "science", "computer science", "understanding", "educator", "mathematics", and "engineering" in Red Cluster. In another word, publications with terms in Red Cluster, mostly focused on integrating CT into STEM education environments. Examples were research on integrate CT into STEM, including a two-year qualitative study examining integration of CT into elementary mathematics instruction (Israel & Lash, 2020), improve and assess physics and engineering integrated CT skills through developing maker activities and assessments (Yin et al., 2019), support elementary teachers in learning to integrate CT into their science teaching (Ketelhut et al., 2020), integrating CT into elementary mathematics and science instruction (Rich et al., 2020), promote CT among mathematics, engineering, science and technology students, through hands-on computer experiments (Benakli et al., 2017), integrate CT into high school science and mathematics curriculum (Weintrop et al., 2016), integrate CT into mathematics and programming education in elementary classrooms (Sung et al., 2017), integrating CT into K-12 science topics (Sengupta et al., 2013), and integrating CT into elementary science curriculum (Waterman et al., 2020). It has been revealed that a number of studies on integrating CT into the STEM mostly included computer science, science, mathematics, and engineering, based on frequently repeated terms in the abstract. This indicates that CT has an increasing interest in computer science and STEM education. However, these current studies, which are limited to only certain disciplines, show that there is a gap where new research can be conducted in other areas where STEM, non-STEM and CT can be applied. In this context, conducting new studies with all disciplines and technologies where CT can be integrated, especially no-STEM and other STEM fields such as physics, biology, and chemistry, will make a significant contribution to the field.

Second, considering the frequently repeated terms in Green Cluster, such as the "effect", "group", "CT skills", "test", "experimental group", "control group", "gender", "scale", and "factor" it can be concluded that the second theme mainly focused on experimental research designs assessing CT skills. That is, articles with terms in Green Cluster, mostly focused on discussing studies measuring STCK skills. The specific contents of the studies in this cluster included the development of CT skill scale for high school students (Korkmaz & Xuemei, 2019; Yağcı, 2019), for university students (Korkmaz et al., 2017), development of instrument for assessing CT skills of young children (Relkin et al., 2020), of the fifth grade students (Chen et al., 2017), using CT skill scale to determine how much various variables explain students’ CT skills (Durak & Saritepeci, 2018), to investigate the relationships between CT skills, STEM attitude, and thinking styles (Srakaya et al., 2020). Also, publications with terms in this cluster often used the effect of using tools such as scratch and robotic applications on learning programming and CT skills. Specific examples were the effects of programming with Scratch and Alice tools on student engagement, reflective thinking and problem-solving and CT skills (Durak, 2020), the effects of learning with the Bee-Bot on young students’ computational thinking skills (Angeli & Valanides, 2020), integrating ScratchJr into a programming curriculum to develop
children's CT skills (Chou, 2020), develop CT with Scratch (Moreno-León et al., 2017), developing CT in a virtual robotics programming environment (Witherspoon et al., 2017). These results show that a significant amount of experimental research has been done on assessing CT skills. However, there are still gaps to be filled. Most of the studies used classical test and scale measurement tools to assess CT-related skills. Whereas, studies involving the simultaneous use of qualitative data collected through interviews, opinions or focus groups can be increased to better understand students' CT competence. Additionally, it has been revealed that the experimental studies based on cause and effect concentrate mostly on Scratch and Robotics. The gap in this area can be filled with studies in which CT is integrated with different educational technology tools. Furthermore, it is seen that there are few studies on the gender factors in this cluster. More research can be conducted to investigate the relationship between gender and CT skills in future studies.

Finally, the third theme, another area of interest, relates to the CT skills or skills of the 21st-century include terms such as "abstraction", "decomposition", "critical thinking", "generalization", "creativity", "algorithm", evaluation, definition, and generalization in Blue Cluster. In brief, articles with terms in Blue Cluster, mostly concentrated on discussing definition of CT and CT skills. Research on CT skills included developing CT skills (Palts & Pedaste, 2020), developing students' twenty-first century skills (Gretter & Yadav, 2016), developing twenty-first century skills (Nouri et al., 2020), developing CT with solved problems (Rodríguez del Rey, 2021), fostering computational thinking through collaborative game-based learning (Turchi et al., 2019), reporting what CT skills to teach at what age (Rijke et al., 2018), discussing the key computational thinking constructs (Yadav et al., 2016), teaching twenty-first century skills through an integrated approach (Gretter & Yadav, 2016), and comparing computational and critical thinking (Kules, 2016). The frequency of terms related to skills of CT in the abstract section of the studies shows that CT skills are one of the hot topics of the CT field. However, when studies on this subject are examined, it is seen that no common consensus has yet been formed among researchers on these skills, just as in the definition of CT (Kalelioglu et al., 2016). For example, some researchers have used different terms such as "CT ideas" (Yadav et al., 2018), "CT topics" (Waterman et al., 2020), "CT practices" (Irgens et al., 2020), and "CT competencies" (Ehsan et al., 2020) etc. instead of CT skills. In addition, it is still unclear what CT skills are and which skills are suitable for which study. It is critical to fill this gap as soon as possible to accelerate the development of the field. In this context, a detailed description of CT skills should be done to have a common understanding of CT skills among researchers. Further collaborative studies, which take these issues into account, will need to be undertaken.

In addition, to uncover the evolution of topical foci of research on CT, overlay visualization analysis was conducted to re-create the same map showing the distribution of the terms in abstracts by years. The created map presented in Fig. 7. Considering the scattering of terms becomes popular recently throughout the map, it can be said that all research topics of CT continue to be active as a whole. However, considering the density of the terms, such as "experimental", "test", "effect", "group", "gender", and "participant" on the yellowish part of the map, it is clear that the most recent studies focus more on empirical studies on CT skills.

© Springer

Content courtesy of Springer Nature, terms of use apply. Rights reserved.
3.8 The most cited authors

Citation analysis is an invaluable tool to determine the influence of an author on a given field by counting the number of times the author has been cited by others. To create a network map of the most cited authors, citation analysis is conducted with these criterions: Minimum number of documents of an author set to 1 and the minimum number of citations of an author set to 100. Note that the number of articles per author was set to be at least 1 to include Wing, J.M., researcher who had a significant influence on the birth of this field. The network map of 38 authors meeting these criteria is presented in Fig. 8, and the top ten most cited authors list, ranked by the number of citations, are presented in Table 5. The results showed that the most cited authors were Stephenson, C. (3 articles, 556 citations), Wing, J.M. (1 article, 451 citations), Barr, V. (1 article, 441 citations), and Yadav, A. (8 articles, 354 citations), respectively.

When the number of citations of the authors conducting research on CT is examined, while 12 authors have more than 100, 36 authors have more than 200 citations. As seen from Table 5, Stephenson, C. published three articles and received a total of 567 citations with 185.33 citations per paper from these articles. Among these three articles, the most cited one was coauthored with Barr, V. (Barr & Stephenson, 2011) and the others two with Yadav, A. and Hong, H. (Yadav et al., 2016, 2017b). It should not be overlooked that Yadav, A. played an important role in these two studies. Interestingly, with the popular publication of Barr and Stephenson (2011), both these scholars appear as top-cited authors. Another author who received
the most citations for her influential article (Wing, 2008), which played a critical role in the development and recognition of the field, was Wing, J. M.

The network map in Fig. 8 shows 8657 citations received by 38 authors in CT research. The relatedness of the nodes is proportional to the number of times the authors cite each other, and the size of nodes is proportional to the number of citations the related author receives. The map presents four distinct clusters that were created through co-authorship of authors. For example, an examination of the Blue Cluster, the nodes indicate co-authorship between Basu, S., Biswas, G., Kinnebrew, J.S., Sengupta, P., and Clark, D. that they published four articles (Hutchins et al.,

<table>
<thead>
<tr>
<th>Author</th>
<th># of Articles</th>
<th># of Citations</th>
<th>Citations per Article</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stephenson, C</td>
<td>3</td>
<td>556</td>
<td>185.33</td>
</tr>
<tr>
<td>Wing, J.M</td>
<td>1</td>
<td>451</td>
<td>451.00</td>
</tr>
<tr>
<td>Barr, V</td>
<td>1</td>
<td>441</td>
<td>441.00</td>
</tr>
<tr>
<td>Yadav A</td>
<td>8</td>
<td>354</td>
<td>44.25</td>
</tr>
<tr>
<td>Bers, M.U</td>
<td>4</td>
<td>300</td>
<td>75.00</td>
</tr>
<tr>
<td>Malyn-Smith, J</td>
<td>4</td>
<td>286</td>
<td>71.50</td>
</tr>
<tr>
<td>Lee, I</td>
<td>4</td>
<td>269</td>
<td>67.25</td>
</tr>
<tr>
<td>Martin, F</td>
<td>3</td>
<td>269</td>
<td>89.67</td>
</tr>
<tr>
<td>Wilensky, U</td>
<td>5</td>
<td>258</td>
<td>51.60</td>
</tr>
<tr>
<td>Basu, S</td>
<td>6</td>
<td>246</td>
<td>41.00</td>
</tr>
</tbody>
</table>

The table is ranked by the number of citations. The highest number of articles and citations per article values are shown in bold.
2020; Basu et al., 2017, 2016; Sengupta et al., 2013) related to integrating CT into science learning. Alternatively, the work of the authors in the Green Cluster mainly focused on the integration of CT into children's education. In this cluster, the most cited papers are coauthored by Bers, M.U. (Bers, 2010; Bers et al., 2014) and Lee, I. (Lee et al., 2011). The authors in the Red Cluster formed several scattered groups. For example, while Stephenson, C., the most cited author (Yadav et al., 2017b, 2016; Barr & Stephenson, 2011) in the field, in one group, Wing, J.M. (Wing, 2008) in another group. Finally, Yadav, A., one of the most productive and cited author in Yellow Cluster, collected the most citations from these articles: "Computational thinking in elementary and secondary teacher education", "Computational thinking in compulsory education: Towards an agenda for research and practice", and "Computational Thinking for All: Pedagogical Approaches to Embedding 21st Century Problem Solving in K-12 Classrooms".

3.9 The most co-cited authors

Co-citation is defined by Small (1973) as the frequency with which two documents are cited together. More specifically, if a third publication cites both publications in its reference list, two publications are co-cited. In the case of co-cited authors, the more two authors are co-cited, the more they have similar research directions. Therefore, co-citation analysis has frequently been used for social network analysis to visualize similarities between authors in a field of study (Hallinger & Wang, 2020; White & McCain, 1998).

To create a map for most co-cited authors, co-citation analysis and cited authors were selected. Then, the value of the minimum number of citations of an author was set to 100. The created co-citation map that displays the most co-cited authors in the CT literature, presented in Fig. 9. The map shows 190 links that connect 19 authors who belong to one of the four clusters.

The four (Red, Green, Blue, and Yellow) clusters represented four teams with different research directions. In another word, each cluster represents scientists who share common theoretical perspectives and research areas. For example, while researchers in the Green Cluster (Grover, 2017; Grover & Pea, 2013; Grover et al., 2017; Yadav et al., 2016, 2014, 2017a, b) are concentrating on the integration of CT into block-based programming environments and teacher education environments from elementary to K12 level, those in the Blue Cluster (Pei et al., 2018; Weintrop & Wilensky, 2017; Weintrop et al., 2014, 2016; Wilensky et al., 2014) are focused on integrating CT into the science, mathematics and STEM-teaching environments with high school students. Generally, the most co-cited authors in the field of CT have been Wing, J.M., Resnick, M., Yadav, A., and Grover, S., with 500, 264, 231, and 230 citations, respectively.

The information about the 15 most co-cited authors is shown in Table 6. Wing, J.M., with co-cited 500 times, is by far the most co-cited author. Moreover, five authors, namely, Resnick, M., Yadav, A., Grover, S., Papert, S., and Wilensky, U., are co-cited more than 200 times. To explain the relationship between the most co-cited authors and the most co-cited references, co-citation analysis of references was
conducted. The threshold value of the number of co-cites for a reference is set to 15. Of 12,847 cited references, fifteen references meet the threshold. The produced network map of references that co-cited 15 and more times is presented in Fig. 10.

<table>
<thead>
<tr>
<th>Authors</th>
<th>Citations</th>
<th>Link strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing, J.M</td>
<td>500</td>
<td>5441</td>
</tr>
<tr>
<td>Resnick, M</td>
<td>264</td>
<td>4235</td>
</tr>
<tr>
<td>Yadav, A</td>
<td>231</td>
<td>2941</td>
</tr>
<tr>
<td>Grover, S</td>
<td>230</td>
<td>3908</td>
</tr>
<tr>
<td>Papert, S</td>
<td>226</td>
<td>3409</td>
</tr>
<tr>
<td>Wilensky, U</td>
<td>209</td>
<td>3633</td>
</tr>
<tr>
<td>Pea, R</td>
<td>184</td>
<td>3104</td>
</tr>
<tr>
<td>Stephenson, C</td>
<td>179</td>
<td>2328</td>
</tr>
<tr>
<td>Bers, M.U</td>
<td>171</td>
<td>2556</td>
</tr>
<tr>
<td>Brennan, K</td>
<td>165</td>
<td>2680</td>
</tr>
<tr>
<td>Roman-Gonzalez, M</td>
<td>143</td>
<td>2965</td>
</tr>
<tr>
<td>Denner, J</td>
<td>129</td>
<td>2420</td>
</tr>
<tr>
<td>Kafai, Y.B</td>
<td>129</td>
<td>2106</td>
</tr>
<tr>
<td>Barr, V</td>
<td>121</td>
<td>1648</td>
</tr>
<tr>
<td>Werner, L</td>
<td>115</td>
<td>2190</td>
</tr>
</tbody>
</table>

The most co-cited authors who contributed to the publication as the first author are shown in bold
Table 7 shows the 15 most co-cited references. Wing (2006) is the only reference that was co-cited more than 170 times. Besides, Grover and Pea (2013) was co-cited more than 60, and four other references were co-cited more than 30 times, including Barr and Stephenson (2011); Lye and Koh (2014); Weintrop et al. (2016); and Voogt et al. (2015). Furthermore, among the 15 most co-cited references, six of them were published among the most co-cited authors that contributed to the publication as the first author. These authors were, namely, Wing, J.M. (Wing, 2006), Resnick,
M. (Resnick et al., 2009), Grover, S. (Grover & Pea, 2013), Bers, M.U. (Bers et al., 2014), Roman-Gonzalez, M., (Román-González et al., 2017), and Barr, V. (Barr & Stephenson, 2011).

It is no surprise that Wing, who played the most important role in the emergence of the field, ranked number one in both most co-cited authors and references lists. Wing’s most cited article, Computational Thinking (Wing, 2006), focuses on a comprehensive definition of the concept of “Computational Thinking” for the first time, as mentioned in the Introduction section. Wing is a highly productive scholar with published 4 edited books, 11 book chapters (referred), more than 40 journal publications, and more than 70 refereed conference and workshop papers (Wing, 2021). She has worked at several organizations such as Columbia University (2017 to present) as Avanessians Director of Data Science Institute, Professor of Computer Science (Computer Science), Microsoft Research (2013–2017) as Corporate Vice President, Carnegie Mellon University (1985 to present) as Professor (Computer Science), National Science Foundation (2007 to 2010) as Assistant Director (Computer and Information Science and Engineering), and University of Southern California (1983 to 1985) as Assistant Professor (Computer Science) (ORCID, 2021). As seen from Fig. 9, Wing’s publications have often been co-cited with the work of 4 out of the top 15 authors in green cluster including Yadav, A. (link strength:438), Grover, S. (433), Pea, R. (349), and Stephenson, C. (323), and Barr, V. (240) respectively. Additionally, according to cluster analysis of Fig. 10, 4 out of the top 15 references such as (Grover & Pea, 2013; Barr & Stephenson, 2011; Lye & Koh, 2014; Weintrop et al., 2016; were often co-cited together Wing (2006) with link strength 45, 33, 31, and 27, respectively.

After Wing, J.M., Resnick, M., co-cited 264 times, was the second most co-cited author. His paper "Scratch: Programming for all " (Resnick et al., 2009) was co-cited 17 times and ranked 13 in the list of most co-cited references. This publication cited 3470 times according to Google Scholar data, is the most cited paper of the author. This popular article discusses the underlying motivations of Scratch, the design principles that guided the development of Scratch, and the efforts and future aspects of making programming interesting and accessible to everyone. Resnick, M. is a popular scholar published 64 papers (29 Articles, 29 Conference Papers, 3 Book Chapters, 2 Review, and 1 Note) indexed in Scopus database. His publications have co-cited many times with the work of Brennan K. and Kafai Y.B., as seen from Fig. 9. He is Lego Papert Professor of Learning Research, Director of the Okawa Center, and Director of the Lifelong Kindergarten group that has developed a new programming language, called Scratch, at the Massachusetts Institute of Technology (MIT) Media Lab. Scratch programming software was developed to create an environment that makes it easier for children to create animated stories, video games, and interactive art. It has also been developed to teach young students CT or essential skills for life in the twenty-first century (https://scratch.mit.edu). Studies have proven that Scratch is a suitable tool for teaching CT skills (Fagerlund et al., 2020; Pérez-Marín et al., 2020; Wei et al., 2021).

Overall, Wing, J.M., and Resnick, M., the first and second most co-cited authors, have contributed significantly to the development of the CT field and the formation of its literature. In this context, while Wing, J.M., contributed to the emergence of
the concept of CT and its spread in the academic community. Resnick, M., provided
the Scratch programming environment to enable teachers to teach and evaluate CT
skills in practice.

3.10 The most cited journals

Citation analysis with the “Sources” option performed to create a network map of
the most cited journals. The minimum number of documents sets to 5 and minimum
number of citations sets to 50. The map of 10 journals that meet these criteria is
shown in Fig. 11. The most cited journals are Acm Inroads (7 articles, 716 cita-
tions), Computers & Education (13 articles, 455 citations), Journal of Science Edu-
cation and Technology (15 articles, 296 citations), and Education and Information
Technologies (12 articles, 289 citations), respectively.

3.11 The most co-cited journals

Co-citation analysis with Cited Sources option performed to create a network map of
the most co-cited journals. The minimum number of citations of source sets to
50. The network map of 15 journals that meet these criteria is shown in Fig. 12. The
most co-cited journals are Communications of the Acm (363 citations), Computers
& Education (303 citations), Acm Inroads (191 citations), and Computers in Human
Behavior (180 citations), respectively.

Fig. 11 The network map of the most cited journals

Content courtesy of Springer Nature, terms of use apply. Rights reserved.
Here, the distance between two journals in the visualization indicates the relatedness of the journals in terms of co-citation links. The closer two journals are located to each other, the stronger their relatedness. For example, there is a strong relation between computers & education and computers in human behavior.

4 Conclusion, future works, and limitations

In this study, a data set of 321 journal articles indexed in the Scopus database was analyzed to uncover the current state of research, trends, and evolution in computational thinking using bibliometric analysis techniques such as citation, co-citation, and co-occurrence methods. In this context, the development trends, general characteristics, collaboration networks, and existing hot spots of the articles in the field of CT were thoroughly examined. Since the initial idea of CT was put forward, the field continues to evolve, and especially in recent years, with an increasing rate of publications, many valuable research results have emerged.

Although this research revealed that CT received little attention from the academic community in the first decade after its introduction in 2006, it shows that there has been a significant increase in the number of articles published annually since 2013. Parallel to this, the number of authors and references is growing, as well as the rate of author cooperation, institutional cooperation and country cooperation rates are gradually increasing. The main reason for this progress is the effort of a group of scientists from the United States and several other European and Asian countries who maintain strong collaborative links nationally and
also with other countries. However, it can be said that this cooperation between researchers is mostly concentrated on a national basis or between neighboring countries.

The most obvious finding to emerge from this study is that CT research is predominantly published in journals specializing in educational technology and feeds from information generated in education, computing, and social sciences.

Also, the results of this research show that researchers in the field investigate various topics such as STEM, CT skills, creativity, algorithm, critical thinking, etc. which are grouped under three themes: Integrating CT into STEM education, conducting experimental studies assessing CT skills, and discussing definition of CT and CT skills.

Furthermore, the results of this research show that CT has the general nature of an emerging discipline that is not yet mature, and will continue to evolve in the future. However, it can be argued that this field will continue to develop and its future is bright. Also, it can be said that the research on CT is mostly interdisciplinary and integrates a range of topics studied by researchers from different disciplines and views. Therefore, the current study will help guide researchers in selecting relevant topics and finding suitable teams to collaborate.

On the other hand, it can be said that the knowledge gained so far in the field of CT is limited to the work done by a small group of authors, institutions and countries. Therefore, leading researchers in this field can conduct international collaborative and comparative studies with academics from other countries.

In the light of the results obtained from this study, it will be necessary to conduct further studies that take the results into account. First, tools such as tests and scales were mostly used to collect data in experimental studies to measure CT skills. Interview forms, rubrics, and new techniques that record the environment should be included in new studies. These assessment methods to be applied can provide a more comprehensive understanding of the students’ progress in CT. Second, there has been no common consensus among researchers on the definition of CT or CT skills. This situation can be said to be one of the biggest obstacles in front of the development of the CT field. For this reason, new studies should be given priority to research, in which as many researchers collaborate as possible, toward the establishment of standards in the field of CT. Third, it has been concluded that the studies in the field are mostly conducted with students from elementary education to high school. In this context, future studies should be expanded to cover higher education to fill the gap in this field. Especially, priority should be given to studies on how CT can be integrated into undergraduate discipline-specific environments. Fourth, programming training has often been used to develop CT skills. But, among the programming tools used to improve students’ CT skills, the Scratch programming language was used the most. In future investigations, it might be possible to use different programming tools, technologies, and environments that contribute to the development of CT skills and bring a new breath to the field. Finally, it was noteworthy that there are few studies on the effect of gender factors on CT. In this context, it is thought that the work to be done in the future to fill this gap is important.

Due to some problems arising from the selection of data in bibliometric studies, it is difficult to perfectly reveal the status and development of a field. In this context,
this research also has certain limitations. The first of these limitations is that the data of this research is limited to publications indexed in the Scopus database. Although the Scopus database provides a comprehensive peer-reviewed literature on social and educational sciences (Hallinger & Kovačević, 2019; Mongeon & Paul-Hus, 2016), it does not include every relevant document in the literature. So, the results could be somewhat different if another database or a combination of databases could be used to collect research data. Another limitation is that the publications whose document type is only articles are included into the dataset to increase the objective and quality of research and also to avoid unnecessary hits. Future research could be solving this problem by using appropriate methods to select high-quality conference papers and include them into the dataset. Still another limitation of this research is to limit the search query to only search CT in the "Title". In future searching CT in both the "title" and "abstract" sections of papers would give more results included in the CT literature. Finally, the data of this research is limited to the literature published in English language.

References


Springer


 Springer


© Springer

Content courtesy of Springer Nature, terms of use apply. Rights reserved.


Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.
Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH ("Springer Nature"). Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users ("Users"), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use ("Terms"). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.

These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.

We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.

While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval, sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.

These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.

To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.

Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.

If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com