Scientific Research Publishing

Open Journal of Social Sciences, 2021, 9, 1-16
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

The Analysis of Research Hotspots and Frontiers of Computational Thinking Based on CiteSpace

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How to cite this paper: Xue, C., & Liu, Y. (2021). The Analysis of Research Hotspots and Frontiers of Computational Thinking Based on CiteSpace. *Open Journal of Social Sciences, 9,* 1-16.
https://doi.org/10.4236/jss.2021.99001

Received: August 8, 2021
Accepted: August 29, 2021
Published: September 1, 2021

Abstract

The article uses CiteSpace software to visually analyze 424 articles on computational thinking research in core journals and CSSCI journals included in the CNKI database from 2011 to 2021, aiming to explore the research hotspots and frontiers in the field of computational thinking. Through keyword clustering analysis and high-frequency keyword analysis to identify the hot spots of computational thinking research, and to identify the frontier trends of computational thinking by detecting keyword timeline and bursts terms, providing an important reference for computational thinking researchers. We found that not only "computational thinking", "computer courses", and "information technology" are research hotspots, but also "artificial intelligence", "education reform", and "programming education". "New Engineering", "Maker Education", "K12 Education", "information technology" and "artificial intelligence" are all frontier research trends. The cultivation of computational thinking is becoming more and more important. In the future, how to cultivate computing more effectively will receive more attention and research.

Keywords

Computational Thinking, Hotspots, Trends, CiteSpace

1. Introduction

The history of computational thinking can be traced back to at least the 1950s (Tedre & Denning, 2016). In 1980, it was first mentioned in the book "Mind storms: Children, Computers, and Powerful Ideas" by Professor Seymour Papert (1980) of the Massachusetts Institute of Technology (MIT). Professor Seymour Papert (1996) mentioned computational thinking again in his published article. He hoped

to use computational thinking to help construct geometric theories with "explanatory nature", but he did not define computational thinking. In 2006, Professor Jeannette M. Wing of Carnegie Mellon University defined computational thinking in the American computer authoritative journal "Communication of the ACM". She pointed out that computational thinking will be one of the basic skills that everyone should have like reading, writing and arithmetic. Nowadays, both computing and computers are promoting the development of people's computational thinking. Computational thinking is to use the basic concepts of computer science to carry out a series of thinking activities covering problem solving and system design etc. It can provide a series of viewpoints and methods for effective problem solving, and it can better deepen people's understanding (Wing, 2006). In 2008, Professor Jeannette M. Wing (2008) pointed out: Computing thinking will affect everyone in every field of struggle. This vision provides a new educational challenge for our society, especially for young people. In 2011, Professor Jeannette M. Wing also pointed out that computational thinking is a thinking process related to formalized problems and their solutions, and its problem-solving representation should be effectively executed by information processing agents (Wing, 2011). Computational thinking is related to 21st century skills, but it is different from other 21st century skills. This ability should be integrated into the curriculum (Dede et al., 2013). Since then, more and more scholars have realized the importance of computational thinking, which has aroused the widespread attention of many scholars at home and abroad on computational thinking.

In China, computational thinking first appeared in the core journal literature in 2009, when Tianlong Gu and Rongsheng Dong (2009) published "Computational Thinking and Methodology of Computer Science and Technology. After that, it gradually developed and received more attention from computer "scientists, educators and other scholars. In 2012, the Ministry of Education formally approved computer curriculum reform projects in 22 universities, focusing on cultivating computational thinking and promoting the reform of university computer courses. In 2013, the Ministry of Education issued the "Declaration of Computer Teaching Reform", which pointed out that the reform of computer courses in universities should be based on computational thinking. In 2017, new edition of "General High School Information Technology Curriculum Standards" further clearly pointed out that the core literacy of information technology is composed of information awareness, computational thinking, digital learning and innovation, and information society responsibility. After that, many regions in China implemented the training of students' computational thinking into K12 education. The research and cultivation of computational thinking are very important in both higher education and basic education.

Analyzing the research status of computational thinking and grasping its development frontiers will be beneficial to provide references for cultivating computational thinking. In this study, a bibliometric approach is used to visually analyze the study content of computational thinking in the core journals of CNKI from 2011 to 2021. Specifically, we use CiteSpace 7.5 to analyze the relevant core

authors, major research institutions and high-frequency keywords of the literature in the field of computational thinking, and then visualize the research hotspots, research trends and research contents of computational thinking, and make certain summaries and outlooks.

2. Data Source and Visual Tool

2.1. Data Source

This article used "computational thinking" as the keyword to retrieve related papers in Chinese National Knowledge Infrastructure (CNKI) that is the most authoritative Chinese journal full-text database at home and abroad. The publication time limitation is 2011-2021, and the source category is the database of CSSCI and core journals. As shown in Figure 1, until July, 2021, there are 424 papers that are related to computational thinking in the CNKI.

2.2. Visual Tool

The visual analysis tool used in this paper is CiteSpace to analyze the literature related to the field of computational thinking. When downloading and extracting information from papers, it is saved in plain text in the "Refworks" format. CiteSpace is one of the common tools for knowledge visualization, which is an interactive visualization tool that combines the three functions of information visualization, data mining, and document measurement so that it's easy for extracting available information (Synnestvedt, Chen, & Holmes, 2005). The main purpose of using CiteSpace in this paper is to visually analyze the literature in

Figure 1. Results of advanced search in CNKI (2011-2021).

the field of computational thinking and reflect the hotspots and trends in the current research phase. Research hotspots can be reflected by keyword co-occurrence networks. Research trends can be reflected in the keyword burst graph. In this study, CiteSpace 5.7 was applied to analyze 424 articles related to computational thinking in CNKI from 2011 to 2021. The knowledge graphs were constructed from three aspects: research institutions, authors keywords, respectively.

3. Visual Analysis

3.1. Number of Media Literacy Papers

The number of academic papers published in a certain research field within a certain time period reflects the research fervor in this field. According to the bibliometric analysis function that comes with CNKI, we can get the annual literature quantity of computational thinking research. According to the dashed line of the trend in Figure 2, we can find that the number of publications has been increasing in the past ten years, and the number of documents is expected to reach the highest value of 71 in 2021.

In detail, the number of documents continued to grow from 12 in 2011 to 47 in 2014. The reason may be that, the C9 Alliance issued the "Nine Schools Alliance (C9) Computer Basic Teaching Development Strategy Joint Statement" in 2010. It is clearly pointed out that the cultivation of computational thinking ability will be an important and long-term core task of basic computer teaching in China. In the three years from 2015 to 2017, the number of documents has stabilized at around 35. Since 2018, the number of computational thinking literature has grown rapidly. An important reason is that the Ministry of Education of China proposed computational thinking as one of the core qualities of information

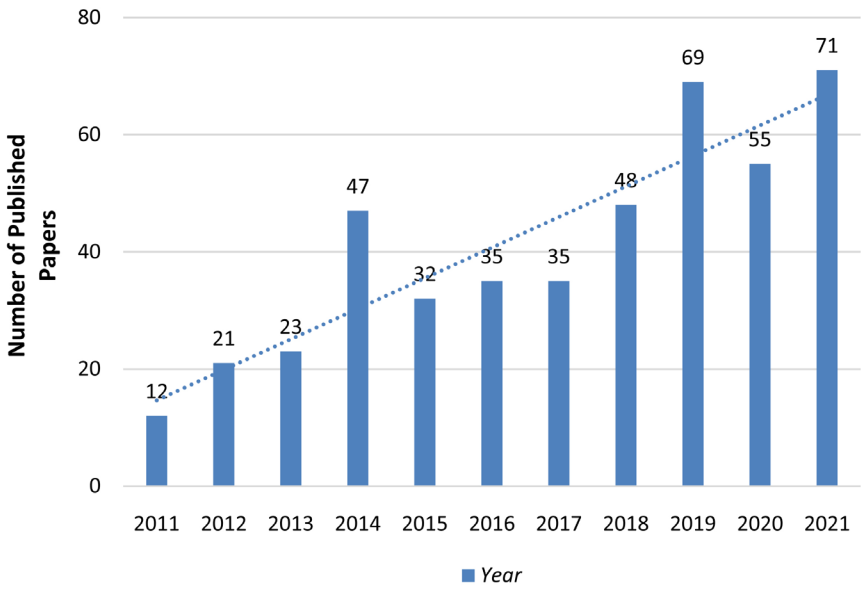

Figure 2. The number of published papers in CNKI (2011-2021).

technology courses in 2017. The education of computational thinking has expanded from higher education to basic education.

3.2. Core Authors and Research Institutions

In a certain research field, knowing which authors are the core authors and which research institutions are the core research institutions can better grasp the overall research direction and keep up with the research trends. In CiteSpace, we get the top 10 authors and institutions in number of published documents after selecting "authors" and "institutions" respectively, shown in Table 1. It can be seen from the table that Feng Li, Youqun Ren and Lihui Sun are the top three authors in terms of the number of publications. As for productive institution, Faculty of Education of Beijing Normal University, Faculty of Education of East China Normal University and College of Education of Tianjin University are the top three institutions with the higher number of published papers.

The author co-occurrence diagram (Figure 3) reflects the number of papers by research authors and the cooperation relationship between authors. The main

Table 1. The authors/research institutions of computational thinking in CNKI (2011-2021).

No.	Frequency	Core Authors	No.	Frequency	Research Institutions
1	10	Feng Li	1	10	Faculty of Education, Beijing Normal University
2	7	Youqun Ren	2	8	Faculty of Education, East China Normal University
3	6	Lihui Sun	3	8	College of Education, Tianjin University
4	5	Jinbao Zhang	4	7	Department of Education information technology, East China Normal University
5	4	Xiaodan Wang	5	7	The Teaching Guidance Committee of the University Computer Courses of the Ministry of Education
6	4	Wang Yining	6	6	School of open learning and education, East China Normal University
7	4	Qin Mu	7	5	The institute of curriculum and instruction, East China Normal University
8	7	Ying Yu	8	5	School of Education Nanjing Normal University
9	3	DeChen Zhan	9	5	School of information technology in Education, South China Normal University
10	3	Qinming He	10	5	Smart learning institute of Beijing Normal University

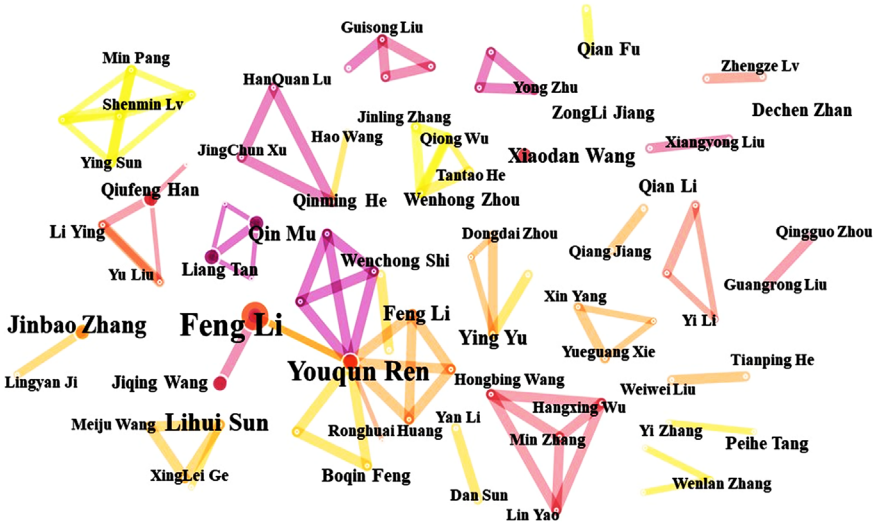

Figure 3. The co-occurrence graph of computational thinking authors in CNKI (2011-2021).

elements of the author co-occurrence graph include nodes, lines and labels. Each node represents an author and the label on it represents the author's name, and the size of the node and the label reflect the number of author papers. The links between nodes reflect the collaborative relationship between authors. The author co-occurrence graph in this study shows a total of 296 nodes and 166 connections. According to the Price law (De Solla Price, 1963), we can calculate which authors are the core authors. The formula of Price's law is: $m = 0.749(n_{max})^{0.5}$. The number n_{max} representing the number of papers published by the author who publishes the most papers is 10, and the number m representing the minimum number of papers to be published by core authors is 3. In this study, the number of core authors with at least 3 publishes papers is 20. As shown in Figure 3, we can see that "Feng Li" and "Youqun Ren" are the two largest nodes indicating that these authors have published the most articles and the line connection between the two nodes indicates that there is a cooperative relationship.

The institutional co-occurrence graph can reflect the number of papers of research institutions in a certain field and the cooperative relationship between institutions. In this study, there are 258 nodes and 145 connections in the institutional co-occurrence graph. As shown in Figure 4, we can see that there are many research institutions with East China Normal University as the main research subject, such as the Department of Education of East China Normal University and the Department of Educational Information Technology of East China Normal University. Feng Li and Youqun Ren mentioned above are both working in East China Normal University. Then came with Beijing Normal University, which shows that these two universities pay more attention to the development of computational thinking. At the same time, we can find out that different organizations within the same university have close cooperation, but there is a lack of cooperation between universities.

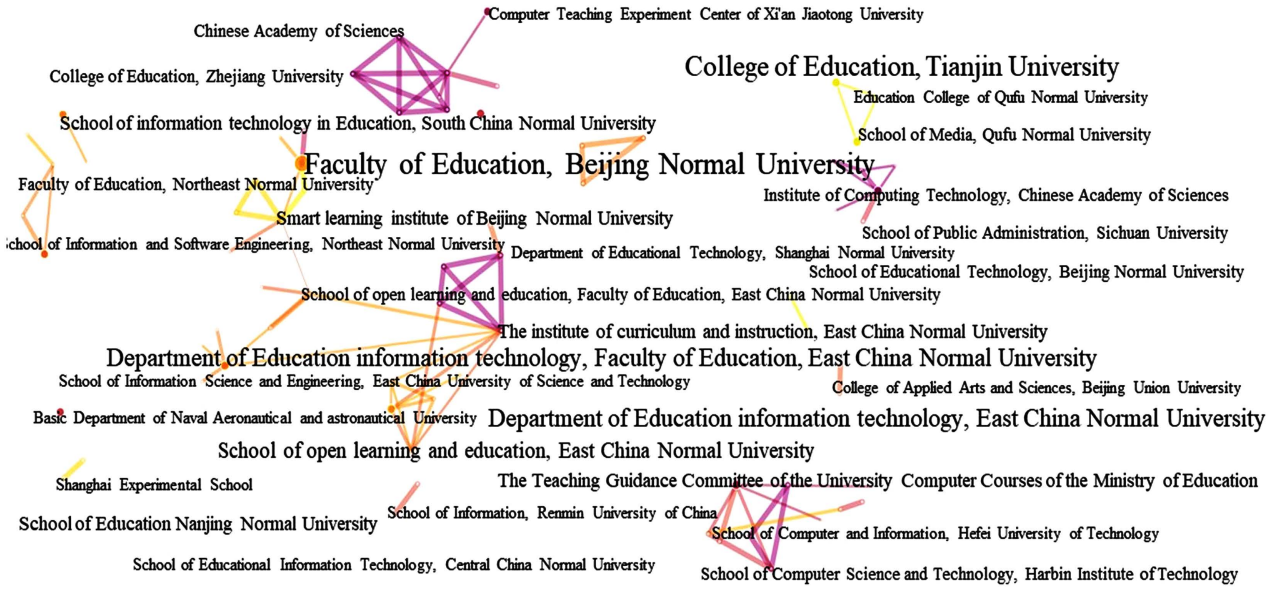

Figure 4. The co-occurrence research institutions of computational thinking in CNKI (2011-2021).

3.3. Keywords Analysis

3.3.1. Keywords Co-Occurrence Analysis

The keywords that appear with high frequency in a certain field are generally the core content of research in this field. The statistics and analysis of keywords in the field of computational thinking can help us understand the current research hotspots and cores, and also reflect the future research trends. We use CiteSpace to get the keywords in the field of computational thinking from 2011 to 2021, and the 15 most frequent keywords are shown in **Table 2** in order, among which the three most frequent keywords are "computational thinking", "artificial intelligence", "teaching reform", appeared 241 times, 32times, and 24 times, respectively.

In the field of computational thinking research, "computational thinking" is the main concepts and branch content. The word frequency of "computational thinking" is much higher than the second word frequency, and it has a higher centrality, indicating that the relevant research content on computational thinking is relatively concentrated. The content includes not only the concept and principle of computational thinking, but also the application of computational thinking in teaching. In 1996, American instructional design expert Professor David. H. Jonassen pointed out that computers in the classroom should not only be effective tools for students' operation and practice, but also cognitive tools for students' thinking development (Jonassen, 1996). The core author Feng Li who has published 10 articles about computational thinking, of which one highly cited article is "Computational Thinking Education: From "For Computing" to "With Computing". This article discusses the essence and connotation of computational thinking education for specific issues, and believes that schools should update their educational concepts and realize the shift from "for computing" to

Table 2. The co-occurrence of computational thinking keywords in CNKI (2011-2021).

No.	Frequency	Centrality	Year	Keywords (in English)
1	241	0.64	2010	computational thinking
2	32	0.20	2017	artificial intelligence
3	24	0.14	2011	teaching reform
4	23	0.11	2013	information technology
5	18	0.07	2011	University Computer Fundamentals
6	15	0.05	2013	Information Technology Course
7	19	0.06	2018	Programming education
8	14	0.05	2011	University computer
9	12	0.10	2012	Information literacy
10	10	0.05	2015	Big Data
11	9	0.10	2012	Computer Basic Teaching
12	9	0.05	2016	The core disciplines literacy
13	8	0.03	2017	Core literacy
14	8	0.01	2011	programming
15	7	0.04	2012	talent development

"with computing" (Li & Wang, 2015). It provides guidance for the further development of computational thinking education in primary and secondary schools.

Entering the era of information technology, artificial intelligence curriculum education focuses on the implementation of different levels of programming teaching in different stages, learning to use programming to solve practical problems, and cultivating basic literacy in the information age such as computational thinking and innovative thinking (Lye & Koh, 2014). Artificial intelligence and other technologies are all based on programming, and the core of programming education for K-12 students is to cultivate children's computational thinking. Sun, Guo, and Hu (2021) use Scratch visual programming software, based on the three-dimensional conceptual framework of Brennan and Resnick (2012), proving that visual programming can promote the cultivation of primary school students' computational thinking. This provides ideas for how to cultivate the computational thinking of primary school students.

The third word of high-frequency keywords is "teaching reform". In order to be more conducive to cultivating students' computational thinking at all stages of education, education researchers have proposed a variety of teaching reform plans and programs. For example, Li and Wang (2015) believe that school computational thinking education not only needs to reconstruct the content of education, but also reform the teaching methods. It is proposed that programming education should focus on procedural experience, and other courses besides information technology should also penetrate computational thinking education.

3.3.2. Keywords Clustering Analysis

Keyword clustering analysis can reflect research hotspots and the topics with high attention. To better grasp research hotspots, we performed the keywords clustering analysis. In the clustering result index, the module Q value is 0.69, higher than 0.3, and the S value is 0.925, higher than 0.7, which indicates that the clustering effect is significant and convincing. The top 10 clustering results are sorted from 0 to 9. The smaller the number, the more keywords are included in the clusters.

Figure 5 shows the clustering keywords results. "Computational thinking", "programming education" and "university computer courses" are the top three clusters of keywords. As shown in the figure, computational thinking is the largest cluster, which we have analyzed in the above. The second cluster "programming education", which is a hot topic that can be expected. In today's China, from computer courses in universities to information technology courses in primary and secondary schools all focus on cultivating students' computational thinking, and these courses emphasize programming education.

Programming is a key tool for cultivating computational thinking (Grover S., & Pea R., 2018). Bers (2020) believes that computational thinking is not only a process of problem-solving, but also a process of expression and creation, and programming is a tool for children to create externally. With the advent of the era of artificial intelligence, children's programming education is emerging. Starting from the origin of children's programming education and its interconnection with computational thinking, Pörn, R., Hemmi, K., & Kallio-Kujala, P. (2021) explained the relationship between children's programming education and computational thinking. From the perspective of programming behavior representation, the hidden relationship between cognitive level and computational thinking is explored. Román-González, Pérez-González, & Jiménez-Fernández (2017) found that students' cognitive level and the development of computational thinking are related and mutually promoting. The achievement of low-level cognitive goals in programming behavior is the basis for the formation of computational concepts, and the cognitive needs of high-level thinking triggered by programming practice can promote students' comprehension of computational thinking. Therefore,

Figure 5. The Keywords clustering graph of computational thinking in CNKI (2011-2021).

it is proposed to embed programming tasks for various cognitive goals into instructional design in a targeted manner, so that programming education can be effectively used to cultivate students' computational thinking. This provides a strategy for teachers to use programming education to cultivate students' computational thinking. In China, the research hotspot of computational thinking originated from the university's computer courses. Coupled with the development of information technology, so far, "university computer course" is still one of the hotspots in the field of computational thinking.

3.3.3. Keywords Timeline Analysis

A keyword timeline graph is a graphical representation showing the development of keywords over time. Essentially, it is also a clustering graph, only clustered by time and showing the clustering results. Figure 6 shows the keyword timeline graph for computational thinking, from which we can see the lineage of the development of computational thinking research in the last decade.

We mentioned above that in 2010, the nine major universities in China issued a joint statement on the development strategy of basic computer teaching, proposing that the cultivation of computational thinking ability will be very important. Reflected in Figure 6, we can see that "computational thinking", "programming education" and "university computer courses" have been research hotspots in the field of computational thinking since 2011. On the timeline of "computational thinking", we see keywords such as C programming, VB programming, personalized learning design, PBL, stem, etc. "Programming education" has become an important content in the field of computational thinking since 2014.

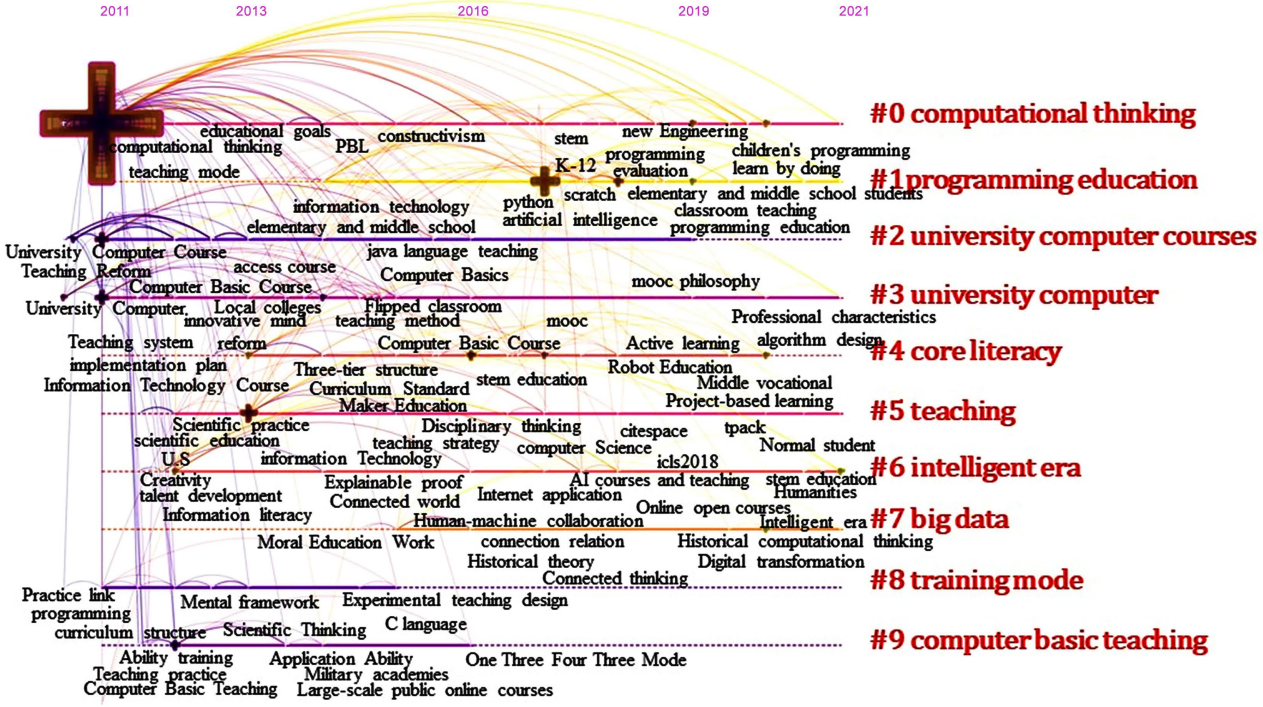

Figure 6. Timeline graph of computational thinking research in CNKI (2011-2021).

On the timeline of "programming education", you can see the emergence of python, scratch programming, artificial intelligence, etc. from 2017.With the advancement of information technology, "big data" entered the field of computational thinking in 2015. As a whole, we can see that computational thinking is related to computer courses and a variety of new technologies in the field of information. From the overall overview, we can see that computational thinking is related to computer courses and a variety of new technologies in the field of information. At the same time, some teaching methods such as learn by doing, project-based learning, and reforming some teaching models are used to cultivate computational thinking.

3.3.4. Keywords Bursts Term Analysis

Keywords bursts can reveal research hotspots in future subject areas. Many literatures study topic bursts from the perspective of keywords bursts. Keywords burst means that the value of a variable has changed one or more times within a short period of time. From Figure 7, we can see that the research of computational thinking appeared earlier in the computer-related fields of universities. We can find that in recent years, related research on computational thinking has focused on the K12 field, and the cultivation of computational thinking for primary and middle school students is a hot topic that many scholars pay more attention. Starting in 2017, maker education and problem-solving skills have become the focus of the field of computational thinking. From 2018 to the future

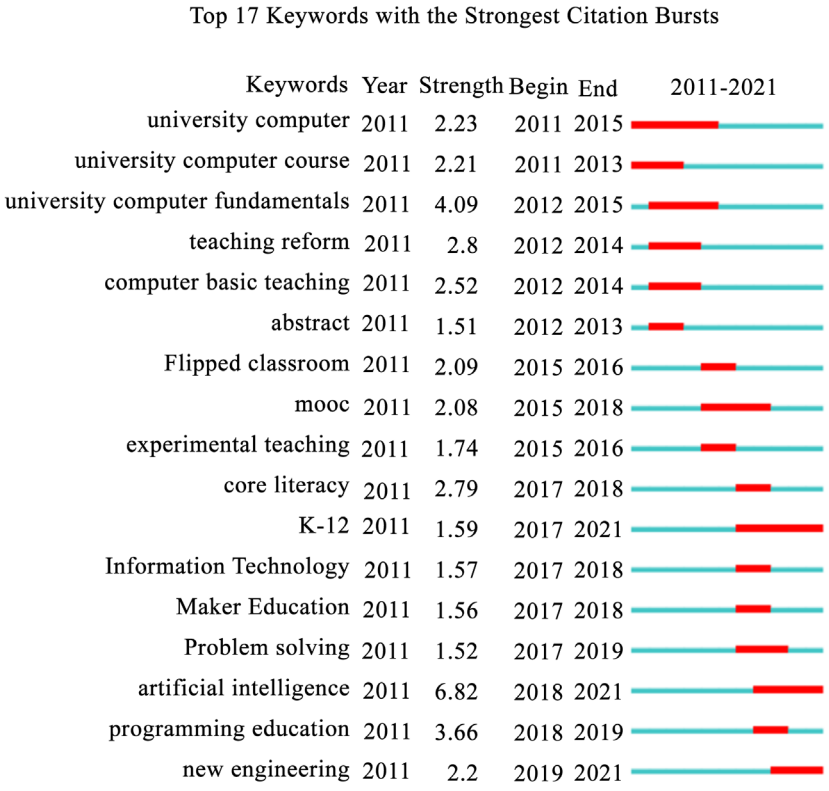

Figure 7. The bursts of computational thinking research in CNKI (2011-2021).

for a certain period of time, artificial intelligence and programming education are relatively hot topics. The last word in this picture is "new engineering", which is the latest topic in the field of computational thinking. MIT is advancing "New Engineering Education Transformation" plan, which clearly states that "the center of engineering education should emphasize the cultivation of students' thinking". Hacker, M. (2018) pointed out that strengthening the cultivation of computational thinking ability is the key to the cultivation of new engineering talents, and analyzes the ways and methods of cultivating computational thinking ability of engineering students, hoping to provide a certain reference for relevant colleges and universities to develop new engineering majors.

4. Discussion

This research is based on 424 papers from the core journals and CSSIC database in CNKI, using data analysis and visualization tools, CiteSpace, to analyze the development status of computational thinking in China. According to the author's co-occurrence knowledge graph, institutional co-occurrence knowledge graph, high-frequency keyword co-occurrence knowledge graph, keywords cluster graph, and keywords bursts graph, etc., the following conclusions are obtained.

4.1. The Status and Hotspots of Computational Thinking Research

In terms of the number of documents, starting from 2017, the number of documents related to computational thinking has increased year by year, and there is a continuing upward trend, indicating that more and more education researchers recognize the importance of computational thinking for the growth of young people and devote themselves to computing Thinking theory research or practical exploration.

From the keyword co-occurrence graph and keyword clustering graph, we can see the current research status of computational thinking. In the past ten years, computational thinking education is popular in computer education in universities, and then gradually expanded to K12 basic education. From the initial interpretation of computational thinking, theoretical exploration, to teaching mode research, teaching application, computational thinking has received more research and development. The application research is mainly concentrated in the K-12 stage, focusing on the teaching of computational thinking to solve problems, tools to promote computational thinking, and evaluation of computational thinking. We can see those keywords such as artificial intelligence, information technology, programming education, university computers, and information literacy have appeared many times. Therefore, we believe that these are important research hotspots related to computational thinking. It is not difficult to understand that both artificial intelligence education and programming education are conducive to the cultivation of computational thinking, and these courses are included in the information technology courses in the basic education stage, and are included in the computer-related courses in the higher education stage.

4.2. The Frontiers of Computational Thinking Research

From the timeline diagram of keywords and keywords bursts diagrams, we can predict the frontiers of computational thinking research. "Artificial Intelligence", "Big Data", "Computer Education", "New Engineering", these words closely related to modern information technology not only represent current research hotspots, but also the frontier research content of computational thinking. In 2017, the Ministry of Education of China actively promoted the construction of new engineering subjects. In 2019, some scholars began to explore the relationship between new engineering and computational thinking, and how to cultivate students' computational thinking in new engineering education. University computer courses have been closely related to computer thinking since 2011 or even earlier. Now with the development of new technologies such as "Internet +", cloud computing, and big data, computer-related courses are also very popular. It is an important research content that research how to better cultivate students' computational thinking in computer courses now and for a long time in the future. Entering the age of information and intelligence, the main object of computational thinking training is getting younger and younger. Not only does elementary school information technology cultivate students' computational thinking ability, pre-school education also begins to focus on the cultivation of computational thinking (Gal-Ezer & Stephenson, 2014). The research of computational thinking and how to cultivate it has received more and more attention. There are more and more student groups that need to receive computational thinking education, and the grade span is constantly expanding. Regardless of the stage, whether it is preschool, elementary school, middle school, or university, enough attention should be paid.

4.3. Relationship between Research Subjectives

During the period of 2011-2021, there are 10 authors who published more than three papers on computational thinking. They are all the core authors in the field of computational thinking research according to the Price law (De Solla Price, 1963). Feng Li of East China Normal University and Youqun Ren of East China Normal University are the top two authors, who are scholars worthy of attention and have co-authored many influential academic articles. it can be seen from the author co-occurrence mapping that the majority of scholars cooperate in groups, and combined with the organization map, we can see that the cooperation between authors is limited to the same university or institution. The largest group that studies computational thinking is organized by East China Normal University. From the centrality data of core authors and research institutions, it is clear that the centrality of each core author is 0.00. As for institution, the centrality of Wuhan University School of Information Management, which has the highest number of publications, is only 0.01. Computational thinking is essential to the cultivation of talents, and modern education needs more effective teaching strategies and teaching models for computational thinking education. It is not limited to computer education and information technology education, but should be in-

filtrated into the teaching of various subjects. If computational thinking wants to have more breaks and innovations to achieve higher value in education, active collaboration would be a noteworthy option (Franco & Pinho, 2019). This includes collaboration not only between research scholars, but also between research scholars of computational thinking and scholars in other research fields.

5. Conclusion

This paper conducts a visual study of 424 high-quality literature related to computational thinking from 2011 to 2021, and analyzes the research hotspots and frontier trends of computational thinking. According to the visual mappings and related literature content, we come to "computational thinking", "artificial intelligence", "information technology education", "programming education", "university computer education", etc., which are hot topics. And we combined the timeline and hot topics to speculate that how to cultivate students' computational thinking in basic education and university education is the current frontier topic, especially the K12 stage of computational thinking education. Computational thinking education is combined with a variety of education, such as maker education, artificial intelligence education, and information technology education. It aims to cultivate students' computational thinking and information literacy so that young people can meet the needs of the development of the times.

However, there are still some limitations in the study. First, we summarize the computational thinking frontiers based on visual analysis mapping and our understanding of computational thinking. Due to the limitation of the researcher's experience and ability, the prediction of the development frontiers inevitably has deviation. Second, many visual analysis tools are available, and this paper uses the most mainstream software, CiteSpace, but the analysis results may differ due to the different analysis tools. It is hoped that the future research will improve these limitations.

Funding

This research was supported by the Priority Academic Program Development of Jiangsu Higher Education Institutions in China.

Author Contributions

Yue Liu designed the research at the beginning. Chuan Xue analyzed the data, and prepared the first draft of the paper. Yue Liu as the corresponding author contributed to the revision. All authors approved the final draft.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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