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BIBLIOMETRIC ANALYSIS OF CONCEPT MAPS IN CHEMISTRY EDUCATION

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A comprehensive systematic review concerning the usage of concept maps in chemistry education (CMiCE) is not available in the literature. Therefore, this study attempts to conduct a systematic review of CMiCE using bibliometric analysis. Within the scope of the main aim of the study, articles related to CMiCE were searched on the Web of Science (WoS) database through the "ALL= ("concept map*") and ALL=("chem*") query. Data analysis was done using Microsoft Excel, VOSviewer software package and WoS analytical tool. According to the findings, information regarding trends, citation, co-authorship, co-word/co-occurrence, and co-citation in studies related to CMiCE were obtained. Results show that the most influential country was the USA, the most influential journal was the Journal of Chemical Education, the author with most citations was Novak, the most frequently used keyword was concept maps and the most commonly used keyword in recent years was the curriculum. The results from this study will contribute to other review studies related to CMİCE- especially in the context of chemistry education.*

KEYWORDS: Concept Maps, Chemistry Education, Bibliometric Analysis, Systematic Review, WoS Database

INTRODUCTION

The concept map (CM) is an educational aid that can be used in curriculum, governance, teaching, and learning (Novak & Gowin, 1984). They can be used as an effective method, especially in formative assessment (Burrows & Mooring, 2015; Hartmeyer et al., 2018; Ruiz-Primo & Shavelson, 1996).

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Considering the fact that concept maps (CMs) are increasingly used in teaching, learning, and assessment; it may be said that teachers have significant responsibilities in students' use of these metacognitive instruments accurately and successfully (Roessger et al., 2018). Therefore, it is important that educators/teachers and new researchers in the area follow the trend and developments in research about CMs as an educational aid for teaching, learning, and assessment. Yet, there are not many reviews in the literature that investigate the change, development, citation, co-word/co-occurrence, co-authorship, and co-citation trends in studies related to concept maps in chemistry education (CMiCE). A study of systematic review of CMs using bibliometric analysis in chemistry education will contribute to both educators/teachers and new researchers in the area.

Concept maps (CMs) that show connections between concepts were developed by Novak (1984). They are the instructional instruments that enable teachers to put Piaget, Ausubel, and von Glasserfeld's theoretical ideas into practice (Markow & Lonning, 1998). They can help learners to understand the key concepts important in interpreting the events and objects they observe and the associations between concepts (Novak & Gowin, 1984).

CMs can be used in learning, teaching, curriculum planning, and in assessing students' understanding of science concepts (McClure et al., 1999). They can contribute to developing learners' conceptual understanding of science concepts in chemistry courses (Francisco et al., 2002; Šišović & Bojović, 2000). In addition to that, they also support chemistry teachers and chemistry students in the positive development of the teaching/learning process (Regis et al., 1996). Various studies in which CMs were used as an educational aid in learning/ teaching in research about chemistry education were reported (Aydin et al., 2009; Brandt et al., 2001; Markow & Lonning, 1998; Nicoll et al., 2001; Turan-Oluk & Ekmekci, 2018; Wang et al., 2021). CMs can help learners learn the subjects and concepts of chemistry (Turan-Oluk and Ekmekci, 2018). The creation of CMs by students during lab classes will enable them to understand the concepts in chemistry experiments (Markow & Lonning, 1998). Students who took part in the study conducted by Turan-Oluk and Ekmekci (2018) stated that CMs helped them see the associations between concepts and that they supported their learning by understanding rather than memorizing.

CMs exhibit information on the organization of concepts in learners' cognitive structure (Ruiz-Primo & Shavelson, 1996). Chemistry educators can determine what concepts or connections to teaching students and what the common misconceptions and lacks of knowledge are through CMs (Burrows & Mooring, 2015). Several studies which use CMs as a tool for the assessment of learning in chemistry are also available (Anzovino & Bretz, 2016; Burrows &

Mooring, 2015; Francisco et al., 2002; Kaya, 2008; Nakhleh & Krajcik, 1994; Pendley et al., 1994; Ye et al., 2020). Teachers can choose to use them as a pre-assessment and formative assessment instrument to reveal the knowledge structures of students related to concepts (Burrows & Mooring, 2015). According to Lopez et al. (2011), CMs are useful, easy-to-manage tools used in promoting students' ability to solve organic chemistry problems, their course performance and promote their understanding in general, and assess teaching and learning processes.

Bibliometric Analysis and Systematic Review of Concept Mapping

Bibliometric methods (analysis) are used in the quantitative analysis of published studies (Ellegaard & Wallin, 2015). The results of bibliometric analysis for an area provide information on the quantity and quality of scientific studies in that area (Narin et al., 1994). Bibliometric analyses are used to have a general perspective of factors such as change, evolution, trend, citation, co-authorship, co-word/co-occurrence, and co-citation. They present information about important features of many scientific documents such as authors, journals, citations, institutions, co-authorship, and countries (Esen et al., 2020).

Reviews in a certain area inform researchers of the trends and potential subjects of research in the area (Chang & Yang, 2022). Various studies of review concerning the use of CMs are available in the literature (e.g. Chang et al., 2022; Chang & Yang; 2022; Gao et al., 2007; Islam et al., 2020; Nesbit & Adesope, 2006). These studies generally investigated the effects or assessment processes of CMs in different learning environments (Chang & Yang, 2022). A meta-analysis study by Nesbit and Adesope (2006) about CMs, for instance, found that CMs had positive effects on students' performance. In addition to that, Gao et al. (2007) also conducted a review study that tried to find the probable reasons for the differing findings obtained by revising the studies which considered the use of CMs in individual or group learning. Hartmeyer et al. (2018), on the other hand, display the results of the systematic review of nine publications that contained interventions made through CMs in primary and secondary science education. Chang et al. (2022) conducted a bibliometric analysis of studies concerning CM-supported education in some journals of instructional technology while Chang and Yang (2022) conducted a bibliometric analysis of publications concerning CMs in computer-assisted learning environments. However, there are no holistic systematic reviews of the use of CMiCE in the literature. Setting out from this point, the current study attempts at making a systematic review using bibliometric analysis about the use of CMiCE. This study will contribute to the results of the review studies

mentioned above, especially in the context of chemistry education.

The Current Study

Schroeder et al. (2018) emphasizes that different and new studies are needed to reveal the cognitive processes better during learning through CMs and to determine how to prepare CMs more effectively. Burrows and Mooring (2015) state that additional studies are needed to find whether or not CMs can measure learners' knowledge structures in a subject. Chang and Yang (2022) also argue that new reviews using different bibliometric analyses with larger samples are needed due to the fact that the reviews available in the literature use small samples because of the selected periods and because of their specific focus on research. In this context, studies of bibliometric analysis can guide new researchers in terms of producing new and different studies on CMs-because studies of bibliometric analysis contribute to the advance and development of an area of research (Song et al., 2019). Such studies also help to demonstrate the significance of studies in the literature and to discover the trends and evolution in the subject of research (Gimenez et al., 2018).

It is important for students, teachers, and educational researchers to notice the current progress in studies concerning CMs. Therefore, one of the studies which will be pioneering in new research in the use of CMiCE is studies of bibliometric analysis. In this way, the researchers new in the area will become informed of collaborating institutions and authors as well as the trends and innovations in the area (Ellegaard & Wallin, 2015). Those researchers will be informed of the publications, authors, and journals that should be read firstly through studies of bibliometric analysis and thus, they will step into the area. Based on this idea, the current study aims to gain a general perspective of trends, citation, co-authorship, co-word/co-occurrence, and co-citation in studies by making a systematic review using bibliometric analysis on CMiCE.

Research Model

This study uses bibliometric analysis. Bibliometric analyses can be used in analyzing a great amount of data over a certain period. Information on the basic publications which come into prominence in an area, the intellectual structure of the studies, and their changes and evolution can be obtained.

VOSviewer is a freely available software tool for constructing and visualizing bibliometric maps. There is a website https://www.vosviewer.com to download the VOSviewer software, access publications about the software, and obtain more detailed information. With VOSviewer, maps (or bibliometric networks) including institutions, journals,

authors, or countries can be constructed. These maps are also constructed based on co-authorship, co-word/co-occurrence, citation, and co-citation relations (Van Eck & Waltman, 2010). VOSviewer constructs bibliometric maps at the end of a three-step process based on the co-occurrence matrix. Van Eck and Waltman (2010) explain these three steps as follows "(I) A similarity matrix is calculated based on the co-occurrence matrix, (II) a map is constructed by applying the VOS mapping technique to the similarity matrix, and (III) the map is translated, rotated, and reflected" (p. 530).

DATA COLLECTION

This study reviewed the articles related to CMiCE on the WoS database through the "concept* map* and chem*" query in June 2022. A flowchart of the process of data searching and collection is presented in Figure 1.

At this phase, documents that use CMs as an educational aid for teaching, learning, and curriculum in chemistry education were included. Totally 269 WoS-published studies in the period between 1990 and 2022 were obtained. On choosing only articles as the type of document, 184 articles were found. First, the titles, author keywords, and abstracts of the articles were reviewed. After that, online texts of each article were read, and 81 of them were excluded from the data set because they were not consistent with the purpose of this study. Extra 24 articles were also included in the study after examining other review articles on CMiCE. For example, one of those articles added at this stage was the one by Novak (1984). Thus, 127 articles in total were obtained. Then, the records were downloaded from the WoS database as raw data files in plain text format and were imported into the VOSviewer software package. The flowchart of the process of data searching and collection is given in Figure 1.

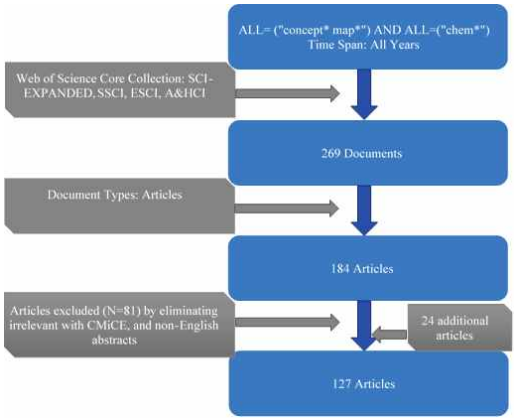

Figure 1. Flowchart of the Process of Data Searching and Collection.

Data Analysis

In this study, Microsoft Excel and WoS Analytical Tool were used for descriptive statistics such as citations of authors, year distribution of articles, and article distribution of by WOS research areas. VOSviewer software package was used for bibliometric analyses and visualizations of citation, co-authorship, co-word/co-occurrence, and co-citation.

Findings of the Study

Within the scope of this study, 127 articles related to CMiCE in the Web of Science Core Collection were obtained. A total of 90 of the publications were published in journals indexed by SSCI while, 66 were published in journals indexed by SCI-EXPANDED, 17 were published in journals indexed by ESCI, and one was published in a journal indexed by A&HCI. An examination of the authors' affiliations demonstrated that Purdue University ranked at the top which was followed by West Virginia University. It was found on analyzing in terms of publishers that 34 articles were published by the American Chemical Society, 20 articles by the Royal Society of Chemistry, and 11 by Springer Nature, Taylor and Francis, and Wiley Online Library each. On examining the studies in terms of countries, it was found that they came from 40 different countries. As seen from Figure 2, the countries most productive in CMiCE are the USA (n=47), which is followed by Turkey (n=18) and Australia (6), respectively.

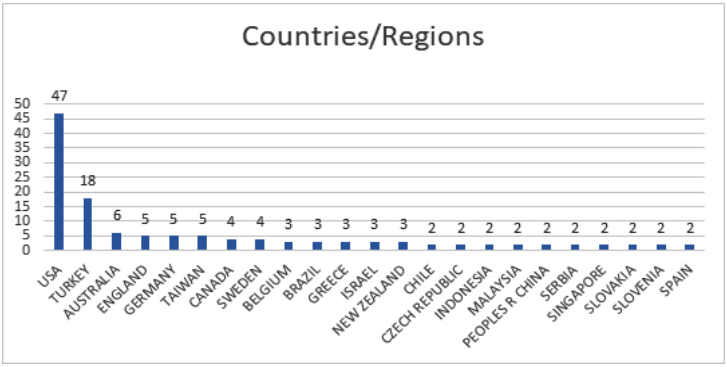

Figure 2. Distribution of Concept Maps Articles in Chemistry Education (CMAiCE) by Country (published at least two articles).

As to the distribution of Concept Maps Articles in Chemistry Education (CMAiCE) according to years, it was found that articles in differing numbers were published in the years between 1984 and 2022. It is clear from Figure 3 that

the number increased in recent years and that there was a peak in the year 2020. However, it may be said accordingly that there is not a trend of continuous increase. There are differences in the number of articles according to year.

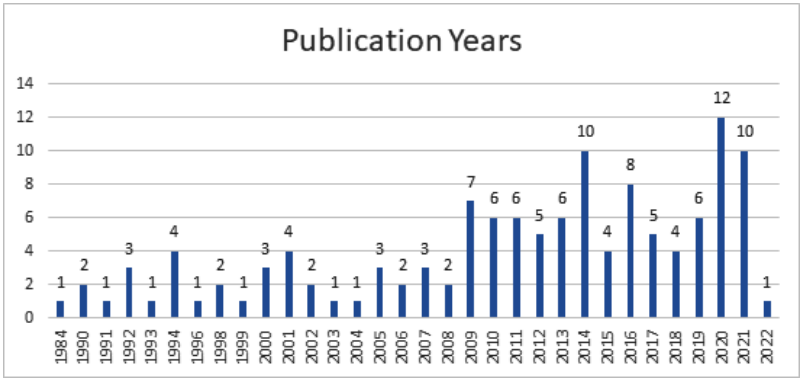

Figure 3. Distribution of CMAiCE by Years.

Figure 4 shows the distribution of CMAiCE by research areas. Education and Educational Research is ranked first followed by Chemistry, Psychology, Biochemistry, Molecular Biology, and Engineering.

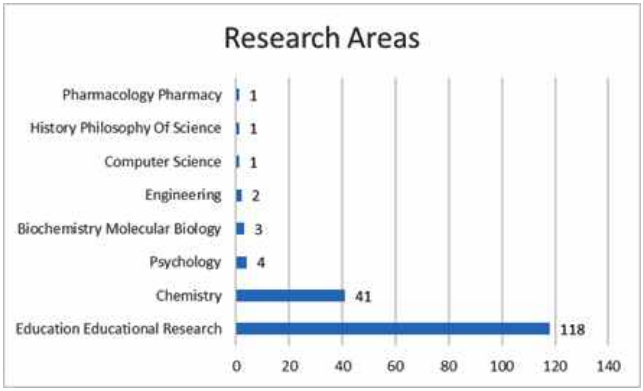

Figure 4. Distribution of CMAiCE by Research Areas.

Figure 5 shows the distribution of CMAiCE by publication titles. According to Figure 5, the greatest number of publications are in the period between 1984 and 2022 in the Journal of Chemical Education (JCE) (n=33), Chemistry Education Research and Practice (CERP) (n=20), Journal of Baltic Science Education (JBSE) (n=8), International Journal of Science Education (IJSE) (n=6), Journal of Research in Science Teaching (JRST) (n=6), and in Research in Science Education (RISE) (n=5). It was not surprising that such journals as the JCE and CERP were at the top due to the fact that this study aimed to

investigate CMs in chemistry education. While the JCE- in which 33 publications appeared- received 746 citations, the CERP received 181 citations, the JBSE received 27 citations, the IJSE received 199 citations, the JRST received 258 citations and the RISE received 95 citations in total.

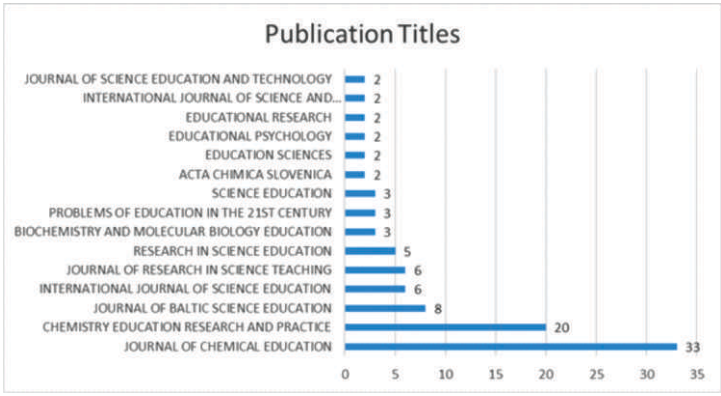

Figure 5. Distribution of CMAiCE by Publication Titles.

The ranking of the authors with the most articles on CMiCE is Mary B. Nakhleh [number of publications (NoP): 5, the total number of citations (TNoC): 237, Without self-citations: 237], John Penn (NoP=5, TNoC: 115, Without self-citations: 113), Richard J. Shavelson (Nop=5, TNoC: 115, Without self-citations: 113), Kiruthiga Nandagopal (NoP=5, TNoC: 115, Without self-citations: 113), Enrique J. Lopez (NoP=5, TNoC: 115, Without self-citations: 113), and Evan Szu (NoP=4, TNoC: 92, Without self-citations: 91). Here, especially Mary B. Nakhleh received 237 citations with 5 publications, which is considerably more cited than other authors. The distribution of CMAiCE by authors is given in Figure 6 (Minimum record count:3).

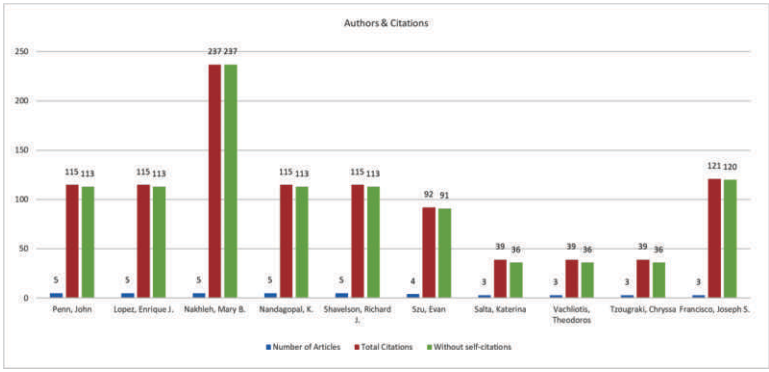

Figure 6. Distribution of CMAiCE by Authors.

A total of 339 articles by 127 authors were analyzed in this study. It may be

said to be based on the availability of so many authors that authors have great interest in the subject of CMiCE. Table 1 shows the data on 5 publications out of 127 with the greatest number of citations (>50). Two of them were in the JCE, two were in the JRST and one was in the IJSE. According to the Table, Rickey and Stacy (2000) and Nakhleh and Krajcik (1994) ranked first with 116 citations. Rickey and Stacy (2000) inform readers of teaching aids used in addition to CMs to develop metacognition. Nakhleh and Krajcik (1994), on the other hand, used CMs to determine the changes in learners' understanding of acid, base, and pH concepts. Ross and Munby (1991)- who received 97 citations, however, used CMs to determine their students' understanding of concepts related to acids and bases and their misconceptions. Markow and Lonning (1998) investigated the effects of CMs on first-year university students' conceptual understanding in the chemistry laboratory. Francisco et al. (2002) prioritized CMs as an assessment technique to determine students' conceptual understanding.

Table 1.

Top 5 Highly Cited Articles (Citations > 50).

No	Authors	Usage Types of CMs	Number of Citations
1	Rickey & Stacy (2000)	Theoretical Framework	116
2	Nakhleh & Krajcik (1994)	Assessment,Evaluation, and Data Collection	116
3	Ross & Munby (1991)	Assessment, Evaluation, and Data Collection	97
4	Markow & Lonning (1998)	Learning/Teaching	65
5	Francisco et al. (2002)	Assessment, Evaluation, and Data Collection	51

Bibliometric Findings

van Eck and Waltman (2012) stated that the maps constructed by VOSviewer consist of various nodes and lines. In map visualization, each node can show an author, an institution, a country, or a journal. The size of these nodes is determined depending on the number of publications. A node with more publications is larger. The lines provide information about the relation between the two nodes. For example, if the line between the nodes containing the two documents (or authors) is thick, it indicates that the relation between these two documents is strong. Also, the distance between two nodes in a map is based on the similarity between the two nodes. If two nodes are similar, they are located closer to each other in a map visualization. In addition, nodes that are similar to each other come together to form clusters. Each cluster is also indicated by a color.

On examining the co-authorship between 339 authors in total, it became apparent that the authors made collaborations (minimum number of documents of an author: 1). Co-authorship was available between 11 authors in total. Talbert, Mortezaei, Henbest, Guregyan, and Eichler made co-authorship with 10 authors (Figure 7).

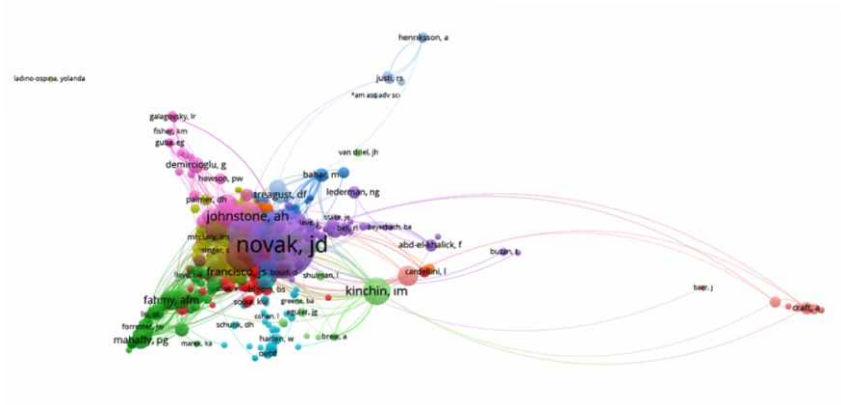

Figure 7. Most Cited Authors (Minimum number of citations of an author: 2)

In Figure 7, the most cited authors (Co-citation analysis) network visualization map is shown. As a result of the co-citation analysis, Novak JD's publications 214, Ruiz-Primo MA's publications 55, Ausubel DP's publications 51, Taber KS's publications 43, Johnstone AH's publications 42, Kinchin IM's publications 35, Nakhleh MB's publications have been cited 33 times. It was determined that Novak with 602 (links) authors (total link strength (TLS): 4831), Ruiz-Primo) with 361 (links) authors (TLS: 1671), Ausubel with 408 (links) authors (TLS: 1325), Taber with 343 (links) authors (TLS: 1605), Johnstone with 337 (links) authors (TLS: 1259), Kinchin with 290 (links) authors (TLS: 1050) and Nakhleh with 313 (links) authors (TLS: 1168) were co-cited.

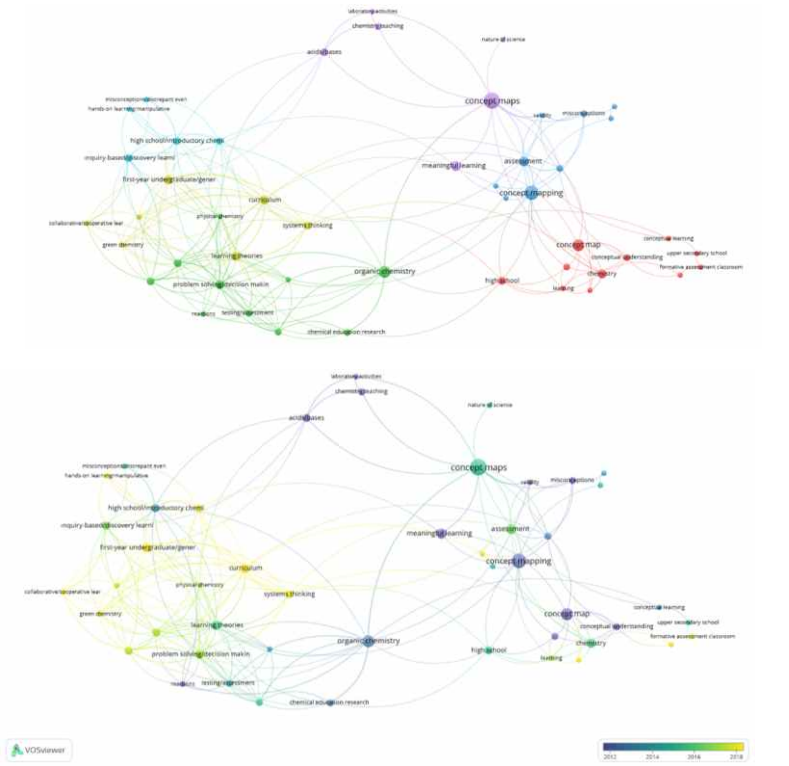

Figure 8. Co-Word/Co-Occurrence Analysis (Minimum number of occurrences of a keyword:2)

Figure 8 shows the co-occurrence network map of the most used author keywords in CMiCE. In addition, the distribution of these keywords by year is shown in Figure 8. A total of 239 author keywords were used in 127 articles examined within the scope of this study. Figure 8 shows that the keywords are in 6 clusters in total. The most used keywords in these articles are concept maps (f=17), concept mapping (f=13), concept map (f=9), organic chemistry (f=9), assessment (f=6), meaningful learning (f=6), problem-solving/decision making (f=5), curriculum (f=5), learning theories (f=5), First-Year Undergraduate/General (f=5), and chemistry (f=5). The yellow and light green circles in Figure 8 Overlay Visualization provide information about the publication years in which these keywords are used. Accordingly, the words used in CMAiCE in recent years have been collaborative/cooperative learning, constructivism, first-year undergraduate/general, hands-on learning/manipulatives, systems thinking, higher education, formative assessment classroom techniques, secondary school, and undergraduate.

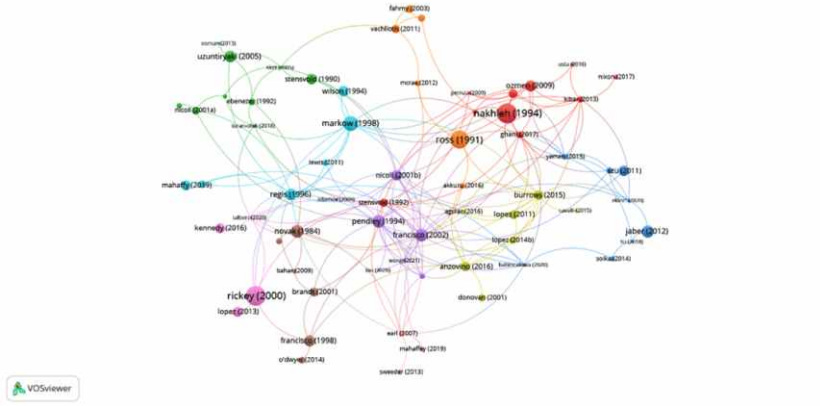

Figure 9. Citation Analysis (Minimum number of citations of a document:2).

Figure 9 shows the network map of the most cited publications among 127 articles. Top−5 highly cited articles are given in Table 1. Similarly, the most cited articles are the publications by Rickey and Stacy (2000) and Nakhleh & Krajcik (1994). However, when the publications are evaluated in terms of links, Francisco et al. (2002) rank first with a total of 22 links. Considering the number of links, there is a sorting of Pendley et al. (1994) (f=16), Nicoll et al. (2001) (f=16), and Burrows and Mooring (2015) (f=15).

Discussion and Conclusion

This study analyzed the current state and research trends in articles on CMiCE published between 1984 and 2022 through a systematic review using bibliometric analysis. As a result, a general perspective was gained about citation, co-authorship, co-word/co-occurrence, and co-citation in studies concerning CMiCE. Totally 127 articles indexed by SSCI, SCI-EXPANDED, ESCI, and A&HCI were analyzed within the scope of this study. Bibliometric analyses provide a summary of the structure and development of a specific research area. Bibliometric analyses offer a quantitative and objective approach with a broad perspective in a shorter time than other methods (Župič & Čater, 2015). It can give researchers information about the appearance of their publication, as well as show what kind of studies other researchers in the field are focusing on (Gülmez, Özteke, & Gümüş, 2020). Bibliometric studies can be used to determine productivity in a specific field. For example, the analysis of the co-occurrence of keywords shows the evolution, the hot topics, and the development of a research area (Župič & Čater, 2015), the Citation analysis reveals the popular research topics and documents (Lai, 2020). In

addition, bibliometric analysis is a method used to determine the influential publications, influential journals, and authors (Župič & Čater, 2015).

On examining the publications according to the their distribution as per years, it was found that the first publication was in 1984 (Novak, 1984) and that the number increased over time. A great majority of the publications were made by American writers. This result was similar to the ones obtained in many studies of bibliometric analysis (Chang & Yang, 2022; Chen et al., 2019; Esen et al., 2020; Li & Wong, 2022). Chang and Yang (2022). In a bibliometric analysis study on CMs in computer-supported learning environments, also found that the greatest number of studies were in the USA. The study by Chang and Yang also found that the USA was followed by Taiwan and Turkey in the number of publications.

The results of citation analysis (minimum number of documents of a country: 1) were examined to find the most influential countries among the 40 countries where publications on CMiCE were made. Thus, the USA was found to rank first according to total link strength values (TLS) (links: 23; TLS: 115)- which was followed by Turkey (links: 12; TLS: 52), Italy (links: 9; TLS: 20), Belgium (links: 8; TLS: 16), Malaysia (links: 8; TLS: 16), Greece (links: 9; TLS: 15), and England (links: 8; TLS: 14), respectively. Considering the total link strength (TLS) values of the USA and Turkey- the two countries with the greatest number of publications, they can be said to be the most influential countries in terms of CMiCE. For example, another country remarkable is Italy. Even though it has only one publication, it ranks third in terms of TLS. The publication made by Regis et al. (1996) received 41 citations in total; therefore, it is one of the publications with the most citations. The title "Concept Maps in Chemistry Education" used in the study also shows its significance. It is one of the important article that researchers who would like to do research in CMiCE and chemistry teachers who would like to use CM in their classes should read.

A total of 127 articles written by 339 authors were put to analysis in the current study. Of them, the five publications which received the greatest number of citations were Rickey & Stacy (2000), Nakhleh & Krajcik (1994), Ross & Munby (1991), Markow & Lonning (1998), and Francisco et al. (2002). They were published in the Journal of Chemical Education (JCE), the Journal of Research in Science Teaching (JRST), and the International Journal of Science Education (IJSE). Two clusters were created as a result of co-authorship analysis in which the authors with at least one publication about CMiCE were included. The authors- Talbert, Mortezaei, Henbest, Guregyan, and Eichler-who made the most cooperation-were included in the same cluster. Yet, the researchers included in the two clusters were the authors

with the smallest number of publications about CMiCE. They were also the authors who received relatively fewer citations.

Based on this finding, it may be said that there is little cooperation between researchers in terms of CMiCE. However, their publications with co-authorship were the articles of Ye et al. (2020) and Talbert et al. (2020)- which were published in 2020. The findings can indicate that using CMiCE has still been important in recent years. It also shows that new cooperation is made between the authors in recent years. Both studies were conducted within the context of general chemistry courses. Because interest in CMs as effective tools in teaching and learning is increasing and applications are gaining speed (Alt et al., 2022). Publications on CMiCE to be made by new researchers will contribute to the area. The contributions to be made to the area by new researchers through new research will enable the area to advance. Using CMs in chemistry education will make significant contributions to educators.

As to cooperation made between countries, cooperation was found between 11 countries which were included in 5 different clusters (minimum number of documents of a country: 1). The ranking of countries with the most cooperation in CMiCE was found as USA (f=6), England (f=6), Belgium (f=4), Israel (f=3), and Canada (f=3). Although Turkey (n=18) and Australia (6) were the countries with the greatest number of publications after the USA, they were weak in terms of cooperation in articles about CMiCE. The universities the most influential in CMiCE were Purdue University and West Virginia University. The bibliometric analysis study on virtual reality in engineering education and training by Lai et al. (2020) also concluded, in a similar vein, that Purdue University was the most influential university.

Totally 239 different keywords were used about CMiCE. Following co-word/co-occurrence of author keywords analysis (minimum number of occurrences of a keyword: 2), 48 different keywords were included in 6 different clusters. The most frequently used keywords in the 127 articles were CMs (links:13, total links strength:21), concept mapping (links:10, total links strength:11), CM (links:7, total links strength:8), organic chemistry (links:13, total links strength:5), assessment (links:10, total links strength:13), and meaningful learning (links:4, total links strength:5). Chang and Yang (2022) also found that the most frequently used author keywords were CM, concept mapping, and CMs.

According to Guo et al. (2019), total links strength (TLS) values inform us of the number of documents in which two keywords co-occur. The ranking concerning the TLS values of the keywords is what follows: problem-solving/decision-making, curriculum, upper-division undergraduate, learning theories, organic chemistry, CMs, first-year undergraduate/general, and student-centered learning. The overlay visualization map which is obtained as a result of the analysis done with

VOSviewer can give us an idea about the trends in publications about CMiCE according to years and the trends in research subjects. The keywords in yellow and light green in Figure 8 give us information about the current research subjects of CMiCE. While such keywords as concept map/ping and meaningful learning were used more in studies of CMiCE at the beginning, they changed into such words as assessment, CMs, organic chemistry, learning theories, problem-solving/decision making, and curriculum through time.

An examination of the overlay visualization map showed that the keywords used in recent years were collaborative/cooperative learning, constructivism, hands-on learning/manipulatives, systems thinking, and formative assessment classroom techniques. Thus, it may be said based on these results that researchers use CMs rather as tools for teaching in recent years. "Formative assessment classroom techniques", for instance, is a keyword used by researchers in recent years and it was used only in two different studies (Babinčáková et al., 2020; Ganajova et al. 2021). The number of publications on digital CMs has also been increasing especially in recent years (Alt et al. 2022; Çakıroğlu et al., 2022; Eshuis et al., 2022). The new CMiCE publications in the future can be made in this area.

On looking at the journals with the greatest number of publications in them, the Journal of Chemical Education (JCE), and Chemistry Education Research and Practice (CERP) were found to be ranking at the top. In fact, the situation is related to the purpose of this study. Yet, it was a remarkable finding that the journal with publications about CMiCE ranking third was the Journal of Baltic Science Education (JBSE). Therefore, the researchers who are going to do research in CMiCE and the teachers/educators and students who study in this area should also see the journal mentioned here. The articles in the JCE were the articles that received the greatest number of citations. In addition to that, the International Journal of Science Education (IJSE) was also found to have a great number of citations even though only six articles were published in the journal. The total links strength (TLS) values of the journals were analyzed according to the results of citation analysis which was done to find the most influential journal in publications about CMiCE. The values found were as in the following: The JCE (TLS=77), CERP (TLS=61), the Journal of Research in Science Teaching (JRST) (TLS= 25), IJSE (TLS=17), the JBSE (TLS=15), the International Journal of Science and Mathematics Education (IJSME) (TLS= 12). Accordingly, the JCE can be said to be the most influential journal about CMiCE. It was an expected result for the JCE and CERP to be the journals containing the greatest number of publications and receiving the most citations. However, the other journals can also be said to be leading journals that are important in the area by considering their TLS values and the number of citations they receive. Tosun et al. (2021), in a study of bibliometric analysis on problem-based learning in chemistry education,

found that the JCE and CERP were the journals that published the greatest number of articles and were cited the most frequently.

The ranking of authors who have made the greatest number of publications on CMiCE is as follows: Nakhleh, Penn, Shavelson, Nandagopal, Lopez, and Szu. Taking the total number of citations received, Nakhleh is the author who has been cited more than the others. One can have an idea about the intellectual dynamics of the area by analyzing the most influential publications on CMiCE through citation analysis (Donthu et al., 2021). Although Rickey and Stacy (2000) and Nakhleh and Krajcik (1994) were the publications with the greatest number of citations concerning CMiCE, they were found to have a smaller number of links in the citation analysis network map. Chang and Yang (2022) found that Ruiz-Primo and Shavelson (1996) and Kinchin et al. (2000) were the publications that were cited the most. Significant data can be obtained about the similarities and differences between publications through citation analysis. It became apparent on looking at the number of links for citation analysis that Francisco et al. (2002), Pendley et al. (1994), Nicoll et al. (2001) and Burrows and Mooring (2015) ranked at the top. The result means that the studies were on similar subjects and similar areas. Thus, it may be said that they are among the CMiCE publications that should be read beside the ones which are cited the most.

The results of the co-citation analysis reveal the intellectual structure of a domain of research (Rossetto et al., 2018). It became apparent from the results of the co-citation analysis that the publications made by Novak JD along with other writers were the publications with the greatest number of citations. They were followed by Ruiz-Primo MA along with other writers. The publications made by Novak received the most co-citation along with Ruiz-Primo (link strength:157), Ausubel (link strength:148), Kinchin (link strength:62), and Nicoll G (link strength:62). Ruiz-Primo, for instance, was co-cited along with Taber (link strength: 31) and Kinchin (link strength: 28) second most after Novak. For example, Chang et al. (2022) and Chang and Yang (2022)- who conducted a bibliometric study on CMs- were the authors who were co-cited along with Novak and other writers according to the results of the co-citation analysis.

The current study had certain limitations. One of them was that it only used the WoS database for data collection. Using databases such as Scopus or Google Scholar could yield different results. Yet, using those databases would also cause some other limitations to arise (Martín-Martín et al., 2021). Another limitation of the current study was that the data downloaded from the WoS database were not the type of data that could directly be used for bibliometric analyses (Donthu et al., 2021). Deficiencies/mistakes were available in some of the data in terms of information about authors and countries. They were included in the analysis after correcting them. It was assumed that the results of the study were acceptable after the corrections.

The publications available until July 2022 were included in the scope of this study. Yet, such limitations are not likely to have a great impact on the results of bibliometric studies (Djeki et al., 2022). As a result, this study used bibliometric analysis to analyze the current state of articles concerning the use of CMiCE and their trends. It analyzed 127 articles on CMiCE available on the WoS database. In conclusion, it may be said based on the analyses of the articles that the importance of CMs in chemistry education is increasing more and more.

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