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Computational Thinking from the Past to the Present: A Retrospective Using Bibliometric Analysis[*]

Deniz KAYA[**]

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ABSTRACT

This study aims to examine the published scientific studies on computational thinking (CT) from the past to the present, based on the Web of Science (WoS) database. In this context, 3123 documents with CT content from the past to the present were evaluated. Articles and proceeding papers accessed from the database were analyzed with the help of bibliometric analysis under the titles of scientific productivity, network analysis, conceptual structure and thematic map. Within scientific productivity, the distribution of studies and citations by years, productive authors, most cited studies, productive institutions and productive countries were considered. A collaboration between authors, sources, institutions and countries was examined in network analysis. Keyword-based techniques were used to determine the intellectual structure of the CT topic. Finally, trend content and thematic changes were analyzed based on the conceptual structure and thematic map. The study analyzed 3123 scientific documents published by 6467 authors representing 83 countries. According to the findings, the number of scientific studies and citations on CT is increasing. Dagiene, V., Biswas, G., and Kong, S. C. are prolific authors. The Education University of Hong Kong, North Carolina State University and Natl Taiwan Normal University are among the most productive institutions. The USA, China, Spain, Brazil, and Italy are productive countries for CT. According to the network analysis, Computers & Education and Communications of the ACM journals stand out. As a thematic change, there are evolutions towards innovative approaches with skill and goal content in studies. At the end of the Multiple Correspondence Analysis performed to determine the conceptual structure in CT, dimension reductions were found to be approximately 43% of the total variability. As suggestions, some thoughts on the future of CT were shared.

Keywords: Bibliometric analysis, computational thinking, Web of Science (WoS)

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1. INTRODUCTION

While general and modern theories have historically influenced the education policies of countries, a skill-oriented understanding is dominant in today's information age. Although a performance-based knowledge of skills is the main goal in the digital age, which we are only in the first quarter, multi-dimensional thinking comes to the fore, unlike in other centuries. Among the crucial reasons for this situation is the 21st-century information society's vision to be built in a more dynamic and sustainable structure than the societies left behind (Leopold, Ratcheva & Saadia, 2018). Therefore, it is inevitable for nations to transform into a more effective and functional form in the face of technology, which takes the lead in development, and to make innovative approaches sustainable in learning environments. Because individual differences come to the fore more in today's understanding of society under the influence of innovative paradigms. Therefore, it is necessary for countries to continuously analyze and improve their educational outputs and to train individuals who are suitable for the requirements of the age by integrating the developmental structure of technology in education. In this direction, it is especially emphasized that the development and application of skill-oriented scientific thinking style in many national curricula reveal solutions to the problems encountered (European Commission [EC], 2008; Ministry of National Education [MoNE], 2018; Organization for Economic Co-operation and Development [OECD], 2018). For individuals to progress with the understanding required by the digital age, teaching standards are organized at an international level while acting with a structure that prioritizes scientific thinking rather than knowledge. In the World Economic Forum's (2018) statement, in the coming years, individuals will be dealing with occupations that we cannot name yet but will need technology, creativity, problem-solving, and flexible thinking to cope with situations of uncertainty. In this direction, it is aimed for individuals to produce innovative and valuable ideas, elaborate their ideas, analyze and evaluate their ideas, develop and implement new ideas, share new ideas, see failure as opportunities for further learning, and have new and different perspectives (Trilling & Fadel, 2009). Therefore, individuals are

[*] No human subjects were used in study. It includes bibliometric analysis of data obtained from the literature. For these reasons, ethic committee approval is not required.

[**] Assoc. Prof. Dr., Nevşehir Hacı Bektaş Veli University, Faculty of Education, Department of Mathematics and Science Education, Division of Mathematics Education, Nevşehir-TÜRKİYE. e-mail: denizkaya@nevsehir.edu.tr (ORCID: 0000-0002-7804-1772)

required to use the types of reasoning to make a judgment and decision, when necessary, to analyze evidence, arguments, claims, and beliefs effectively, to make connections between information, to have a critical and flexible point of view, and to use multiple media and technologies (Partnership for 21st Century Skills [P21], 2019).

The contemporary world is known for effectively using digital technology in all areas of life. Therefore, researchers and educational policymakers specialize in developing the essential life skills required in this digital age (Kong & Wang, 2023). In this context, one of the fields of study that has found an essential response in the literature and is needed more and more every day is computational thinking (CT). CT is characterized as a cognitive structure that can be applied in a wide area as a systematic approach (Marinus, Powell, Thornton, McArthur & Crain, 2018). It is emphasized that programmers and everyone should acquire CT skills (National Research Council [NRC], 2010). CT is an applied field of study that demonstrates a pedagogical approach to developing flexible, reflective, analytical, and inquiring thinking skills as well as developing thinking skills among contemporary learners (Agbo, Olaleye, Bower & Oyelere, 2023; Carretero, Vuorikari & Punie, 2017; Wing, 2009). Because of its powerful features, CT is accepted as a critical competency required in the digital world, and its necessity is strongly emphasized (Lee, Francom & Nuatomue, 2022; Voogt, Fisser, Good, Mishra & Yadav, 2015; Weintrop et al., 2016). The fact that it can be used in many fields and contains crucial components in determining the future of nations increases the importance of CT. The significant increase in the number of theoretical and applied studies on CT, especially in the last ten years, is the most robust evidence of this situation. Numerous discussions and studies on the development and design of CT, with the help of explanations, definitions, frameworks, models, approaches, and applications in the relevant literature, increase the importance of the subject day by day. Therefore, the theoretical background of our study determines the general tendencies of the studies with the content of CT, provides an essential source for the literature, and gives an idea for the studies to be done in the same direction.

1.1. Computational Thinking

Although the concept of CT has been used in the literature before and has certain connotations, the starting point of this approach has become known by Wing with its explanations at the Communications of the ACM anniversary celebration (Wing, 2006). However, CT, which allows effective problem-solving and is cognitive skill-based, was first discussed by Papert (1980) in a book on child education with a logo. Papert believed that specific uses of affective computing technology and computing thought could open up new possibilities for students' learning. In this respect, the critical component of CT is the activation of thinking processes to solve specific problems. This thought process emphasizes the importance of clarifying the computational models that help us solve the problems we will face and the methods to be used in these models. In other words, CT is individuals' confrontation with what information-based tools do better or what information-based tools can do better than individuals (Vieira & Hai, 2023). Today, the widely accepted definition of CT is the ability to use mathematical/logical operations to understand the nature of the problems and produce alternative solutions to the identified problems, and to construct a thinking process for solutions that can be realized effectively with the help of information tools (Shute, Sun & Asbell-Clarke, 2017). Therefore, CT is a cognitive tool that simplifies complex tasks into easily solvable subtasks (Wang, 2023). CT includes some concepts such as algorithmic thinking or designing algorithms, computer science, coding, analytical thinking, abstracting the problem, parsing the problem, interpreting data/done, pattern recognition, iterative thinking, and parsing the accuracy, effect, and results of problem-solving (Agbo, Oyelere, Suhonen & Laine, 2021; Wang, 2023; Wing, 2009). While the widespread use of these concepts from preschool to higher education is described as an algorithm, abstraction, separation, and pattern, the most common approaches are tampering, debugging, persistence, cooperation, and creation (Berry, 2013).

The first definition created for this ever-increasing concept clarifies that CT is a form of analytical thinking and that computability, intelligence, intellect, and understanding human behavior through engineering in evaluating and elaborating a complex system design are made (Wing, 2006, 2008). Today, we can call CT the art of buying the future. Because in the construction of the future, multi-dimensional thinking skills are needed more than ever. CT, which overlaps with mathematical thinking, requires breaking down complex problems into smaller and more manageable parts and using logical thinking, mathematical computation, data analysis, and algorithms in this process (Wing, 2010). While CT represents a process, it also focuses on problem-solving skills at computer science's core. Berland and Wilensky (2015) consider CT as a "CT ability" (p. 630). In this respect, CT includes a multi-dimensional structure. Computational concepts, which form the first dimension of the CT framework, consist of ideas or skills that can be applied far beyond programming (McCormick & Hall, 2022). While the second dimension of the framework is computational applications, the third dimension includes CT perspectives (Brennan & Resnick, 2012). Therefore, CT includes developing individuals' relationships with themselves, with individuals other than themselves, and with the digital ecosystem based on computational experiences. In addition to being a dynamic pattern, CT helps individuals to cope with complex problems effectively by improving their creative thinking skills (Kong & Wang, 2023). At the same time, this way of thinking represents the capacity to solve problems that concern more than one discipline rather than one discipline (Wing, 2006). Therefore, it necessitates effective problem-solving processes and the fundamental way of thinking that can be placed in various academic subjects (Grover & Pea, 2013). This aspect paves the way for individuals to communicate effectively with the discipline they work with and other disciplines (Shute et al., 2017). CT also has essential components in understanding 21st-century skills. Especially with the inevitable rise of the digital world, the globalization and internationalization of the economy increase the discourse of giving more place to CT in curricula (Chan, Looi, Ho, & Kim, 2023; Voogt & Roblin, 2012). CT is becoming a valuable field of study for the nations that will build their future efficiently.

1.2. Computational Thinking Components

In 2011, the Computer Science Teachers Association (CSTA) and the International Society for Technology in Education (ISTE) re-characterized CT components following the definition proposed by Wing (2006). CT components designed by CSTA & ISTE (2011) are creative thinking, critical thinking, algorithmic thinking, problem-solving, collaboration, and communication. In the process, new and different kinds of explanations were brought about, the components determined by this association. While Selby (2015) deals with the components of CT as abstraction, problem decomposition, generalization, algorithm, and evaluation, Yeh, Xie, and Ke (2011) define memorization, application, and problem-solving as critical elements of CT. In addition, CT perspectives (confidence, perseverance, self-efficacy, *etc*.) have been widely discussed by related researchers, and opinions have been put forward to include them in the solution of specific problems (Berland & Wilensky, 2015; Chen, Sun, Hsu, Yang & Sun, 2023). The use of algorithms is more prominent in the standard views of studies that question the components of CT. Although algorithmic thinking and CT represent separate understandings, the thought processes involved in solving a problem include certain types of calculations, abstractions, generalizations, decompositions, and evaluations performed by the computer and human brain together with algorithms (Curzon & McOwan, 2017). The collaborative work presented by CSTA and ISTE (2011) considers CT as a problem process while (i) formulating problems to be able to solve them with the help of computers or other tools, (ii) logically organizing and analyzing data, (iii) data through simulations and models. (iv) automate solutions depending on the algorithmic thinking framework, (v) identify, analyze and apply optimal solutions using resources effectively, and (vi) transfer and generalize the found solution to different problems (p. 1). According to Cetin and Toluk-Uçar (2022), although there is no definite opinion on what the components of CT will be, they state that the components of abstraction, algorithmic thinking, problem-solving, problem separation, pattern recognition and generalization, and evaluation are widely accepted in the literature.

Abstraction is crucial in distinguishing CT from other skill types (Grover & Pea, 2013). The abstraction component can be explained as ignoring or debugging ineffective elements in achieving the goal. Abstraction allows the problem to be simplified by ignoring specific details of the problem (Cetin & Toluk-Uçar, 2022). Algorithmic thinking is solving the rules and the steps to be followed by the rules, solving problems, and making sense of the problems (Csizmadia et al., 2015). In other words, it is the production of solution steps that an information-processing unit can operate to solve particular problems (Cetin & Toluk-Uçar, 2022, p. 65). Decomposition attempts to solve the problem by dividing it into simpler units. Thus, instead of dealing with a complex problem, complexity is reduced by solving more straightforward problems at every stage, and an easier and faster solution can be reached. Therefore, the fundamental problem is divided into small parts, and the solution to the fundamental problem is reached (Selby & Woollard, 2013). Pattern recognition and generalization identify similarities, differences, or data rules. Therefore, finding a pattern is essential for the solution to the problem, and as the number of patterns increases, the solution to the problem will be easier and faster (Kalelioglu, Gulbahar & Kukul, 2016). On the other hand, producing solutions to new problems by using the solved problems is called generalization (Csizmadia et al., 2015). Generalization is evaluated in numerical, spatial, or logical relations that are always true in a specific field (Cetin & Toluk-Uçar, 2022, p. 70). In this respect, pattern recognition and generalization skills are described as the core capacity of individuals (Greenspan & Shanker, 2007). Evaluation is the general judgment reached from the study on the quality or quantity of something. Evaluation is a crucial concept in CT (Selby & Woollard, 2013) because algorithms that are solutions to a particular problem should be tested again if they are sufficient to solve the problem when desired to be used later.

1.3. Computational Thinking in Education

Since 2006 awareness of the concept of CT began, there have been many changes in the contents of the curriculum. CT activities have been given more place in the curriculum, mostly in high school curricula and undergraduate programs (Grover & Pea, 2013). Since 2006, American computer scientist Jeannette Wing put forward her claim that CT should be taught to every student as a basic skill (Wing, 2006). In this context, although there is still no consensus on how CT should be included in curricula, there are frequent discussions about which processes should be followed in teaching CT, to whom it will be taught, how it will be included in curricula and what will be included in its content (Agbo et al., 2021; Atmatzidou, & Demetriadis, 2016; Czerkawski & Lyman, 2015; Lockwood & Mooney, 2018; Mannila et al., 2014; Vieira & Hai, 2023). Especially with the widespread/easier use of information tools and the development of computer technology, improving individuals' technological competencies has also increased the interest in integrating CT into curricula (Kong, Chiu & Lai, 2018). Three aspects of CT concerning the curriculum have been clarified; computer science (CS), information technology (IT), and digital literacy (DL). Within the scope of CS, it is evaluated that all individuals can understand and apply the basic principles/concepts of computer science, including the ability to abstract, knowledge of logic, the level of using algorithms, and the organization of data. At the same time, it is emphasized that individuals can distinguish the nature of problems using computational terms effectively and understand the programming language using information tools to solve problems. Within the scope of IT, it is stated that all individuals can understand the structure of information tools at an analytical level and use the opportunities offered by information tools to display realistic approaches to the problems that arise in a particular field. Within the scope of DL, it is stated that all individuals can increase their proficiency in using information tools, evaluate the features of information tools from a different perspective, and have good mental practice (Berry, 2013, p. 5).

Today, depending on technological development, there are radical changes in the content of engineering applications in the curriculum of many nations. Especially in the digital world, the sharp evolution of the value sets, which has become a necessity, accelerates this process even more. In this direction, digital learning tools, especially robotic applications, have become an important goal in developing students' CT in many primary and secondary schools (Wang, 2023). Therefore, computer science, information technology, and software began to find a severe response in curricula (EC, 2008; MoNE, 2018; OECD, 2018). With the understanding that CT-based information and communication technologies education will enable individuals to be more successful and productive in their working lives, innovative changes are also obligatory for nations. Because the CT style does not represent only a single study area or a single teaching style; on the contrary, it has a structure that is applied in a wide area covering more than one study area (Hsu, Chang & Hung, 2018), today, many scientific steps widely accept the benefits of CT on individuals. There are current debates on how to promote their teaching effectively. Since many teachers are familiar with original teaching methods, it seems challenging to integrate CT into all curricula quickly (Denning, 2017). However, educators and researchers who adopt the cognition perspective believe that CT can be improved if it is channeled with the help of rich perceptual experiences (Deng, Guo, Cheng & Zhang, 2023). Although we are in the first years of the information age, with the definition of CT becoming more understandable, program makers, instructors, and field researchers have made an intense effort to integrate CT into learning environments (Payne, Tawfik & Olney, 2022; Weintrop et al., 2016). Moreover, encouraging steps are taken in this direction, paving the way for CT to occur more in learning environments.

1.4. Literature Review on Computational Thinking

In the last ten years, there has been progress in the awareness of CT and the number of scientific studies/publications carried out accordingly. The volume of studies focusing on CT is increasing, especially in understanding its effect on academic success (Lei, Chiu, Li, Wang & Geng, 2020). When the contents of these studies are examined, it is noteworthy that the development of individuals' CT skills, the effect of technological applications on individuals' CT, integrating CT into curricula, and its relationship with some variables (attitude, motivation, anxiety, STEM, 21st-century skills, gender *etc.*) are emphasized. Virtual reality and robotics applications, programming language tools (allice, scratch, vimap, matlab *etc.*), and digital game-based designs (Andersen, 2022; Agbo et al., 2021; Agbo et al., 2023; Aminah, Sukestiyarno, Cahyono & Maat, 2023; Broza, Biberman-Shalev & Chamo, 2023; Cheng et al., 2023; Fidai, Capraro & Capraro, 2020; Wang, 2023), integration into the curriculum (Grover & Pea, 2013; Lockwood & Mooney, 2018; Mannila et al., 2014; Vieira & Hai, 2023; Vinnervik & Bungum, 2022; Voogt et al., 2015), interdisciplinary collaboration and learning approaches (project-based, problem-solving, collaboration *etc.*) (Hava & Ünlü, 2021; Kong et al., 2018; Kwon, Ottenbreit-Leftwich, Brush, Jeon & Yan, 2021; Wang, 2023; Weintrop et al., 2016) and assessment of practice/training (Deng et al., 2023; Kong et al., 2018; Kong & Wang, 2023; Peng, Murti, Silitonga & Wu, 2023; Tadeu & Brigas, 2022) are other prominent topics in CT.

There are also study findings similar to our study topic in the literature. For example, a review based on CT skills was done in the empirical study by Ye, Lai, and Wong (2022). The findings indicate that students who develop CT skills positively affect their cognitive learning development, even in areas where CT is unnecessary. At the end of the bibliometric analysis, which includes the issue of CT by Ozcınar (2017), it was determined that CT is being studied more and more widely in education and computer science. The systematic literature review conducted by Top and Arabacıoglu (2021) determined that the number of studies on the subject of CT increased compared to previous years. At the end of the study, it was reported that many studies were conducted with secondary school students, and Likert-type measurement tools were frequently used. Chen et al. (2023), the evolutions in the studies on CT in the period from 2012 to 2021 were examined using the retrospective analysis method. Accordingly, the bibliometric features of 249 studies in the WoS database were analyzed. At the end of the study, it was determined that CT showed an increasing trend in the last ten years. In addition, it has been determined that there has been progressing in the number of studies on the importance of CT in kindergarten, primary, secondary, and high school education and that the publishers of Communication of the ACM, Computers and Education and Computers in Human Behaviors have high common citations. In CT, it has been determined that the study by Grover and Pea (2013) has made significant contributions to the field, and the research done in the USA, China, Turkey, Spain, and Australia are well organized. In the study by Tosik-Gün and Güyer (2019), a systematic literature review examined 47 studies accessed from Scholar Google, WoS, and ERIC databases. According to the analysis results, it has been determined that the most evaluated components of CT skills are abstraction, algorithmic thinking skills, breaking into small pieces, testing accuracy, clearing error/incorrect situations, and data collection tools/data literacy.

Hsu et al. (2018) conducted a meta-review. At the end of the examination of the studies covering the years 2006-2017, it has been determined that the usage areas of CT are increasingly diversified, and decisive steps have been taken in this direction. Lee et al. (2022) determined that although educational interventions in CT education are not always successful, in general, CT education has a valuable contribution to students' producing different ideas, flexible thinking, and expressing other thoughts by influencing their cognitive thinking habits. In the study conducted by Tekdal (2021) to determine the general view of the publications in the Scopus database, it was determined that the number of studies with CT had increased exponentially since 2013. It has been determined that the USA is the country that stands out in the studies and that the investigations take place more in educational technology journals. The thematic analysis of CT was made in the survey by Usta and Düzalan (2021). In the study covering the years 2012-2020, it was seen that the interest of researchers in studies on mathematics education was high, and the popularity of CT increased. Roig-Vila and Moreno-Isac (2020) examined the reflections in the education category in the WoS database with the literature analysis method. According to the research findings, it has been determined that Spain, where the tendencies towards CT are increasing, attracts attention as a productive country. Saqr, Ng, Oyelere, and Tedre (2021) reviewed 1874 documents on CT accessed from the Scopus database. It has been determined that CT is USA-centered, and USA researchers' dominance in the field continues. Although international collaboration is relatively small, it has been found that joint research clusters have formed between some Scandinavian countries, lusophone and hispanophone countries (Portugal, Brazil, Latin America *etc*.), and central European countries. Bibliometric analysis was performed by downloading the articles in the Scopus database on CT between 1987-2023 by Rafiq, Triyono, Djatmiko, Wardani & Köhler (2023). The study's findings showed diversity in the uses of CT (education, engineering, computing). It has been determined that the USA hosts publications that significantly contribute to the field, and words such as CT-engineering-education-mathematics are used more as the preferred keywords in the studies. The articles in the Scopus database were examined in the survey conducted by Kusnan & Tarmuji (2022). It has been determined that the studies on CT between 2006-2020 have increased continuously since 2006. In this regard, it has been determined that while the USA is a productive country, the People's Republic of China follows this country. In this area, it has been determined that the most publications are the ACM International Conference Proceedings Series. Research on CT has generally been evaluated within the scope of scientific productivity and network analysis. In this study, unlike other studies; it was examined with the help of bibliometric analysis under the headings of scientific productivity, network analysis, conceptual structure and thematic map.

1.5. Statement of the Problem

In bibliometric analysis studies, it provides a framework in which it is aimed to reveal the scientific quality in terms of statistics such as author, subject, subject headings, citation information, effects of sources, keywords, publication language of the articles, co-author information, publication years of the articles, information about the institutions and countries of the authors. This type of research provides scientific data to be obtained with the help of quantitative analyzes on the relevant subject (Bouyssou & Marchant, 2011). Bibliometric studies allow quantitative evaluation of qualitative dimensions such as scientific quality or effectiveness/effectiveness of the subject chosen by the researcher (Zhao & Strotmann, 2015). In this respect, the findings of scientific studies in databases, considered necessary in the field, guide both researchers and readers and make it possible to follow the developments in the field. Therefore, it is crucial to follow the publications in critical databases to obtain information about the general status of a scientific subject. In this way, the findings reveal that discipline's change, development, and dominant trends over time and provide a solution-oriented discussion opportunity by identifying existing problems, if any. In this respect, the study's starting point is to examine scientific studies published from the past to present on CT from a bibliometric perspective and to determine their tendencies. The study will guide the field experts to determine the current study topics for the relevant field. Examining scientific studies on CT indexed in the WoS database has a scientific necessity and importance in determining the international effectiveness of the field, the trends, and the visibility of changes. This study will both accelerate the studies in the field and guide by contributing to the effective development of the field.

1.6. Purpose and Problem of the Study

The study evaluated documents listed in the WoS database on CT according to performance-based descriptive statistical findings, network analyses, conceptual structure, and thematic mapping. In this direction, 3123 scientific documents published from 2006 to the present, the annual number of publications and citations, productive authors, the most cited studies, the countries of the responsible authors, the authors who have assumed the dominant role, productive institutions, geographical distribution, joint citation, collaboration, and word analysis, The trend was examined according to the topic and thematic changes, conceptual structure and thematic mapping. The identified research questions (RQ) of the study are as follows:

RQ 1. What is the CT scientific documents distribution according to years and the number of citations?
RQ 2. What authors, studies, institutions, and countries have contributed to CT?
RQ 3. Which authors and sources interact with the topic of CT?
RQ 4. What is the collaborative working profile of authors, institutions, and countries on CT?
RQ 5. What are the co-keywords and co-occurrence profile in studies on CT?
RQ 6. What are the trending topics and thematic changes in CT research?
RQ 7. How do the conceptual structure and thematic map in CT research change?

2. METHODOLOGY

This study conducted a descriptive and cross-sectional but retrospective bibliometric analysis by analyzing documents published on CT from the past to the present (18.05.2023). Bibliometrics, which makes it possible to examine the scientific literature and the authors who produced them, according to statistical procedures, was used. Bibliometric analyses enable readers and researchers to gain a holistic view of the research topic (Chen, Yu, Cheng, & Hao, 2019). This analysis consists of collecting, processing, and evaluating bibliographic contents obtained from scientific studies (Verbeek, Debackere, Luwel & Zimmermann, 2002). The general lines of the study subject are simplified by examining the social and structural associations formed between the standard components of bibliometrics (Donthu, Kumar, Mukherjee, Pandey & Lim, 2021, p. 287). From this perspective, it is a beneficial and effective application technique in defining the relevant field. (Donthu et al., 2021; Grzybowska & Awasthi, 2020). Bibliometric analyses contain dynamic and structural strengths (Chaparro & Rojas-Galeano, 2021). In dynamic analysis, impact values such as scientific production network (publication, citation, author, keyword *etc*.) and general views of terms are examined (Jamali, Ebrahim & Jamali, 2022). In the structural analysis section, indicators such as word trees, interaction networks, conceptual structure formation, thematic change, and collaboration/co-citation networks are examined

(Jamali et al., 2022). The research framework proposed by Arksey and O'Malley (2005) was used as a guide in the study. The basic framework of the research is defining the research question, accessing the study subject and documents from the decided databases, deciding on the study selection, creating the research set from the databases, general analysis of the data set, evaluating the data set, reporting according to the findings, discussing the findings and reviewing the processes. The primary purpose of following the forming processes in this way is to ensure the reliability of both the data set and the study. The process information, which includes the basic framework of the research, is given below (Figure 1).

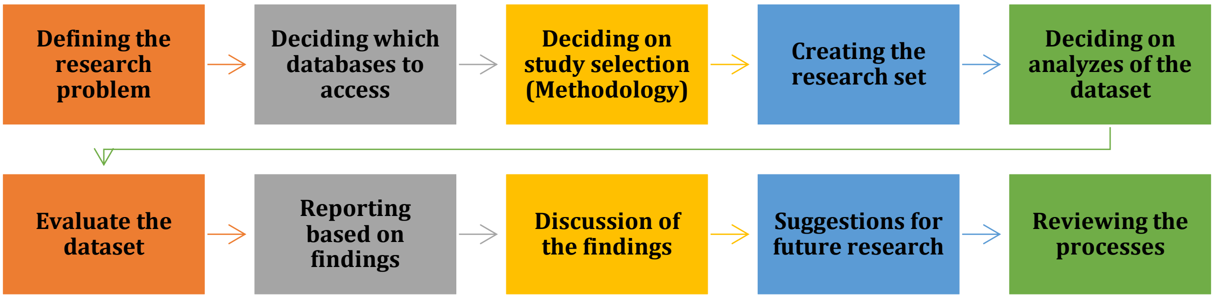

Figure 1. The Basic Framework of the Research

2.1. Data Collection and Procedure

The Web of Science™ Core Collection database was used to obtain the dataset related to CT. The WoS™ database has been preferred as a search engine because it is a well-known and popular database to examine published scientific articles in detail (Zhu & Liu, 2020). These databases allow statistical and mathematical techniques in accordance with the nature of bibliometric analysis on the determined subject. The WoS database is globally accepted and includes many disciplines in Clarivate Analytics. Similarly, the WoS™ database facilitates access to scientific studies and generates information with its data quality and advanced analytical technology. Among the fundamental reasons for using this database in the study are the presence of many subject categories, the possibility of accessing peer-reviewed full-text available versions, the presence of prestigious journals recognized in the world, the presence of publisher business partners, the compatibility of data record sets with statistical programming languages, and a large number of reference information. (Web of Science Group [WoSG], 2023). The strength of the WoS™ database is that it is easy to access, includes valuable studies in the field, and includes detailed information to ensure consistency within itself (Zhao & Strotmann, 2015; Zhu & Liu, 2020). In addition, it allows researchers to analyze, evaluate and record the information related to the study subject in depth, allowing statistical data analysis (Fang, Zhang & Qiu, 2017). Due to these features, WoS database was preferred in the research.

Within the scope of the research, the title, keywords, and summary sections were determined as the priority criteria taken into account in creating the data set. In our study, primarily scientific records on CT were searched in the WoS™ database. Accordingly, a preliminary search was performed by typing the -Topic = [Title-Abs-Key ("computational thinking")]- command in the search module of the WoS™ database. All categories in the database were included in the search. The topic title [title, abstract, author keywords, keywords plus] was considered in the search. As a result of the pre-scan, 3674 documents [proceeding paper: 1669; article: 1558; early access: 134; review article: 112; book chapters: 78; editorial material: 69; meeting abstract: 27; book review: 9; corrections: 8; letter: 7; book: 2; biographical-item: 1; reprint: 1] has been accessed. In the research, no restrictions were made to WoS Index. Titles in WoS indexes: Conference Proceedings Citation Index-Science (CPCI-S) [1410], Social Sciences Citation Index (SSCI) [691], Conference Proceedings Citation Index-Social Science & Humanities (CPCI-SSH) [559], Emerging Source Citation Index (ESCI) [525], Science Citation Index Expanded (SCI-Expanded) [376], Book Citation Index-Social Sciences & Humanities (BKCI-SSH) [72], Book Citation Index-Science (BKCI-S) [22] and the Arts & Humanities Citation Index (A&HCI) [19]. When the contents of the studies conducted in the pre-screening were checked, it was determined that no document in 2006 was accepted as the starting point of the concept of CT. Therefore, the time interval, one of the search criteria, has been determined as the time interval from 2006 to the present [18.05.2023]. As with other criteria, the writing language of the studies was "English", and the document type was "article" and "proceeding paper". In order to reach more studies and to see the field from a broader perspective, not only articles but also papers were included in the study. When the selection was repeated, depending on the determined criteria, 3123 documents were accessed. These obtained data formed the final study set. The figure reflecting the research criteria is shown below (Figure 2).

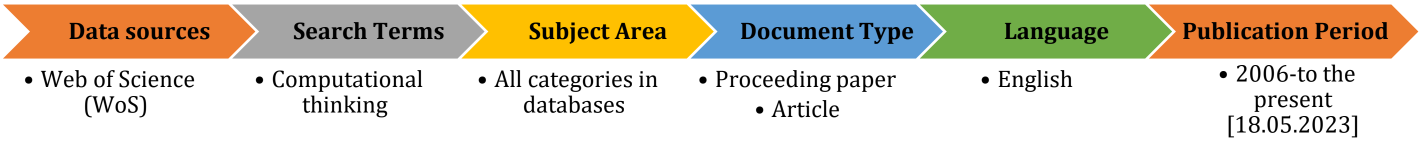

Figure 2. Information on Research Criteria

In the last step of the research, the data downloaded from the WoS™ database were saved in the "Plain Text" format. This format type is used to evaluate documents as it is compatible with VOSviewer and RStudio applications. With the help of the final data, bibliometric analyzes related to the research topic were carried out. Detailed information about the processes followed in the data analysis is explained in detail in the title of the data analysis process below.

2.2. Data Analysis Process

The study used documents from the WoS™ Core Collection database for data analysis. Within the scope of the survey, bibliometric analysis was used, which helps to understand the changes experienced in the information structure and research areas in written documents (Pritchard, 1969). In this way, it helps to reveal the general structure of many disciplines. In our study, the bibliometric analysis process was structured in four steps. First, the data set was accessed from the database to evaluate the study subject. According to the determined criteria of the research [Document Type: Articles, Proceeding Paper; Language: English; Publication Period: 2006 to the present (18.05.2023)], 3123 scientific documents were reached. Analysis was performed because there were no duplicate data in the WoS™ database. In the next stage, pre-descriptive statistical applications based on performance were carried out. In this context, the annual number of publications and citations of scientific documents published on CT, productive authors, the most cited studies, responsible authors by country, dominant authors by years, effective institutions, and countries are included. In another step, network analyses were carried out. Co-citation network analysis, co-author network analysis, geographic atlas, co-word network analysis, trend topic, and thematic change analyses cited within the scope of network analysis are included. In the last stage, the conceptual formation and thematic outlines of CT are given. Information about the analysis process is summarized below (Figure 3).

Figure 3. Steps Followed in the Analysis Process

Performance-based descriptive analyses and scientific mapping techniques were used to evaluate the data set. VOSviewer 1.6.18 software was used to visualize the similarities of the data set in dynamic and structural analyzes (Van Eck & Waltman, 2010). The items included in the analysis of the VOSviewer program are in the form of labels and circles. The size of the circle indicates the weight of the item. The program calculates the colors in the network analysis visualization and represents clusters of similar items. The distance between the items represents the strength of the articles (Yuan, Bie & Sun, 2021). On the other hand, the R-tool 4.3.0 software of the Bibliometrix package, which was designed for quantitative bibliometrics research, was preferred in evaluating the data set (Aria & Cuccurullo, 2017). VOSviewer [https://www.vosviewer.com] and R-tool [www.rstudio.com] tools, preferred in bibliometric analysis, are open-access and free applications researchers frequently prefer. VOSviewer software allows direct viewing and evaluating of large maps to facilitate understanding datasets (Van Eck & Waltman, 2010). This way, a holistic approach is displayed in the visualization of large data groups. Thanks to the RStudio software included in the Bibliometrix software application, more comprehensive evaluations of the quantitative analyzes related to the research subject are made. Comprehensive explanatory information of the data set is given in the figure below (Figure 4).

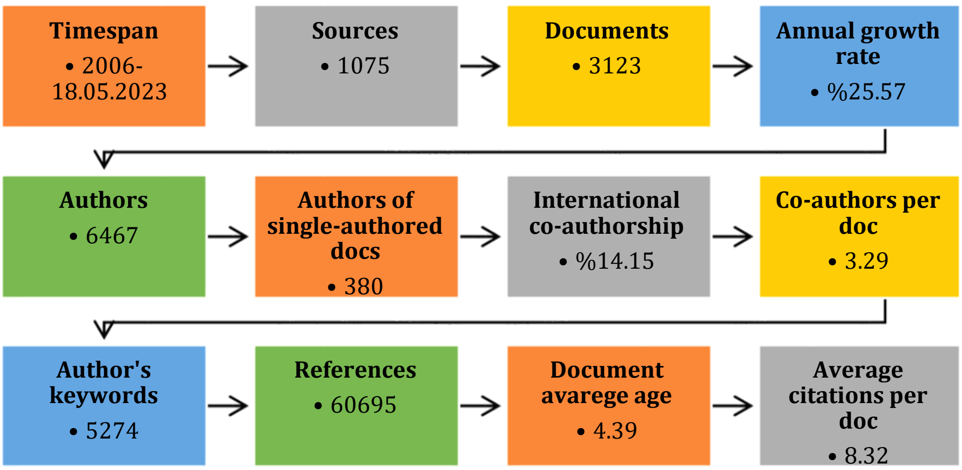

Figure 4. Descriptive Main Information on CT

Since 2006 was accepted as the starting date for CT to take its place in the literature, 2006 was preferred as the start of data collection. When Figure 4 is evaluated in general, 3123 scientific articles and proceeding papers were handled by 6467 authors in the data analysis of the studies conducted since 2006. While the cooperation index between the authors was 3.29, the percentage of international cooperation was determined as 14.15%. Thematic and strategic diagram analyses have been included in the analysis of scientific studies since 2006. This structure, proposed by Law, Bauin, Courtial & Wittaker (1988), reveals dynamic cluster formations by analyzing keywords or coaxial words. Identified cluster formations allow the evaluation of the general lines of the study subject (Gonzales-Valiente, 2019). Conceptual maps divide the content determined by the researcher into information sets, provide elaboration of the conceptual structure of the research topic and provide comprehensive findings for interpreting the content (Wetzstein, Feisel, Hartmann & Benton, 2019). Findings from a descriptive social network, conceptual structure, and thematic mapping analyses provide valuable clues to reveal valuable patterns in revealing future research areas (Khan & Wood, 2016). Therefore, care has been taken to use rich data analyses to provide in-depth information and evaluations about CT, which is the subject of our research.

2.3. Validity and Reliability

Validity is accepted as one of the essential criteria in the conduct of a study. Within the scope of the study's validity, detailed information about how the data were obtained and the process of getting the data were presented. In this context, the website from which the data set was accepted and the date it was collected are stated. In order to make the external validity of the research reliable, explanations about how the data was analyzed, how the data were obtained, the criteria taken into account in the selection of the data, the justification of the research method, and data analysis tools were made in detail. In order to increase the reliability of the research, the findings obtained from the data set were presented without comment, and attention was paid to the consistency between the obtained data and discussed in accordance with the literature in the conclusion section. In addition, web addresses containing detailed information about the preferred software in the data analysis were specified, and detailed features of the software were clarified. The reliability of the study was tried to be increased by including the program information used under the screenshots containing each analysis. In addition, the preferred threshold values in common citation and collaboration network analyses and calculations based on keywords are indicated in parentheses under each analysis image. In this way, the internal reliability of the research was tried to be increased.

3. FINDINGS

This section presents the findings obtained for the sub-problems in CT with their explanations. First, under the title of scientific productivity, the distribution of articles published on CT by years and citation numbers, the results for the authors, studies, institutions, and countries that contributed the most are given. At another stage, co-citation and co-author analyzes were included under the title of network analysis. Under the heading of keyword and co-occurrence analysis, cooperation networks between institutions and countries and word cloud analyses are included. Under the trending topic and thematic change heading, trending keywords and article titles in CT were analyzed. The last chapter analyses the conceptual structure and thematic mapping of scientific articles published on CT.

3.1. Scientific Productivity on Computational Thinking

The figure below shows the number of annual publications and citations on CT from the past to the present (18.05.2023). In our study, the date when the subject of computational thinking was defined by Wing in 2006 and brought to the literature was taken into consideration. In this context, the documents published on computational thinking since 2006 have been analyzed descriptively. According to the data obtained from the WoS database, the annual production and annual citation numbers related to the study subject are indicated in different colours.

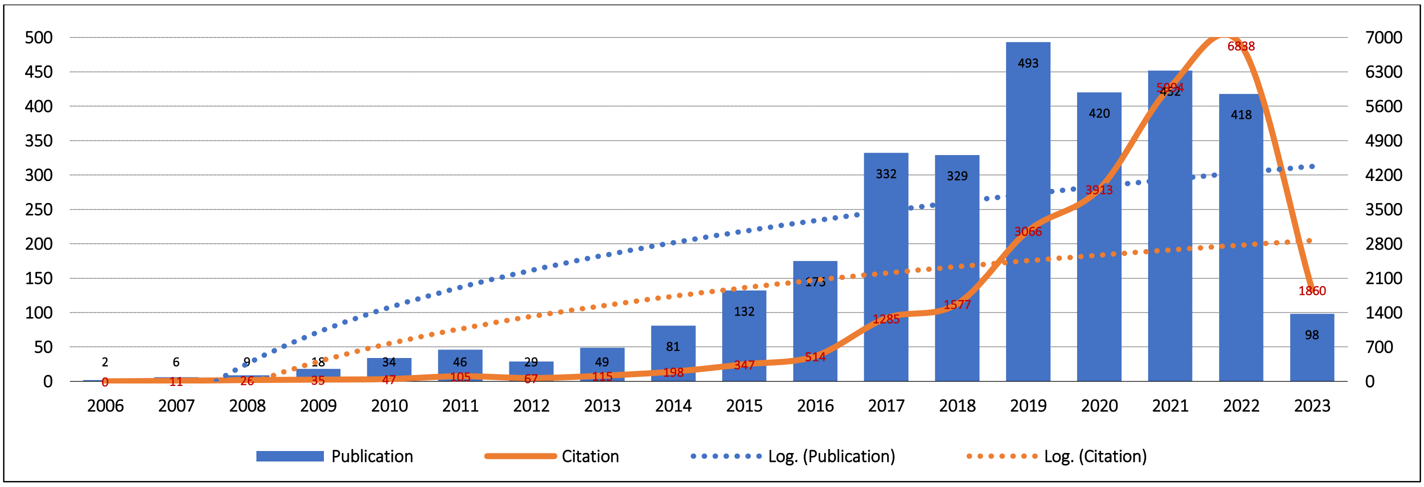

Figure 5. Productivity and Citation Count by Year in CT

Figure 5 shows the results regarding the values of published studies on CT. Accordingly, it is observed that there has been a marked increase in the number of publications, especially since 2014. The number of publications peaked in 2019 and decreased in 2020 compared to the previous year. The number of publications, which started to increase again in 2021, showed a slight decrease in 2022 compared to last year. When the annual number of citations is taken into account, it is seen that the number of citations has been on an increasing trend since 2006. The logarithmic values for 2023 show that the number of publications and citations will continue to increase. It is noteworthy that there has been an increase in the volume of citations due to the increase in the number of published studies. It has been determined that there has been a significant increase in the number of citations, especially since 2016. The table below gives information about prominent authors in CT (Table 6).

Table 1.
Most Productive Authors on CT

Authors	Publications	Publications Fractionalized
Dagiene, V.	32	11.91
Biswas, G.	24	6.00
Kong, S. C.	24	10.49
Sabitzer, B.	24	7.28
Yadav, A.	23	6.80
Garcia-Penalvo, F. J.	21	12.18
Robles, G.	21	6.76
Roman-Gonzalez, M.	21	6.08
Repenning, A.	19	7.16
Bers, M. U.	17	8.33
Franklin, D.	17	3.53
Grover, S.	17	5.81
Moreno-Leon, J.	17	5.73
Weintrop, D.	17	4.10
Barnes, T.	16	2.86
Li, Y.	16	5.92

Table 1 shows the authors who have contributed the most to CT since 2006 and their related publications. These authors are core and have an important place in the field. Within the scope of our study, Egghe's (1987) formula [0.749*√Pmax] Pmax was used to determine the minimum number of publications of a core author. Accordingly, since the number of documents published by Dagiene Valentine is the highest, the Pmax value was determined as 32. The minimum number required for an author to qualify as a core author is calculated as 4. Since there will be a large number of author additions, the number of documents of the author is limited to 16 to make the table above understandable. Core authors make up more than half of the published documents on CT. According to the data in the table, Dagiene, V. (32), Biswas, G. (24), Kong, S. C. (24), Sabitzer, B. (24), and Yadav A. (23) are the authors who contributed the most to this field. These authors are respectively Garcia-Penalvo, F. J., Robles, G., Roman-Gonzalez, M. (21), Repenning, A. (19), Bers, M. U., Franklin, D., Grover, S., Moreno-Leon, J., Weintrop, D. (17), Barnes, T., and Li, Y. (16) follow the authors. The table below gives information about the prominent publications regarding citation (Table 2).

Table 2.
Most Cited Publications on CT

Publication	Doi	Total Citations	TC per Year	Normalized TC
Wing, J. M., 2006	10.1145/1118178.1118215	2497	138.72	2.00
Wing, J. M., 2008	10.1098/rsta.2008.0118	668	41.75	8.46
Weintrop, D., 2016	10.1007/s10956-015-9581-5	489	61.13	28.35
Bers, M. U., 2014	10.1016/j.compedu.2013.10.020	372	37.20	22.27
Roman-Gonzalez, M., 2017	10.1016/j.chb.2016.08.047	271	38.71	22.29
Sengupta, P., 2013	10.1007/s10639-012-9240-x	221	20.09	25.30
Atmatzidou, S., 2016	10.1016/j.robot.2015.10.008	220	27.50	12.76
Saez-Lopez, J. M., 2016	10.1016/j.compedu.2016.03.003	209	26.13	12.12
Voogt, J., 2015	10.1007/s10639-015-9412-6	188	20.89	12.81
Yadav, A., 2014	10.1145/2576872	181	18.10	10.84
Aho, A. V., 2012	10.1093/comjnl/bxs074	176	14.67	11.34
Chen, G. H., 2017	10.1016/j.compedu.2017.03.001	172	24.57	14.15
Korkmaz, O, 2017	10.1016/j.chb.2017.01.005	158	22.57	12.99
Grover, S., 2015	10.1080/08993408.2015.1033142	158	17.56	10.77
Kalelioglu, F., 2015	10.1016/j.chb.2015.05.047	156	17.33	10.63

Table 2 shows detailed information about the most cited authors. According to the data, the most cited work was published by Wing in 2006 (138.72 citations per year). This is followed by the study published by Wing in 2008 (41.75 citations per year) and the study published by Weintrop in 2016 (61.13 citations per year). It is also heavily cited in studies published by Bers (37.20 citations per year), Roman-Gonzalez (38.71 citations per year), Sengupta (20.09 citations per year), Atmatzidou (27.50 citations per year), Saez-Lopez (26.13 citations per year) and Voogt (20.89 citations per year). Similarly, Yadav (18.10 citations per year), Aho (14.67 citations per year), Chen (24.57 citations per year), Korkmaz (22.57 citations per year), Grover (17.56 citations per year), and Kalelioglu (17.33 citations per year) are highly cited authors. Published studies include studies with a single author and more than one author. The following figure shows the distribution of responsible authors by country (Figure 6).

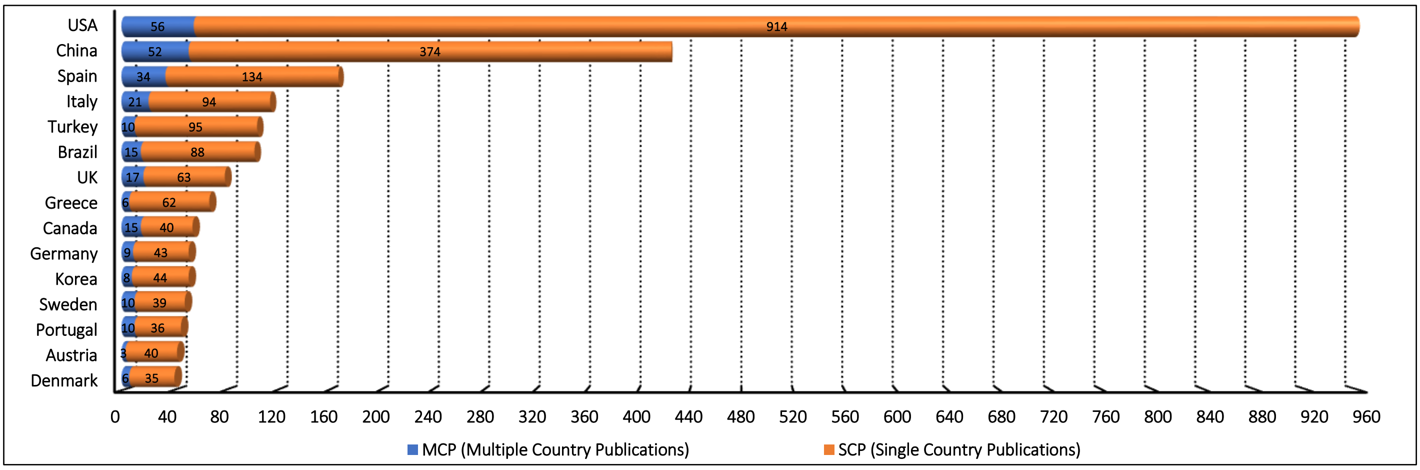

Figure 6. Number of Responsible Authors by Country on CT

Figure 6 shows the number of responsible authors working on CT. It was determined that the number of single country authors was higher. Corresponding authors are mostly USA (*n*=970), China (*n*=426), Spain (*n*=168), Italy (*n*=115), Turkey (*n*=105), Brazil (*n*=103), United Kingdom (*n*= 80), Greece (*n*=68), Canada (*n*=55), Germany (*n*=52), Korea (*n*=52), Sweden (*n*=49), Portugal (*n*=46), Austria (*n*=43) and Denmark (*n*=41) countries. The figure below shows the distribution of authors who dominated CT at certain time periods (Figure 7).

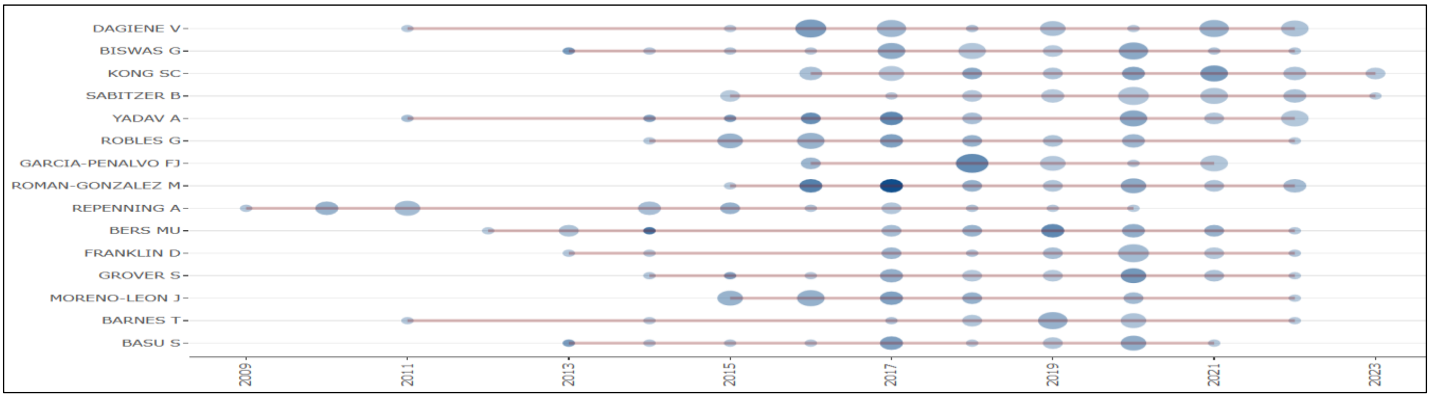

Figure 7. Authors' production Over Time on CT

Figure 7 shows the authors who assumed the dominant role over time. For studies with multiple authors in the dominant role, the first author is considered and determined by the ratio of studies with multiple authors to the total number (Kumar & Kumar, 2008). When the figure is examined, Dagiene between 2011 and 2022, Biswas between 2013 and 2022, Kong between 2016 and 2023, Sabitzer between 2015 and 2023, Yadav between 2011 and 2022, and Robles between 2014 and 2022 between the years 2009 and 2020. Repenning, Bers from 2012 to 2022, and Franklin from 2013 to 2022 are the dominant authors. Apart from these, dominant writers periodically draw attention. For example, Dagiene and Yadav in 2022, Dagiene and Kong in 2021, Garcia-Penalvo and Bers in 2018 in 2020, and Repenning in 2011 take an essential place as dominant authors. Information about the institutions that are productive in CT is given in the figure below (Figure 8).

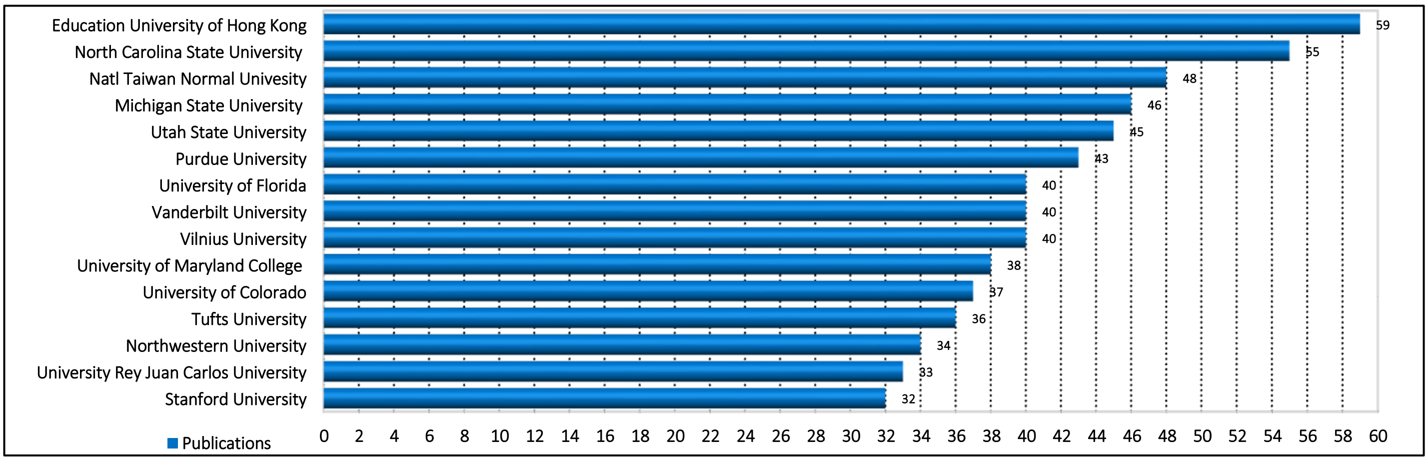

Figure 8. Most Relevant Affiliations Over Time on CT

According to Figure 8, it is understood that the institution that has done a lot of work on CT is the Education University of Hong Kong (59 publications). This is followed by North Carolina State University (55 publications), Natl Taiwan Normal University (48 publications), Michigan State University (46 publications), Utah State University (45 publications), Purdue University (43 publications), and University of Florida (40 publications), Vanderbilt University (40 publications) and Vilnius University (48 publications) follow. Below is a geographical atlas of the documents published on CT (Figure 9).

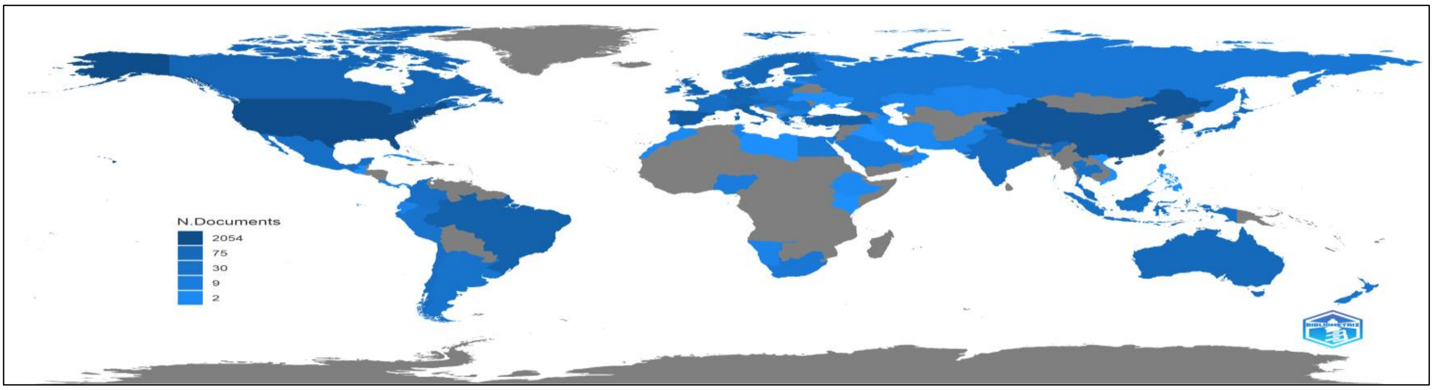

Figure 9. Country Scientific Production

According to Figure 9, it is understood that the products of the USA (2054) on CT are far ahead. This is followed by China (790), Spain (362), Brazil (208), Italy (204), Turkey (188), United Kingdom (149), Portugal (130), Germany (116), Greece (115), Canada (112), Sweden (97), South Korea (91), Switzerland (86), Netherlands (83), Austria (79), Finland (78), Australia (74), Israel (72), Norway (66), India (62) and Japan (59). When the geographical map is evaluated in general terms, it is understood that many continental countries have been working on CT and these studies have been published. In this respect, it can be said that studies on CT have a widespread impact.

3.2. Network Analysis on Computational Thinking

3.2.1. Co-citation networks

It is aimed to determine the situation experienced when citing two scientific publications together with the co-reference determined with the help of network analysis. In this analysis, the effect of the number of citations made to two different studies/publications in a source or the citation image/network of two studies together creates a joint citation (Bagıs, 2021). The network structure that occurs when two authors are cited together in a third source indicates the coexistence of co-citation. In this section, the analyzes of the authors and sources cited within the scope of co-citation are given. Network visualizations of co-citation analysis according to defined criteria (authors and institutions) are shown in the figures below (Figure 10-11).

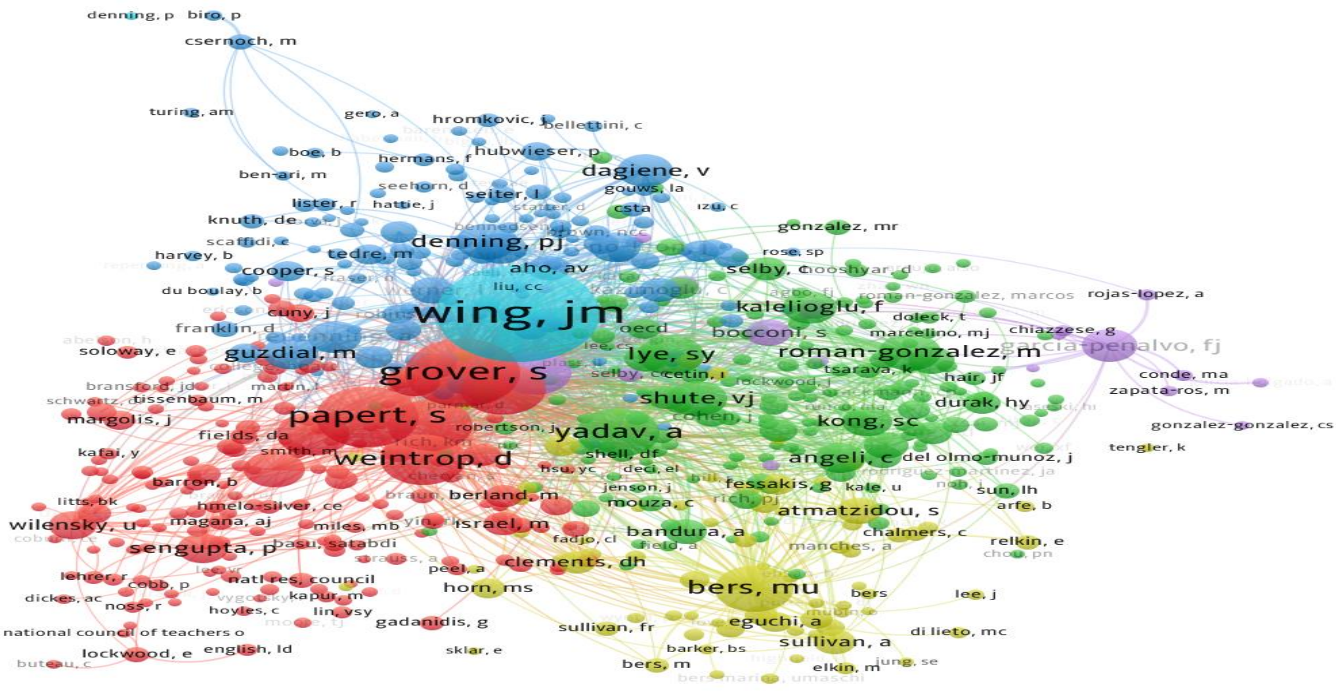

Figure 10. Co-Cited Authors Network on CT (≥20)

When Figure 10 is examined, it is seen that six different colored clusters are formed. The analysis program reveals six different clusters. The node's width in the cluster indicates that the responsible authors are in an important position. On the other hand, the proximity of the nodes indicates that the authors discussed common issues. This is called the "homophily effect" (Findlay & van Rensburg, 2018). For example, nodes representing the authors of Grover, S., and Papert, S. are very close together, creating a possible homophily effect. Authors such as Grover, S., Papert, S., Brennan, K., Weintrop, D., and Resnick, M. dominate the red-colored cluster formed at the end of the network analysis. In the Cyan colored set, the author Wing, J. M., strongly influences and establishes strong connections with other authors. In addition, this cluster is located in the central position and interacts intensely with other clusters. It is seen that the authors Roman-Gonzalez, M., Yadav, A., Kalelioglu, F., Lye, S. Y., and Shute, V. J. stand out in the green-colored cluster. In the yellow cluster, the author Bers, M. U. is centrally located and has strong links with authors such as Atmatzidou, S., Sullivan, A., and Clements, D. H. In the purple set, the author of Garcia-Penalvo, F. J., is prominent, while in the blue-colored set, the author of Denning, P. J., is more dominant. Authors who occupy a central position in each cluster are considered influential because they "tend to anchor their community" (Mostafa, 2020, p. 664). Information on the network structure formed according to the resource criteria is given in the image below (Figure 11).

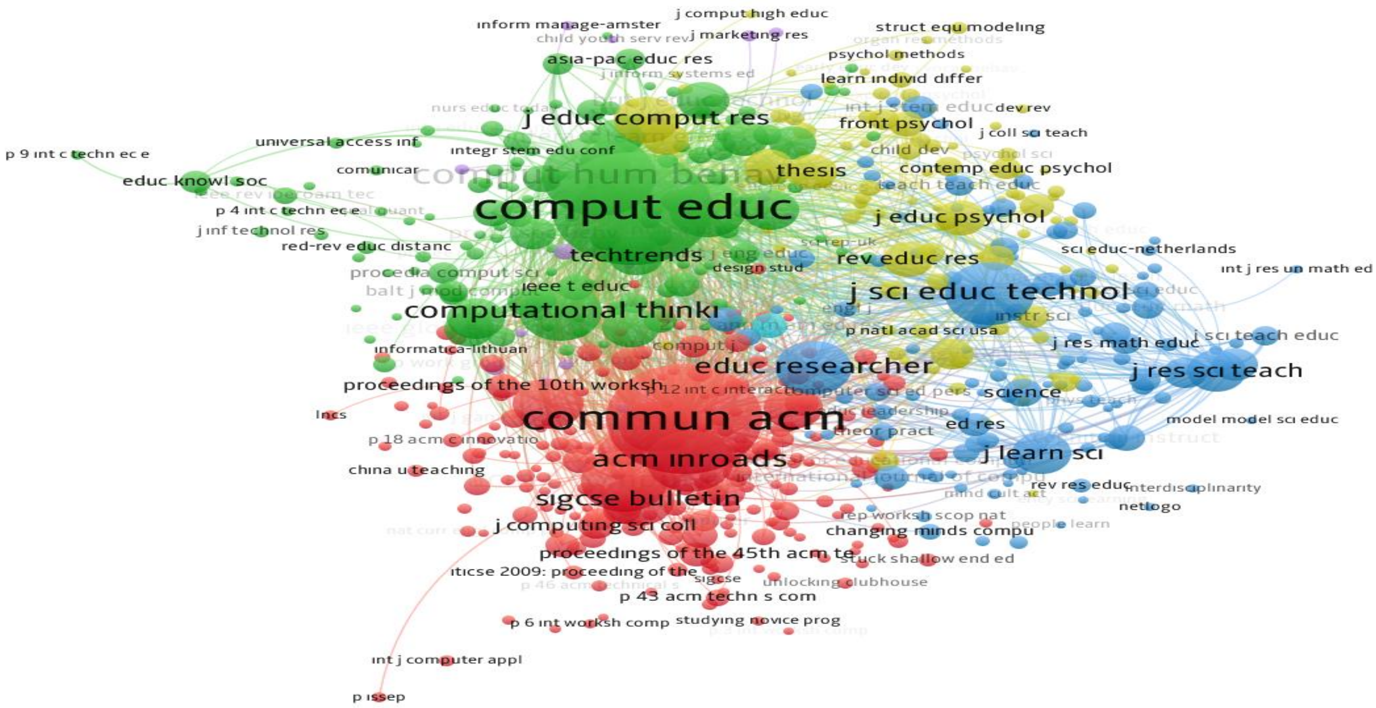

Figure 11. Co-Cited Sources Network on CT (≥20)

When Figure 11 is examined, it is seen that the structure representing the six main clusters is formed. The green cluster shows it is co-cited in sources such as Computers & Education, Computers in Human Behavior, Education and Information Technologies, and Informatics in Education. The red cluster contains resources such as Communications of the ACM, ACM Transactions on Computing Education, and Computer Science Education. These resources are centrally located and involve intense interaction with resources in other clusters. On the other hand, co-references in the blue cluster include the Journal of Science Education and Technology, Journal of Research on Technology in Education, Journal of Engineering Education and Journal of the Learning Sciences. Resources such as the yellow cluster Journal of Computers in Education and Journal of Computer-Assisted Learning stand out. Since these sources are often cited together, most contain topics with the same content. Due to the intense interactions between these sources, core sources have become more prominent. Therefore, these sources direct the studies in the field.

3.2.2. Collaboration networks

This section includes the collaborations on CT and the interactions that emerged from these collaborations. Within the scope of the co-author analysis, the general structure of the cooperation network between authors, institutions, and countries is presented by visualization. Co-author collaboration is used to have more than one author participate in work and to determine how collaborations on scientific publications form a structured network (Acedo, Barroso, Casanueva & Galan, 2006). This analysis explains the coexistence of the social network structure that emerges according to the determined criteria (authors, organization, *etc*.) (Bagıs, 2021). The figures below show the results of the co-author analysis according to the criteria (author, organization, and country) (Figure 12-13-14).

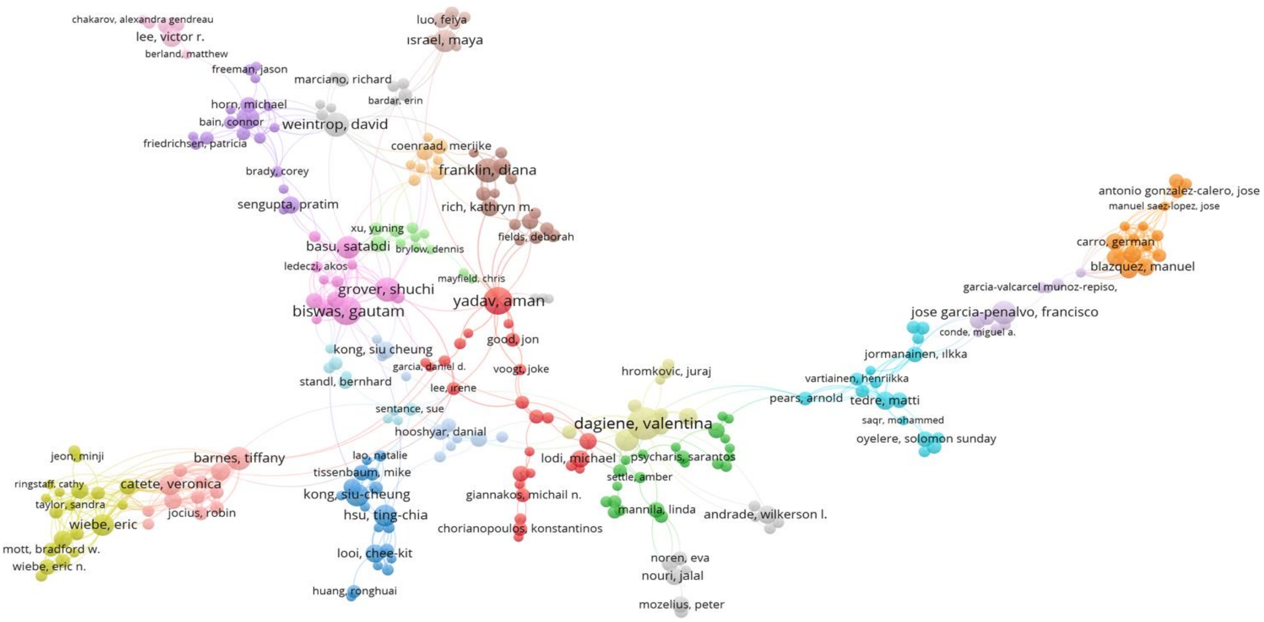

Figure 12. Authors Collaboration on CT (≥3)

As a result of the network analysis performed in Figure 12, it is noteworthy that there is clustering in more than one color. As a result of the network analysis, it is noteworthy that there is clustering in more than one color. In this respect, the cooperation network between the authors in CT has spread over a wide area. However, since the connection thicknesses are proportional to the studies written together, the number of nodes in most cluster groups is also limited in a specific axis. For example, while Yadav, A. dominates the red cluster, Dagiene, V. dominates the yellow cluster more. In the magenta-colored cluster, the authors named Biswas, G. and Grover, S. stand out, while the authors' named Kong, S. C. and Hsu, T. C. are more dominant in the blue-colored cluster. In addition, isolated authors have made certain connections with small clusters. For example, authors Nouri, J. in the grey set and Barnes, T. in the dark red set stand out. On the other hand, although there are interactions between many cluster groups in the graph, the existence of nodes indirectly connected by the centrally located red cluster draws attention. Although there are many clustered groups due to the large number of authors, it is seen that both isolated and influential authors who have contributed to the research are at the forefront. While the interaction increases towards the clusters located in the center of the network, the sparseness of the network increases as the distance from the center increases. The following image shows organization collaborations (institutions) (Figure 13).

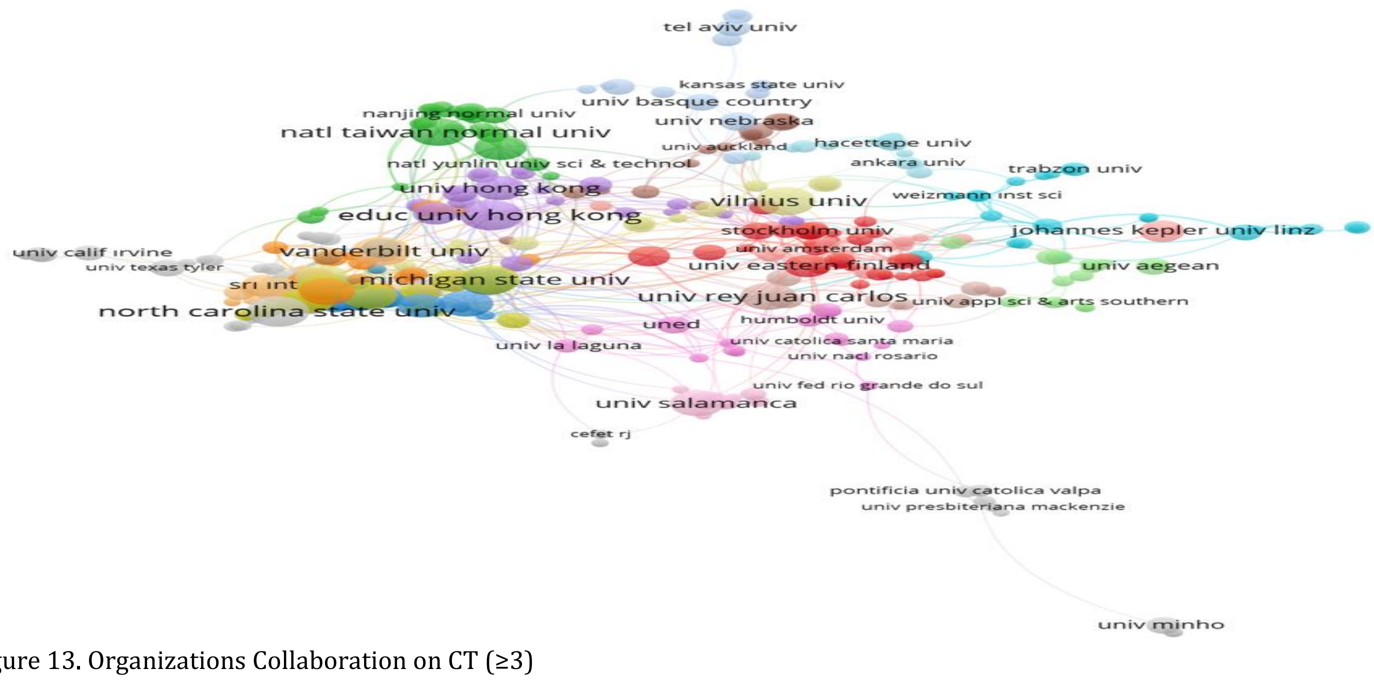

Figure 13. Organizations Collaboration on CT (≥3)

According to the structure in Figure 13, the cluster of universities in Stockholm in Sweden, Oslo in Norway, and Eastern in the United States are the most collaborative institutions in the red cluster. National Taiwan Normal in Taiwan and Nanyang Technological universities in Singapore in the green cluster appear to have the most collaborative initiatives in the network. There is a robust cooperation network between Michigan State, Utah State, and Stanford universities in the United States of America, which are in the yellow cluster. The fact that these institutions are located in the same country indicates the prevalence of the combined cooperation network globally. Similarly, there is a dense network of collaborations and interactions with other institutions between Education University and The University of Hong Kong institutions in Hong Kong, which are in the purple cluster. The fact that these institutions are located in the same country and cooperate with institutions such as Capital Normal University in China in their cluster shows the strength of the local network. In addition, Purdue University in India and Tufts University in the United States, which are in the blue cluster, have an effective network structure and cooperate with other institutions. It has been determined that there is a cooperation network between the University of Florida and Carnegie Mellon University in the United States of America in the orange cluster, and they interact as institutions of the same country. The figure below shows collaborations by country (Figure 14).

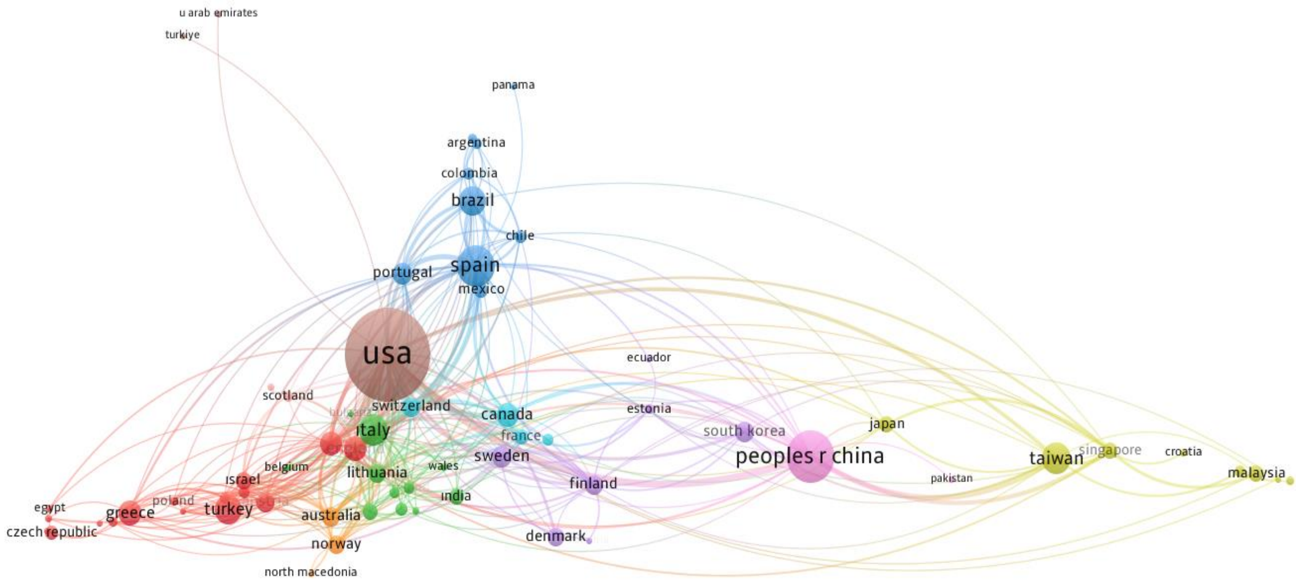

Figure 14. Country Collaboration on CT (≥3)

According to Figure 14, it is noteworthy that among the countries that cooperate in the scientific production of published documents, the USA and China are the most productive countries in the network and interact with many countries. For example, the brown cluster containing the USA also includes countries such as Germany, Egypt, Turkey, Taiwan, Singapore, China, England, Canada and Italy, while the magenta cluster containing China also includes countries such as the USA, South Korea, Taiwan and Singapore. Other main clusters include countries such as Turkey, Israel, Cyprus, Austrai and Greece, which are included in the red cluster. Taiwan, Malaysia and Singapore countries in the yellow cluster stand out in this area. The blue-coloured cluster includes countries such as Spain, Brazil, Argentina, Colombia, Chile and Portugal. Leading countries such as Italy, Lithuania, India and Hungary stand out in the green cluster. According to the clusters in the network, it is seen that collaborative initiatives between countries stand out, especially in terms of geographical or linguistic proximity. For example, the proximity and geographical similarities of the countries in the blue, red, yellow and green coloured clusters increase cooperation interactions. In addition to these, it is seen that there are quite a lot of collaborative structures and network connections between developed and developing countries.

3.2.3. Keywords and co-occurrence network analysis

Keywords are essential to reveal a document's content and reflect the study's main lines. It is frequently used in bibliometric analyses to reveal documents' content in terms of their abstract structure (Chen et al., 2023). The structure containing a simple word cloud based on the keywords created by the author of the documents is shown in the figure below (Figure 15). The size of the word and the proximity/distance of the word to the cloud formation reveals the value of the keyword in the study topic (Liao, Tang, Li & Lev, 2019).

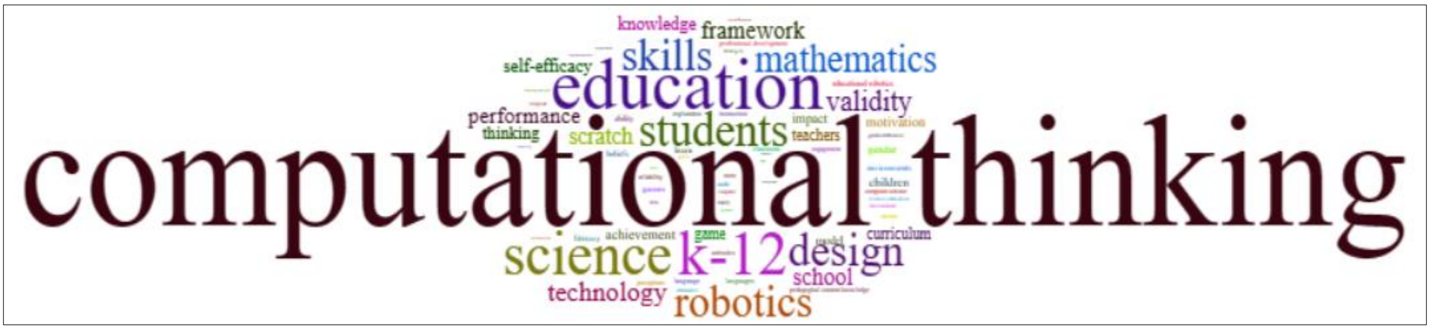

Figure 15. Word Cloud for CT (≤70)

In Figure 15, the frequently used keywords related to the study subject are "computational thinking", "education", "K-12", "science", "students", "design", "skills", "robotics", "technology", and "mathematics". The words "keywords plus" reach more keywords in the same document. The preferred number of common keywords was used to reveal the general structure of the CT topic in order to reveal the areas in which the studies were more inclined and the number of use in the studies. The formation networks of the keywords preferred by the authors for CT were examined. The following image shows the situation in the common word network structure (Figure 16).

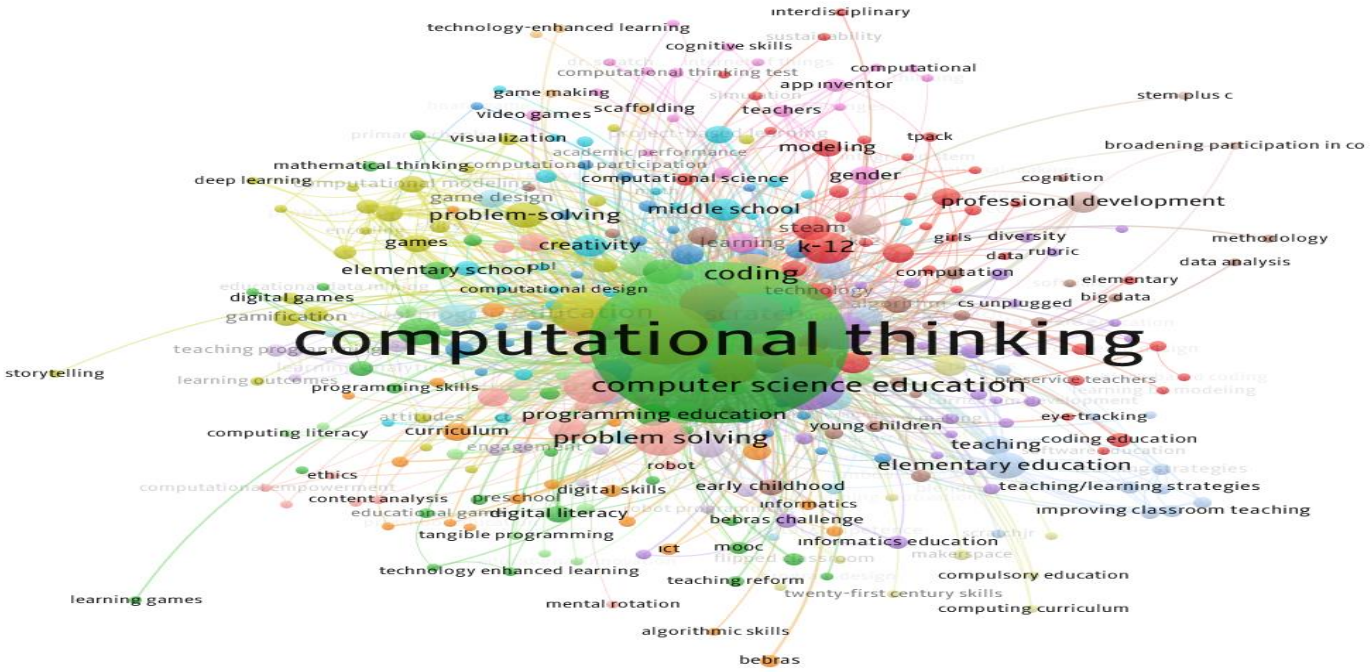

Figure 16. Co-Occurrence Network Analysis in the Context of Author Keywords (≥5)

In Figure 16, it is seen that the word "computational thinking", especially in the green cluster, is in the center of the network and is in intense interaction with other keywords. In addition, the words "computer programming" and "computing education" are prominent in this cluster (green). The red cluster contains words such as "STEM", "K-12", and "STEAM". The yellow cluster contains words such as "education", "games", "skills", "deep learning", "gamification", and "problem-solving". The central word in the purple cluster is "science education". The following figure shows the A Three-Pilot, the Sankey diagram (Figure 17). In order to reveal the flow developments in CT, keywords in the left block, authors in the middle block, and institutions in the right block are discussed relative to each other.

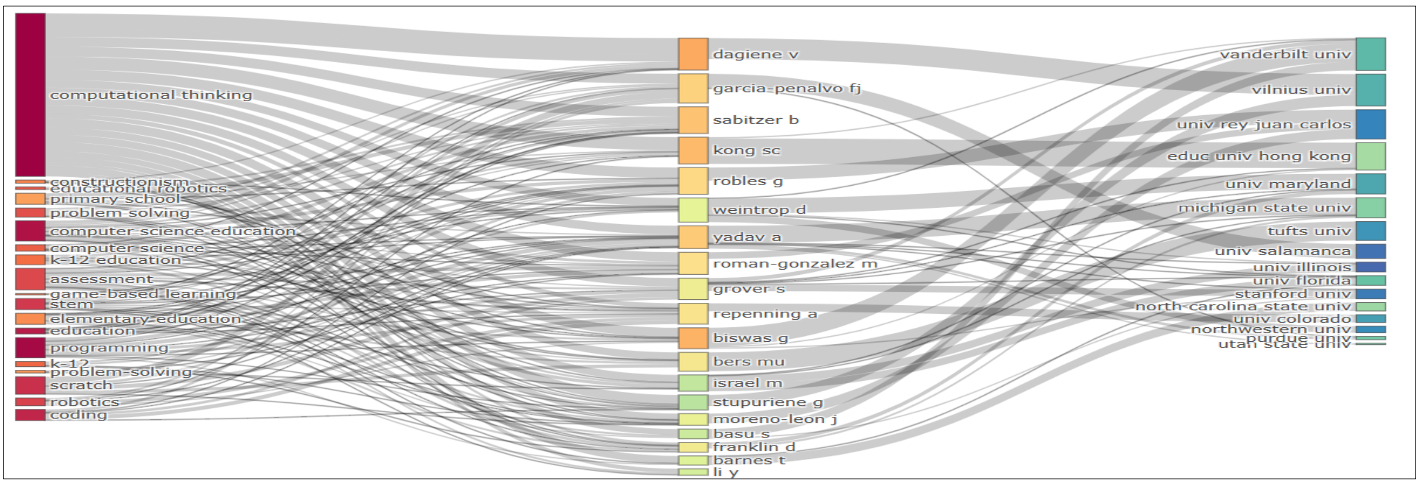

Figure 17. CT Sankey Plot (keyword- author-affiliation)

According to Figure 17, the number of criteria (keyword, author and institution) based on the size of the boxes was determined proportionally. The side widths of the boxes originating from keywords such as "computational thinking", "computer science education", and "programming" are the largest. The size of the margin width in the diagram indicates that the preferred keywords for CT are included in their works by many authors. Accordingly, while some authors support their work with rich words to better reflect the content of the subjects they are working on (Dagiene, V., Yadav, A., Weintrop, D., Robles, G., Grover, S. *etc*.), it is seen that some authors do not prefer to use a rich word when reflecting the content of the subjects they are working on (Li, Y., Barnes, T. *etc*.).

3.2.4. Trending topics and thematic evolution

This section covers trending topics and thematic changes in CT. Trending topics are an essential study dimension that helps to understand the evolution in the work of researchers from past to present. Trend topics and thematic evolution represent research hotspots or emerging themes on a particular topic (Chen et al., 2023). Trending topics are accepted as hot spots in scientific documents with interactive learning environments (Mostafa, 2022). Determining the trending topics by year also reveals the trends and changes in research. The following figure shows the study titles showing the emerging trend in CT (Figure 18).

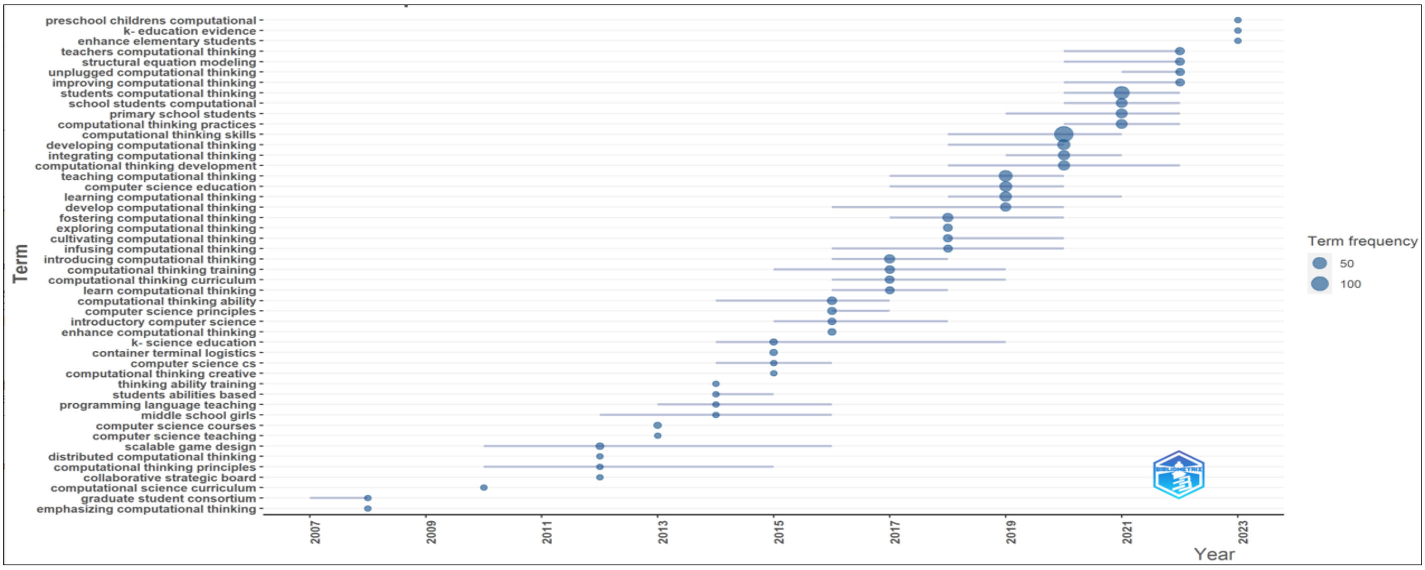

Figure 18. CT Trending Topics Map

When Figure 18 is examined, it is seen that there is a transition from established topics with orientation content such as "scalable game design" (2010-2016), "computational thinking principles" (2010-2015), "computational thinking ability" (2014-2017), "introductory computer science" (2015-2018), "computational thinking training" (2015-2019) to innovative approaches with skill and target content such as "infusing computational thinking" (2016-2020), "develop computational thinking" (2016-2020), "fostering computational thinking" (2017-2020), "teaching computational thinking" (2017-2020), "computational thinking development" (2018-2022), "teaching computational thinking" (2017-2020), "computational thinking practices" (2020-2022), "students computational thinking" (2020-2022), and "improving computational thinking" (2020-2022). Sudden changes in subject headings indicate knowledge accumulation and increasing trends in a particular discipline. Therefore, skill has been focused on the change of skill-oriented CT over the years, and more topics have been given in this direction.

3.3. Conceptual structure and thematic maps

It tried to determine the general lines of the conceptual structure by applying a Multiple Correspondence Analysis (MCA) on the keywords specified for CT by the author(s). In this way, conceptual mapping of CT is done. The resulting map reveals the conceptual structure of the documents published on CT since 2006. The MCA results applied for CT are in the figure below (Figure 19).

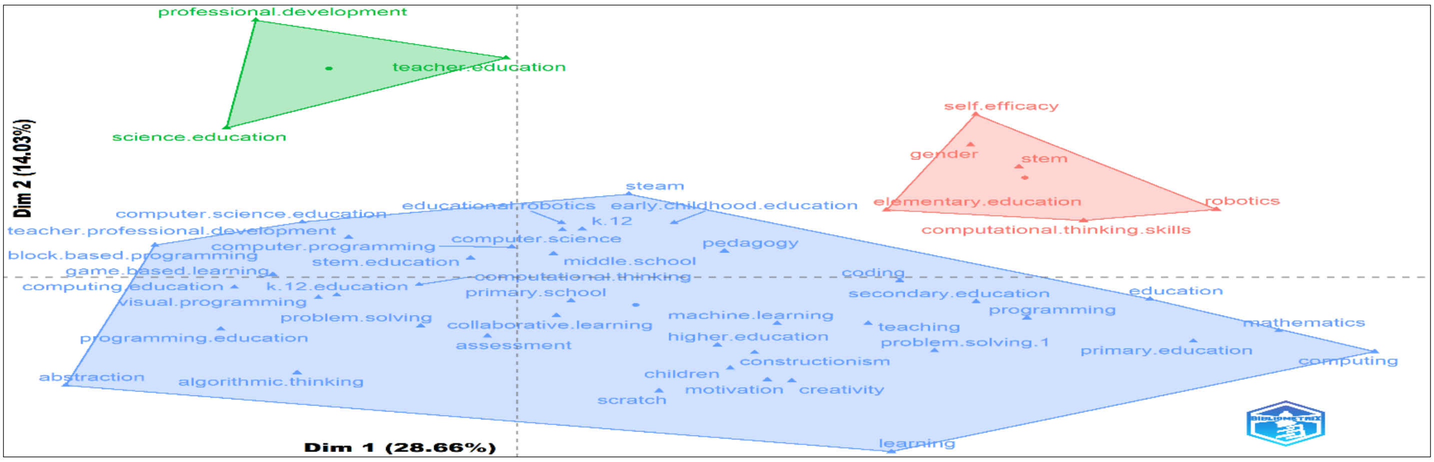

Figure 19. CT Conceptual Structure Map (MCA method)

Figure 19 shows that the best size reduction of the MCA accounted for approximately 43% of the total variability. According to the graph, the smaller the distance between the points, the more similar they are in the profile they represent (Wong, Mittas, Arvanitou & Li, 2021). The figure reflecting the practice of factor analysis (MCA) reveals the depth and breadth of studies on CT. MCA was applied to the keywords provided by the authors to reveal the conceptual structure. Accordingly, according to the keywords provided by the authors, the blue coloured cluster that constitutes the most extensive area contains words that emphasize different computer/informatics learning understandings such as "computer science", "algorithmic thinking", "K-12 education", "machine learning", "computational thinking", "coding", "computer programming", "problem-solving", "pedagogy", "game-based learning", "STEM education", "creativity" and "higher education". The red-coloured cluster in the word map that forms the second area contains words that emphasize teaching/educational programs such as "self-efficacy", "computational thinking skill", "robotics", and "STEM". The following figure shows the thematic/strategic map representing the topic of CT (Figure 20).

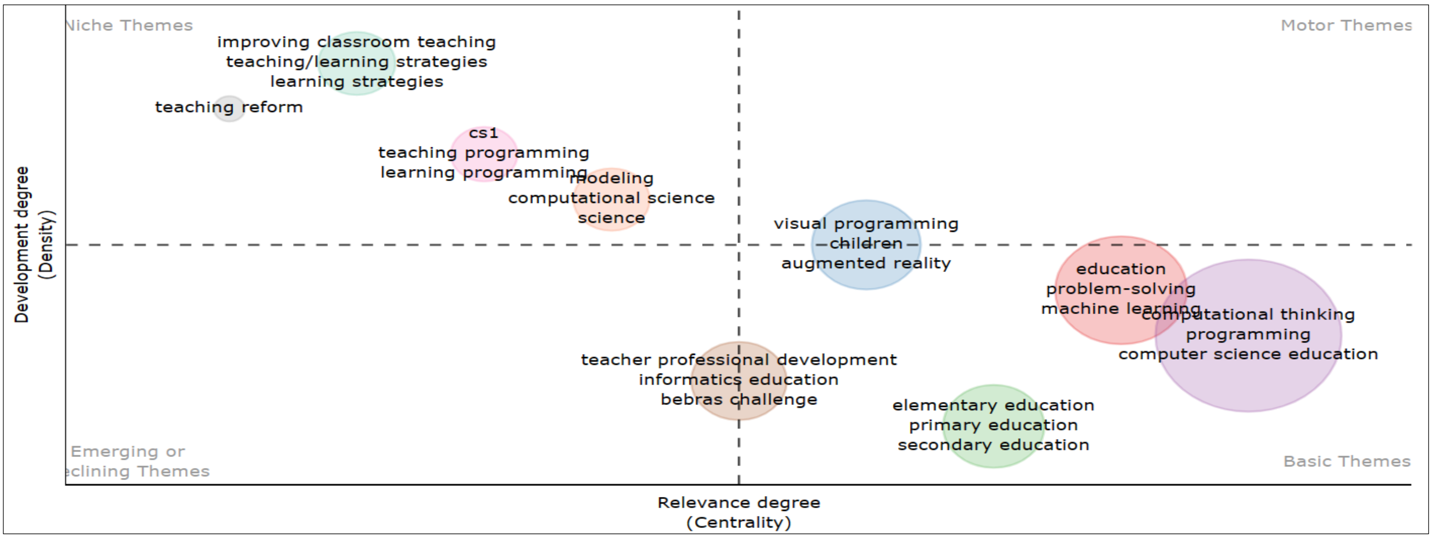

Figure 20. CT Thematic Map

In Figure 20, the thematic/strategic changes in CT are visualized, and the details of the structure formed are indicated. While doing this mapping, Walktrap was preferred as the clustering algorithm, and the average value of both axes divided the map into four quadrants. Three values of minimum cluster frequency (per thousand docs) were chosen to reduce contiguity in clusters. Three values of minimum cluster frequency (per thousand docs) were chosen to reduce contiguity in clusters. As a result, each quadrant represents a different theme, and the bubble size is drawn in proportion to the number of preferred keywords and evaluated accordingly (Mostafa, 2022). The first quartile, "motor themes", indicates high density and is characterized by centrality (Cobo, Lopez-Herrera, Herrera-Viedma & Herrera, 2011). This formation indicates internal and external development. Such themes as "children", "visual programming", and "augmented reality" are included in the subject of CT. In addition, these themes are included in "basic themes" and represent common themes. The second quarter, "Niche themes", is under the very advanced but isolated theme title. This quadrant of high density and low centre is internally well developed but externally of little importance. CT includes such themes as "computational science", "modelling", "improving classroom teaching", "learning programming", "sciences", "teaching/learning strategies", and "learning strategies". The third quarter, "emerging or declining themes", indicates low density and centrality. Themes in this quadrant characterize weakness at the inner and outer levels. Such themes as "teacher professional development", "informatics education", and "bebras challenge" are included in the subject of CT. In addition, these themes are included in "basic themes". The last quarter includes "basic themes". This theme features low density and high centrality. In addition, this theme is characterized by critical external links (Mostafa, 2022). This theme includes "computational thinking", "elementary education", "primary education", "secondary education", "machine learning", "problem-solving", "education", "computer science education", and "programming".

4. RESULTS, DISCUSSION AND RECOMMENDATIONS

This study it is aimed to determine the changes in CT by making a general analysis of the scientific studies published on CT in the WoS database. A bibliometric analysis of 3123 scientific documents published by 6467 authors representing 83 countries was conducted in this direction. First, the number of scientific publications and citations were examined to reveal the comprehensive view of the adventure of scientific studies on CT from 2006 to the present. The presentation by Wing at the anniversary celebration of Communications of the ACM was taken as the starting point of studies on CT (Wing, 2006). According to the determined criteria, it is seen that there has been a severe volume change in the number of CT studies-publications in the period from 2006 to the present. For example, while the total number of scientific studies between 2006 and 2012 was 144, this number has reached 2979 since 2013. Especially in the last decade, with a better understanding of the importance of CT, it is noteworthy that the tendency towards this field and the richness of the content of the study field have differentiated. The increase in the number of studies that refer to the studies in the literature confirms this situation, and the volume of the number of references shown increases depending on the increase in the number of studies. Although this result is not surprising, researchers' orientation to this subject constantly increases, mainly depending on technology development. Due to these trends, although we are still in the first quarter of today's information age, fundamental changes in the education systems of many developed and developing countries are familiar (MoNE, 2018; OECD, 2018). The main reason for these changes is to give more place to innovative approaches, where scientific thinking is at the forefront of curricula. Therefore, nations should increase their orientation towards technology-based learning approaches for innovative approaches to be sustainable. At this point, CT is an important opportunity for contemporary learners and includes a practical pedagogical approach to develop the skills of our age and attracts the attention of many program makers (Agbo et al., 2023; Carretero et al., 2017; Lee et al., 2022; P21, 2019; Voogt et al., 2015). In addition, this result supports the findings of similar studies conducted in previous years. In the studies, it is stated that the interest in research on CT is gradually increasing, and the volume of published documents increases as the years progress (Chen et al., 2023; Hsu et al., 2018; Kusnan & Tarmuji, 2022; Ozcınar, 2017; Roig-Vila & Moreno-Isac, 2020; Tekdal, 2021; Top & Arabacıoglu, 2021). Therefore, it is hoped that CT studies will be essential in the future, as it contains rich technological infrastructure knowledge and can be used in many areas. Although the interest and tendency towards CT are positive, it is crucial to diversify the application areas and support them with richer content.

Another research finding includes productive authors and the most cited scientific studies. Accordingly, the most productive authors on CT are Dagiene, V., Biswas, G., Kong, S. C., Sabitzer, B., and Yadav, A. These authors are pioneers in CT and direct developments in the field. The works of these authors both make valuable contributions to the relevant literature and become reference sources thanks to their rich information structure. When the most cited studies on CT are examined, it is seen that the study findings of these authors are also included. The most cited work in the field was "computational thinking" by Wing, J. M. (2006). In this study, which is accepted as the starting point of CT, the theoretical infrastructure and components of CT are explained in detail. Therefore, Wing's explanations are essential in similar studies in the literature. Another most cited work is "computational thinking and thinking about computing" by Wing. This study mentions the coexistence of CT with technology and its importance for today's societies. Another most cited study is by Weintrop et al. (2016). The study discusses the approach of placing CT in mathematics and science contexts and presents a taxonomy proposal. An important responsibility for these studies in the relevant literature is to include both the application areas of CT and the details of the components that make up the computation. Therefore, these explanations are frequently included in the theoretical explanations of similar studies.

Another finding of the research was obtained from the information of the responsible authors about their countries. According to the findings, the USA, China, Spain, Italy, and Turkey authors come to the fore in this field. The remarkable result is that the authors are primarily single-country authors. On the other hand, when we look at the authors who have assumed dominant roles over time, it is seen that the authors named Dagiene, V., Yadav, A., Biswas, G., Repenning, A., Sabitzer, B. and Kong, S. C. were influential in specific periods. These authors direct the development of CT and shed light on similar studies. When productive institutions in CT are examined, Education University in Hong Kong ranks first. North Carolina University, Michigan State University in the United States, and Natl University in Taiwan follow this. When productive countries are examined in line with these findings, it has been determined that the USA, China, Spain, Brazil, and Italy are effective. In the study by Grover and Pea (2013) ten years ago, it was reported that the USA, China, Turkey, Spain, and Australia are productive countries in CT. Similarly, Kusnan & Tarmuji (2022) and Saqr et al. (2021) conducted a bibliometric analysis of the studies in the Scopus database on CT. As a result of the studies, it has been determined that CT is based in the USA, and the dominance of researchers in this country continues. According to these findings, collaborations on CT, which is needed more and more every day, need to be diversified. In particular, in order to increase the effectiveness of CT in curricula, more intensive studies should be conducted with countries and authors who have a say in the field and their experiences should be benefited from. CT has an important place among the 21st century skills and it is emphasized that it forms the teaching approach of the future (ISTE, 2011). In this regard, the importance of cooperation between countries and researchers on CT is also increasing. It is very important for countries and researchers with less work and collaboration on CT to do more work together with countries and authors who are dominant in the field and benefit from their suggestions.

Another research finding was obtained from the network analysis on CT. According to analysis in the context of authors, the author named Wing, J. M. is at the center of the network visualization. The author shows the critical reason for this situation, which enabled CT to gain an important place in the field. Similarly, connecting nodes were determined to be thick and tight in the network visualization of Grover, S., Papert, S. Weintrop, D., Garcia-Penalvo, F. J., Yadav, A., and Bers, M. U. It can be said that these authors are united in the axis of similar subjects but have similar thematic contents depending on their positions in different clusters (Chen et al., 2023). Authors at the cluster's center in CT tend to influence other communities. Therefore, these authors control their work and encourage the work of other authors by supporting them (Mostafa, 2020). In this respect, they are stated as influential writers in their cluster. When the analysis results of co-citation network analysis visualization in the context of journals are examined, it has been determined that Computers & Education, Computers in Human Behavior, Communications of the ACM, Journal of Science Education and Technology, Journal of Computers in Education journals are pretty effective in their cluster. The prominent feature of these journals is the high number of studies on CT. In addition, these journals include the work of influential authors in CT. These journals are the leading journals in the field of research and publish quality technology-based studies. Since these journals center the studies on technology and technological tools, they are the first references in studies conducted in similar directions and determine the trends in the field. The obtained findings are also consistent with similar studies in the literature. For example, Chen et al. (2023), Communication of the ACM, Computers and Education and Computers in Human Behaviors journals were found to be leading journals.

When the collaboration network visualizations on CT were examined, it was determined that the collaboration network formed between the authors spread over a wide area. Therefore, it has been determined that many authors are interested in CT, and they carry out studies in this field. The redundancy of the clusters formed due to the diversity of the authors in the network analysis also indicates the size of the domain of CT. Cooperation networks between institutions and countries show that CT has an important place in the agenda of many institutions and countries. When the word cloud analysis reflecting the content of CT is examined, "computational thinking", "education", "K-12", "science", "students", "design", "skills", "robotics", "technology", and "mathematics" come to the fore. Keywords offer valuable clues in illustrating the workspace. It guides researchers in obtaining a general idea about the study and provides opportunities for new study areas related to the field (Chen et al., 2019). In this context, studies focusing on robotic applications, technology-based designs, skills and disciplines in CT are carried out intensively. Therefore, depending on the reflections of technology on learning environments, there is diversity in CT content studies. The determination that studies with the content of e-learning, blended learning, educational technology, evaluation, higher education and mathematics education are core words in CT supports the diversity in the studies. It is known that teaching CT improves the creative and critical thinking skills of individuals (Chan et al., 2023; Lee et al., 2022; Shute et al., 2017; Wing, 2008; Ye et al., 2022). Therefore, the widespread effect of CT is felt in many fields and disciplines, and it provides an opportunity for skill-oriented training of individuals. The keywords of the studies also indicate that CT develops skill-oriented and focuses on the technology competencies of individuals. This finding also highlights that CT is included in the curricula of many nations. Because core words also reflect studies in disciplines such as mathematics, science, and engineering. The study by Usta and Düzalan (2021) points out that CT is essential in math education. Many researchers emphasize the importance of including CT in the curriculum and developing vital discourses in this area (Chan et al., 2023; Voogt & Roblin, 2012; Wing, 2006). One of the remarkable findings of the researcher was obtained from the conceptual structure of studies involving CT and thematic mapping. Findings from the study showed that the dimensions included in the MCA represent approximately 43% of the total variation. This indicates the depth and breadth of CT. When the thematic mapping related to CT is examined, "computational science", "modelling", "improving classroom teaching", "learning programming", "teaching/learning strategies", and "learning strategies" come to the fore as high-intensity and internally well-developed themes. Themes show trending current developments in the field (Cobo et al., 2011). Considering the well-developed themes both internally and externally, "children", "visual program", and "augmented reality" comes to the fore. These themes point out how there will be a change in CT and indicate that the subjects of the study will develop in this direction (Cobo et al., 2011). As the benefits of CT, whose popularity is increasing daily, are better understood, studies in this field will gradually increase. Therefore, it is hoped that the richness in the number and content of the studies will continue to understand better the framework of CT, which profoundly affects many fields and disciplines.

4.1. Limitations and Agenda and Implications for Future Research

The study has some limitations and a series of contributions to the studies on CT. Among the study's limitations, it can be shown that the data set used in data analysis includes the WoS database. Only scientific articles and papers on CT have been evaluated in this database. Other academic databases such as EBSCO, Scopus, ProQuest, PubMed, DOAJ, and ERIC may be alternatives for future research. Studies can be diversified with the Scopus database, which has rapidly grown in recent years. Only "article" and "proceeding paper" were selected as document types in the research. Detailed data can be obtained by examining the contents of different document types (early access, review article, book review *etc*.). Therefore, the contents of these document types may differ. By narrowing the scope of the studies on CT, inferences can be made about what studies include a single discipline. One of the strengths of such studies is to identify the changes in the field and show the gaps in the area to similar studies. Therefore, similar studies in the future may continue to analyze the trends of scientific studies published on CT after 2023. Our study considered productivity, network analysis of formations, conceptual structures, thematic formations, and popular topics. However, diversity can be achieved by using the content or descriptive analyses in studies to be conducted similarly. In addition, considering that current information tools and applications (artificial intelligence applications (AIA), augmented reality (AR), machine learning (ML), internet of things (IoT), hologram, robotic applications, quantum computers, nanotechnology *etc*.) that will shape and shape the future will be more effective, the need for CT will increase even more. Therefore, it is possible to focus on comprehensive studies that include areas that make and feel the impact of CT.

Research and Publication Ethics Statement

All the rules specified in the Higher Education Institutions Scientific Research and Publication Ethics Directive have been complied with in the entire process, from the planning and implementation of this research to the data collection and analysis, and no damage has been done to the data set. Ethics and citation rules were followed during the writing process, and it was not sent to any other academic publication journal for evaluation. In addition, since the study was not carried out on humans, it does not require ethics committee approval due to its method and scope.

Contribution Rates of Authors to the Article

This is a single-authored paper.

Statement of Interest

The researcher declares that there is no conflict of interest.

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