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21st Century Skills in Mathematics and Science Education: A Bibliometric Analysis

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Abstract

This research aims to develop a detailed bibliometric map of all published academic works concerning 21st-century skills in the fields of mathematics and science education (MSE). By utilizing the Web of Science (WoS) database, the analysis covered 312 publications authored by 913 researchers from 56 different countries, spanning the years 2001 to 2024. The study examined various dimensions, including scientific output, network analysis, thematic trends, changes in themes, and the conceptual framework of the literature in this field. The bibliometric analysis revealed that while the number of annual publications varies, citation counts show a steady increase. Key contributors to this area of research include Zubaidah, Mahanna, Susilo, and Harun, with the University of Nigeria Malang recognized as the most productive institution. The leading countries represented by corresponding authors are the USA, Germany, and Indonesia. Network analysis revealed significant connections between the journals Computers & Education and Computers in Human Behavior. Commonly used terms in the literature include students, technology, education, 21st-century skills, science, and mathematics, while trending topics feature technology, critical thinking, thinking skills, and STEM. The conceptual analysis indicated that about 30% of the variability was accounted for by the most effective size reduction identified. The study concludes with several recommendations based on its findings.

Introduction

In recent years, educational systems across various nations have sought to develop individuals who can effectively contribute to the economy, embrace social and scientific progress, and acquire skills pertinent to the twenty-first century. These competencies have gained prominence in the context of the current information age (Sayın & Seferlioğlu, 2016). While there is no universal agreement regarding the definition of twenty-first-century skills within academic discourse, several institutions and organizations have attempted to delineate these competencies (Çolak, 2018). Notable entities in this domain include the Partnership for 21st Century Learning (P21), the Organization for Economic Co-operation and Development (OECD), Asia-Pacific Economic Cooperation

(APEC), the International Society for Technology in Education (ISTE), the North Central Regional Educational Laboratory (NCREL), the European Commission (EC), and the American Association of School Librarians (AASL) (APEC, 2008; EC, 2018; ISTE, 2016; OECD, 2012; P21, 2007). Among these, P21 is particularly recognized in the literature for its comprehensive research, which categorizes twenty-first-century skills into three primary themes: the Learning and Innovation Skills Category, encompassing critical thinking, problem-solving, creative thinking, and collaboration; the Life and Career Skills Category, which includes adaptability, initiative, social skills, and leadership; and the Information, Media, and Technology Skills Category, focusing on information literacy and ICT literacy (P21, 2009).

The categorization of skills pertinent to the 21st century predominantly highlights competencies such as problem-solving, collaboration, communication, and critical thinking, as noted by Anagün et al. (2016). Additionally, there is a significant focus on technological literacy alongside social and cultural competencies, as discussed by Erten (2020). In a similar vein, Lai and Viering (2012) have underscored the importance of critical thinking, creativity, self-directed learning, and collaboration within this skill set. Conversely, Köğce et al. (2014) have pointed out that the foundation of 21st-century skills lies in information literacy and the principles of lifelong learning. Various classifications of these skills are illustrated in Figure 1.

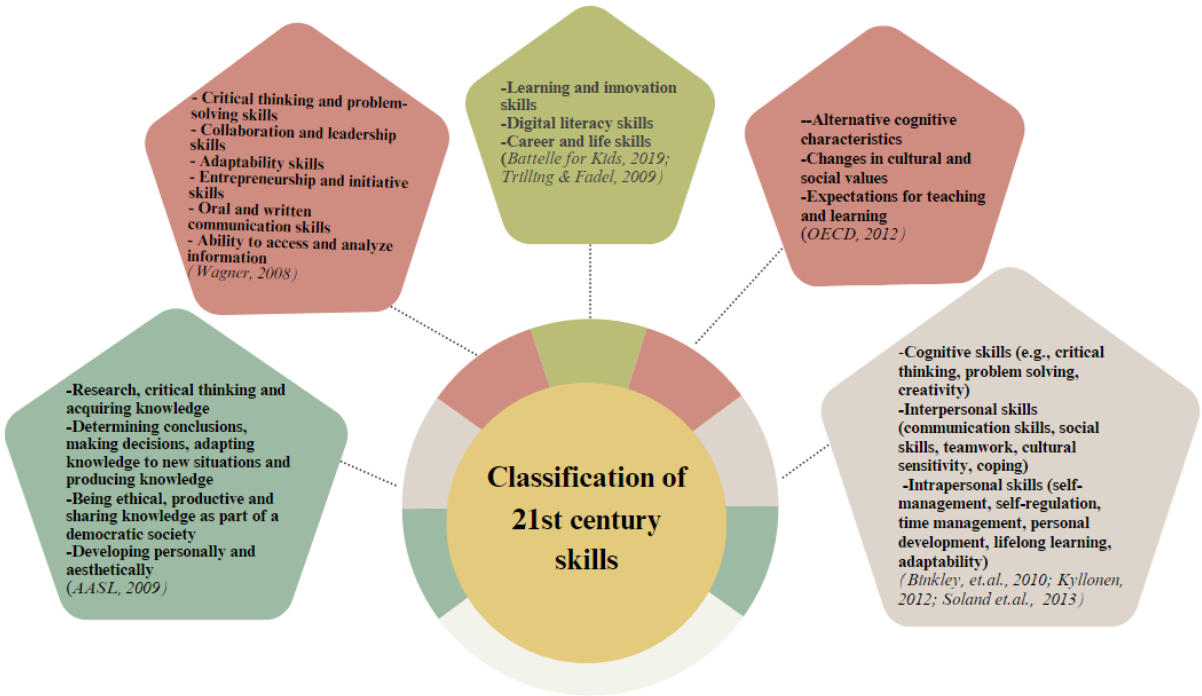

Figure 1. Classification of 21st-Century Skills

The analysis presented in Figure 1 illustrates a prevailing agreement regarding the essential skills required in the 21st century, emphasizing the importance of universally applicable competencies that serve individuals well within a collaborative, knowledge-driven, and technology-oriented economic and social context (AASL, 2009; Battelle for Kids, 2019; Binkley et al., 2010; Kyllonen, 2012; OECD, 2012; Soland et al., 2013; Trilling & Fadel, 2009; Wagner, 2008). Despite the existence of various classification systems, there is a notable consistency in the

inclusion of certain skills across these frameworks. Consequently, it is anticipated that individuals should demonstrate proficiency in a range of competencies, including teamwork, technological proficiency, effective communication, digital literacy, critical thinking, problem-solving, creativity, productivity, and the ability to gather information from diverse sources (Gore, 2013; Voogt & Roblin, 2012).

The evolving dynamics of society and the economy necessitate that individuals acquire new skills and competencies, enabling them to engage with innovative forms of social interaction and to play an active role in economic advancement (Ananiadou & Claro, 2009; Greenhill, 2010; Luna Scott, 2015; P21, 2007; Saavedra & Opfer, 2012). The imperative to equip individuals with 21st-century skills has emerged as a crucial requirement (Autor et al., 2003; P21, 2008). Mastery of these skills not only facilitates success in professional environments but also enhances educational outcomes (Ball et al., 2016). It is essential for individuals to begin acquiring these competencies during early childhood to ensure their success throughout their educational journeys (Louis, 2012). Numerous scholars emphasize the significance of imparting these skills in the context of global economic competition and workforce readiness (Rotterdam & Willingham, 2009; Saavedra & Opfer, 2012). A primary driver for the necessity of these skills is the rapid pace of technological advancement, which profoundly influences societal cultural life and heightens the demand for 21st-century skills in the workforce amid economic rivalry (Kellner, 2000; P21, 2019). This scenario underscores the expectation that individuals must receive training in essential 21st-century skills, including critical and scientific thinking, problem-solving, and the application of cognitive skills, particularly within mathematics and science education, where these competencies are prominently emphasized.

Consequently, this study will serve as a vital resource for researchers exploring this subject, while also playing a pivotal role in shaping and guiding future investigations into 21st-century skills within the realm of mathematics and science education (MSE):

RQ 1. What are the patterns of articles with 21st-century skills in MSE content according to years and citation count?

RQ 2. What authors, institutions, and countries have contributed the most to 21st-century skills in MSE research?

RQ 3. Which authors and journals are closely linked to the topic of 21st-century skills in MSE?

RQ 4. Which authors and countries are involved in collaborative research on 21st-century skills in MSE?

RQ 5. How is the distribution of keywords and co-occurrence in research on 21st-century skills in MSE?

RQ 6. What are the trending topics and thematic changes in 21st-century skills in MSE research?

RQ 7. How do the conceptual structure and thematic map in 21st-century skills in MSE research change?

Method

Research Design

This research presents a comprehensive bibliometric analysis of academic publications from 2001 to 2024 that focus on the theme of 21st-century skills within the context of mathematics and science education (MSE). Utilizing bibliometrics, the study employs statistical methods to analyze both the scientific literature and the

authors responsible for its creation. Through quantitative examination of scholarly articles, the analysis aims to provide readers and researchers with an in-depth understanding of the identified research topic over a defined temporal scope.

Bibliometric analysis serves as a practical and insightful approach for delineating relevant fields of study. By conducting descriptive and performance analyses, this method allows for a thorough evaluation of sources and document types. Additionally, scientific mapping and network analysis can be employed to explore document relationships. The bibliometric evaluation encompasses two primary advantages: structural and dynamic analysis phases. The phase of dynamic analysis examines various impact metrics, including publication and citation counts, timelines of authors, significant trends or changes in terminology, as well as the frequency and distribution of keywords, in addition to the h-index.

In contrast, structural analysis emphasizes indicators such as word dendrograms, maps of concepts and themes, networks of co-occurrence, patterns of collaboration, and traditional citation networks (Jamali et al., 2022). The research adhered to the framework established by Arksey and O'Malley (2005), which provided a systematic approach for identifying research topics or questions, sourcing relevant literature, selecting studies, creating datasets, analyzing the data, summarizing the findings, and discussing the results. This methodological rigor aimed to bolster the reliability of both the dataset and the overall research endeavor.

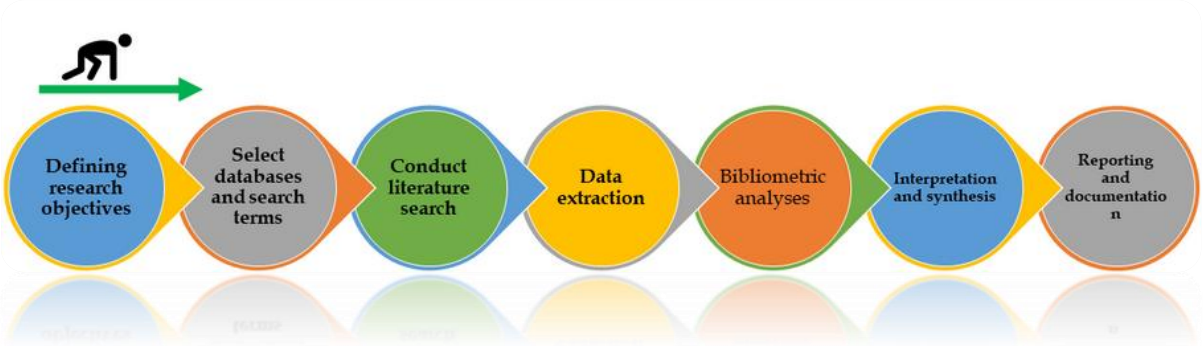

Figure 2. Process Followed in the Study

Data Collection and Analysis

A comprehensive database focused on 21st-century skills in mathematics and science education was developed utilizing the Web of Science™ Core Collection. This database, managed by Clarivate Analytics, encompasses a wide array of academic disciplines. The decision to utilize the WoS database was influenced by several critical factors, including its extensive range of topic categories, access to peer-reviewed full-text articles, reputable journals, partnerships with 220 publishers, and a wealth of reference materials (Web of Science Group [WoSG], 2023). The exponential growth of scientific literature presents a significant challenge for researchers striving to stay informed about developments in their fields (Aktoprak & Hursen, 2022). Consequently, the WoS database was selected for its repository of reliable and validated research studies.

Bibliometric methods were employed to analyze the foundational structure of the identified domain (Donthu et al., 2021). In this context, the primary elements considered during the data collection process included the title, keywords, and abstract sections. Notably, the abstract is the most frequently consulted section, as it encapsulates the essence of the entire study, while the keywords serve as specific terms that offer insight into the research focus. Initially, a review of scientific literature pertaining to 21st-century education in science and mathematics was conducted, resulting in the identification of 1,138 documents through a preliminary search in the WoS database using the query [Title-Abs-Key ("21st century") AND ("math and science education"). Following this initial search, a secondary scan was executed, incorporating the author's keywords, title, abstract, and keywords plus, which yielded 1,005 relevant items. Subsequently, the search was refined to include only articles, limiting the publication years to 2001–2024, ultimately resulting in a final dataset of 312 articles. The selected articles from the WoS database that aligned with the research topic were then saved in "Plain Text" format, and the files were downloaded accordingly.

Data Analysis

Conventional literature reviews often rely heavily on the expertise, viewpoints, and capabilities of researchers or their affiliated institutions. Subsequently, a narrow array of analytical methods is employed to present the findings. In contrast, this study opted for bibliometric analysis due to its ability to illuminate the evolution of knowledge structures and the research domains identified in published works (Pritchard, 1969). Bibliometric analysis enables a systematic and quantitative evaluation of scholarly documents, focusing on various elements including authorship, topics, citation patterns, sources, and publication metrics. This approach not only delineates the specific discipline under investigation but also provides a broader context across various fields. The methodology of bibliometric analysis is characterized by descriptive and scientific mapping techniques. To assess the data collected, both descriptive analysis and scientific mapping methods were employed. Within the scope of descriptive analysis, key data sources, including journals, authors, and documents, were scrutinized. Comprehensive investigations were conducted under the scientific mapping framework, utilizing visualization techniques such as theme maps, three-field plots, and network analysis.

In their research, Van Eck and Waltman (2010) employed the VOSviewer software to visually depict the similarities within the dataset, facilitating both structural and dynamic analyses. Additionally, they utilized the R-tool 4.2.2 from the Bibliometric package, designed for quantitative bibliometric studies as outlined by Aria and Cuccurullo (2017), to further investigate the dataset. The analysis was grounded in descriptive studies derived from the Web of Science (WoS) database. By leveraging the connections among articles through the VOSviewer tool, the researchers assessed the strength of these interconnections. This software not only aids in generating visualizations that encapsulate related research topics but also enhances collaboration among authors, institutions, and countries by linking articles based on data sourced from the WoS database, as noted by Yuan et al. (2021). VOSviewer is frequently favored by researchers conducting bibliometric analyses, and it is available for free download at https://www.vosviewer.com, ensuring open access. According to Van Eck and Waltman (2010), the VOSviewer tool significantly simplifies the direct visualization and interpretation of extensive bibliometric maps, thereby enhancing the understanding of large datasets in scientific research.

One can systematically organize bibliographic matching, co-authorship relationships, publication networks, journals, researchers, co-citation patterns, and terminology utilized in manuscripts. Conversely, the conceptual, intellectual, and social frameworks of the dataset were examined, alongside a comprehensive analysis of the authors and documents, facilitated by the R-tool software. The RStudio program, which is integrated within the Bibliometrix framework, enables the execution of quantitative analyses pertinent to the research topic. This open-source software can be freely downloaded from www.rstudio.com. Within this program, an item is characterized as an object of interest, while elements and connections symbolize groups and entities within a network. In addition to the primary subjects explored in these analytical investigations, other frequently employed data encompass keywords, annual publication distribution, citation counts, abstract terminology, prolific authors, institutions, countries, and the most frequently cited authors (Kaya & Kutluca, 2024).

Validity, Reliability and Ethics

The procedure was thoroughly described in order to improve the research's validity as well as to make clear how the data were collected. Furthermore, the data set's collection date, the modules utilized in the WoS database, the limits imposed, and the assessment method during data analysis were all described. The techniques were also described during the data-collecting and processing phases. The results were given without commentary to guarantee the validity of the study. They prioritized the consistency of the data, which allowed for a discussion of the findings within the framework of relevant literature.

Results

This section represents the findings derived from the subproblems of the research. Initially, it outlines the volume of citations and the temporal distribution of academic publications concerning 21st-century skills. Subsequently, it highlights key findings regarding the authors, institutions, and countries that have significantly contributed to the pedagogy of 21st-century skills in the domains of science and mathematics. The following segment details the journals that are specifically associated with the instruction of these skills, along with the contributors—authors, organizations, and nations—engaged in collaborative efforts. An analysis of cluster distributions based on author collaborations is then provided.

Finally, the section concludes with the presentation of the conceptual framework and thematic maps that illustrate prevalent topics and search terms relevant to science and mathematics education in the 21st century. The findings encompass various aspects, including scientific output, network analysis (co-citation, collaboration, keywords, co-occurrence, and author clustering), emerging topics and thematic development, conceptual frameworks, and thematic mapping.

Scientific Production on 21st Century Skills in MSE

The chart provided here illustrates the annual publications and citations related to 21st-century skills in mathematics and science education from 2001 to 2024. Figure 3 shows the yearly output associated with this

research field, based on data obtained from the Web of Science (WoS) database.

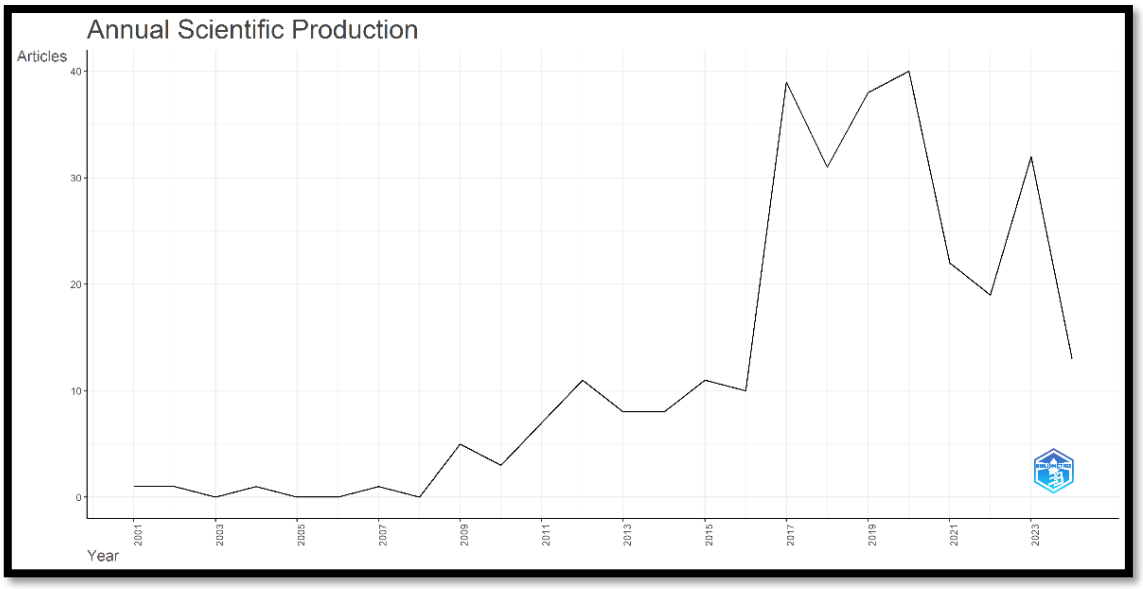

Figure 3. Annual Scientific Production on 21st Century Skills in MSE

The research findings concerning 21st-century skills in MSE are illustrated in Figure 4. Notably, the year 2017 saw the publication of 38 papers, while 2020 recorded an increase to 40 articles published annually. In contrast, the years 2003 and 2008 experienced the lowest output, with no articles published during those periods. Additionally, a modest number of one to four papers were produced in the years 2001, 2002, 2004, 2005, 2006, 2007, and 2010. Although there was a decline to 18 publications in 2022, the trend has shown an upward trajectory in 2023, with expectations for continued growth in the forthcoming years. Below, further details regarding the authors of the most significant publications in this field are provided.

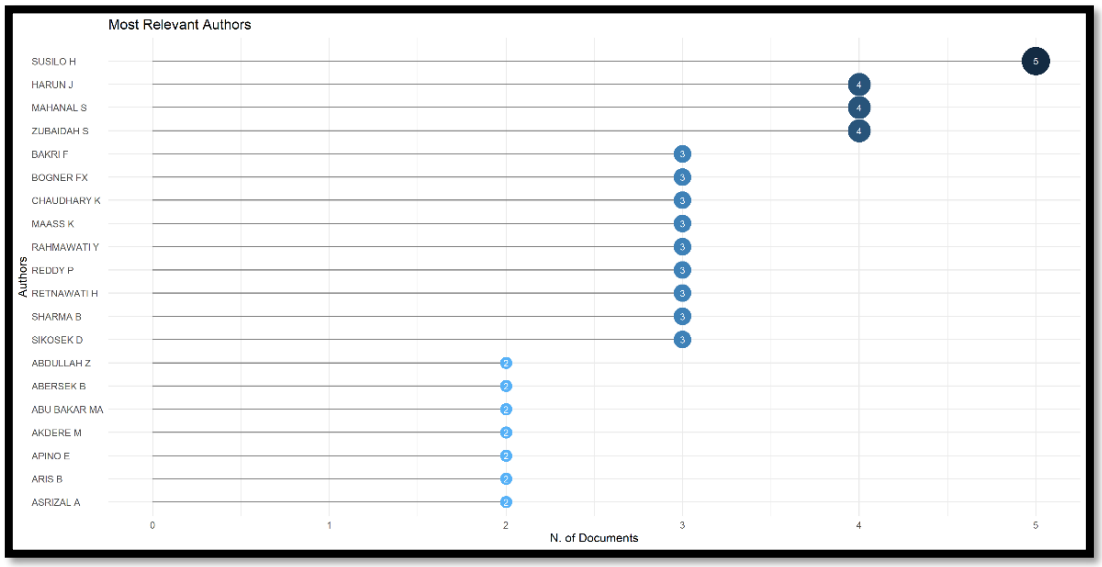

Figure 4. Most Productive Authors on 21st Century Skills in MSE

Figure 4 illustrates the authors who have significantly impacted the development of 21st-century skills in MSE over the last 24 years. Notably, the most prolific contributors to this field are Susilo, H., with five publications, followed by Harun, J., Mahanna, S., and Zubaidah, S., each of whom has authored four articles. Additionally, several other scholars, including Bakri, F., Bogner, F.X., Chaudhary, K., Maass, K., Rahmawati, H., Sharma, B., and Sikosek, D., have each contributed three publications to this area of study. An analysis of these authors will be provided, focusing on their national affiliations.

A detailed examination of Figure 5 reveals that the majority of authors contributing to the discourse on 21st-century skills within the context of MSE primarily hail from two countries: the United States and Indonesia. The data indicates that a significant number of authors originate from various nations, including Germany (approximately 15), Australia (around 14), Malaysia (close to 24), Turkey (about 18), China (nearly 17), Slovenia (roughly 16), Indonesia (approximately 70), and the United States (nearly 65). Notably, the analysis uncovers that there is only one author representing each of the countries of Brazil, Bulgaria, Estonia, Fiji, Ireland, the Philippines, the UK, and Austria in the articles reviewed. The figure below illustrates the distribution of authors who have emerged as key contributors to the exploration of 21st-century skills in MSE.

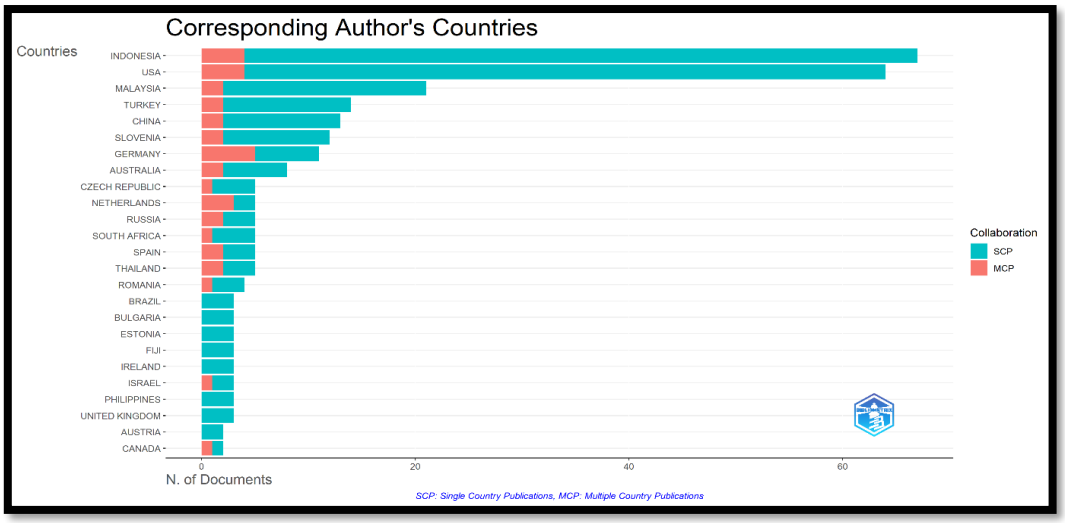

Figure 5. Corresponding Author's Country on 21st Century Skills in MSE

The authors who have ultimately established their dominance in the field are illustrated in Figure 6. The calculation of author dominance is determined through the dominance factor, which is derived by dividing the total number of papers with multiple authors by the number of publications with multiple authors where the author is listed as the first author (Kumar & Jan 2014). An analysis of the figure reveals the significant contributions of the Susilo authors from 2019 to 2023, Harun from 2014 to 2018, and Sikosek from 2009 to 2013. Additionally, several other authors have emerged as key figures during their respective periods. Notably, Zubaidah, Boner, Mahanal, and Maas have been particularly influential between 2019 and 2023, while Abdullah and Aris held prominence from 2016 to 2018, and Asrizal served as the primary author from 2018 to 2022. The subsequent chart provides data regarding the MSE institutions that have demonstrated higher productivity in the context of 21st-century skills.

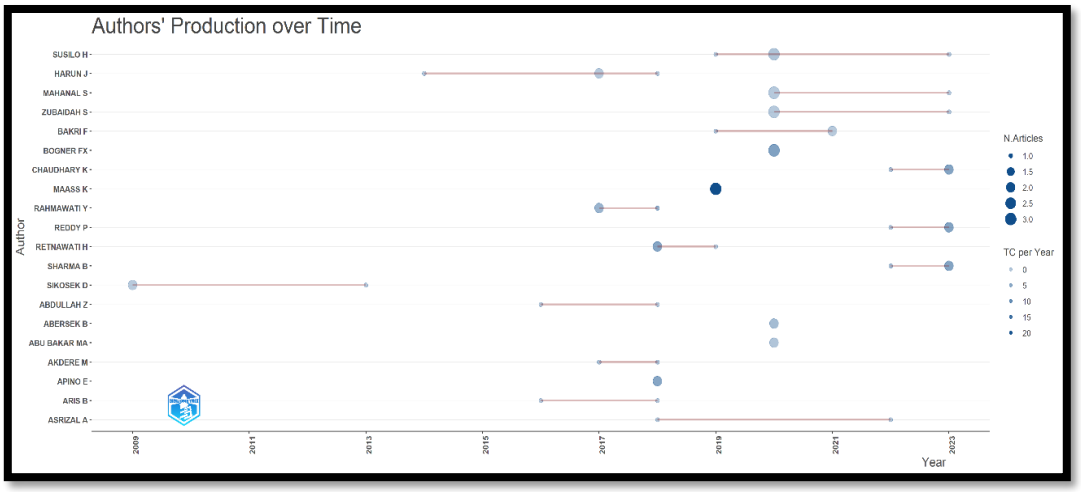

Figure 6. Authors' Production over Time on 21st Century Skills in MSE

An analysis of Figure 7 reveals that the University of Negeri Malang stands out as the leading institution in terms of contributions to 21st-century skills within the context of MSE, having published 45 articles. This is succeeded by the University of Maribor with 30 articles, followed by Teknol Malaysia with 25 articles, and Negeri Jakarta with 21 articles. Additionally, Yok Yakarta State University has contributed 20 articles, while Pendidikan Malaysia Indonesia has published 17 articles. Negeri Padang follows with 13 articles, and Pontificia University of Catolica Chile has produced 10 articles, with other institutions contributing fewer than ten articles. The subsequent section provides insights into the countries that have made the most references to 21st-century skills in MSE.

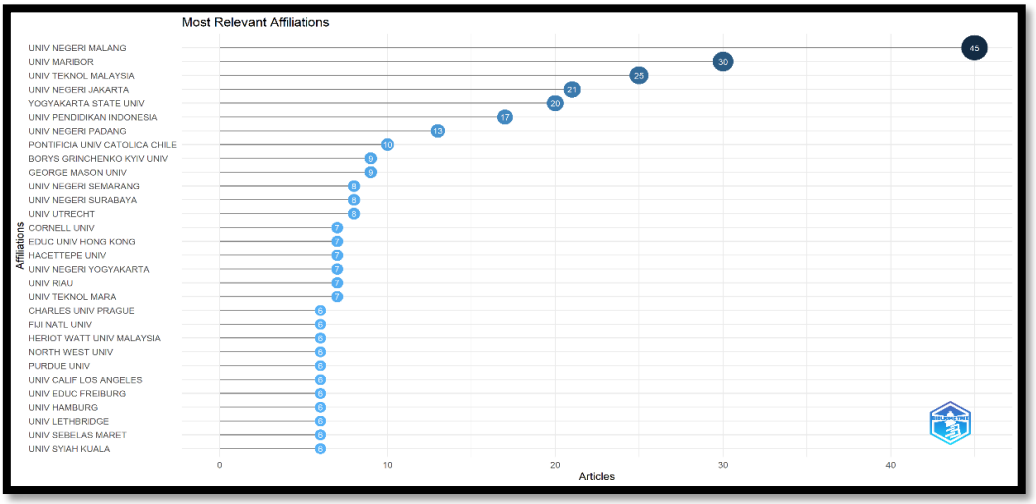

Figure 7. Most Relevant Affiliations over Time on 21st Century Skills in MSE

Upon analyzing Figure 8, it is evident that the United States (n=730) ranks as the most frequently cited country in the dataset. This is succeeded by Germany (n=205), Indonesia (n=163), and the Netherlands (n=162), with Chile (n=148) and Sweden (n=117) also featuring prominently. Other notable mentions include Australia (n=99), Turkey (n=79), and Malaysia (n=78), followed closely by Spain (n=77), Korea (n=44), and Thailand (n=42).

Additionally, Mexico (n=34), New Zealand (n=33), and China (n=32) contribute to the citations, while Israel (n=19), Fiji (n=17), and Slovenia (n=17) are also represented. Cyprus (n=15) and the United Kingdom (n=15) share similar citation counts, with Russia (n=12), Finland (n=11), Canada (n=10), the Czech Republic (n=9), and South Africa (n=9) rounding out the list. The subsequent section will delve into network analysis, trending topics, and the thematic evolution of articles related to 21st-century skills in the context of MSE.

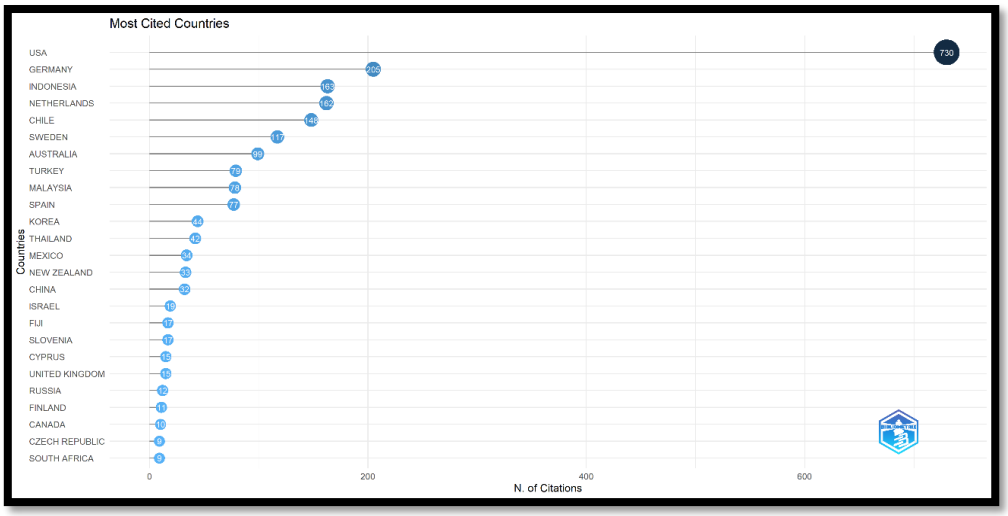

Figure 8. Most Cited Countries on 21st Century Skills in MSE.

Network Analysis on 21st Century Skills in MSE

This section presents a comprehensive network analysis of scientific research concerning 21st-century skills in the context of MSE, spanning the years 2001 to 2024, with a focus on thematic development and emerging trends. The analysis highlights the evolution of themes and the identification of trend-related issues within the body of research. Co-citation analysis, depicted in the accompanying image, refers to the frequency with which two research studies are cited together, providing insights into their interrelatedness. This analytical approach illustrates the citation frequency of two distinct research units within the same scholarly work, as noted by Bagis (2021). In essence, it serves as a visual representation of the co-citation dynamics among studies, with the figure below illustrating the network visualization of this analysis within the relevant academic journals.

The analysis of co-citation networks within the realm of academic journals is illustrated in Figure 9. The MSE established a criterion that any referenced journal focusing on 21st-century skills must have a minimum of two citations. Within the dataset utilized for this research, a total of 6,407 papers were cited, of which 1,312 met the established threshold. These figures align with the predetermined threshold value. It is logical that the selected color scheme would emphasize journals with differing degrees of connectivity. Notably, the journals Computers & Education and Computers in Human Behavior are prominently featured within the blue cluster, while the purple cluster is primarily represented by the journals Educational Studies in Mathematics, ZDM Mathematics Education, and the International Journal of Science Education. The green cluster indicates stronger associations among the journals related to Educational Technology & Society.

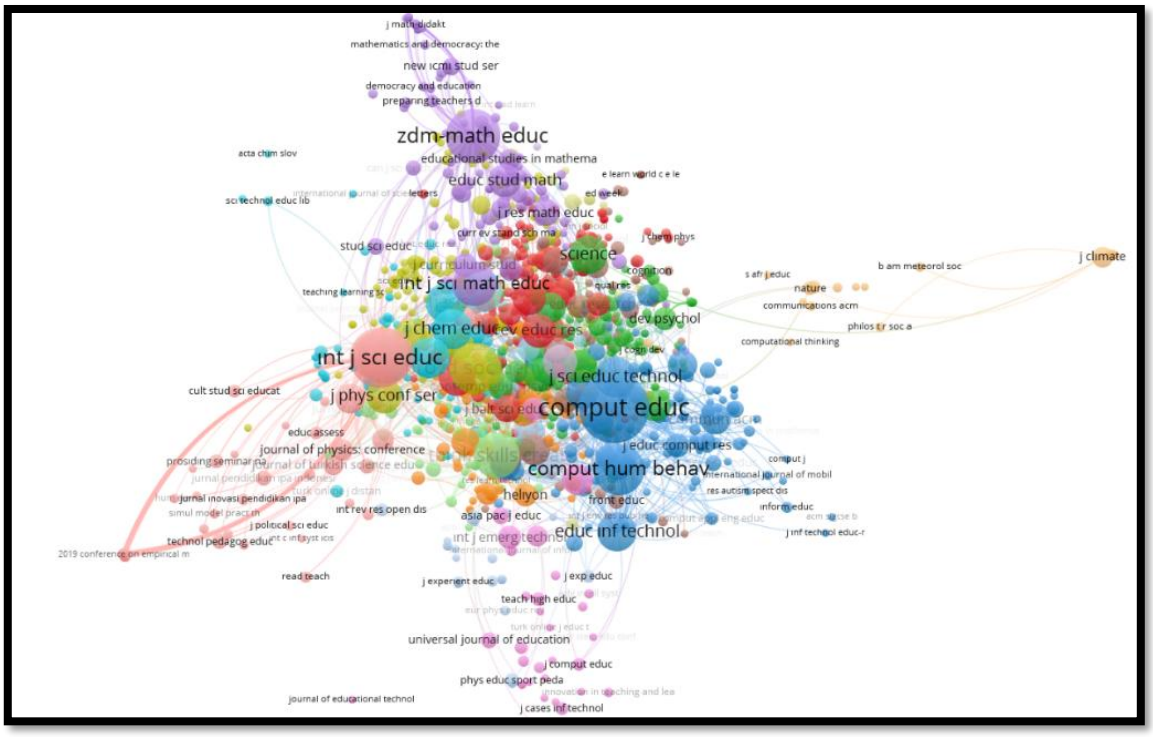

Figure 9. Co-citation Network in the Context of A Journal

Collaboration Networks Analysis on 21st Century Skills in MSE

The results of the co-author network analysis concerning authorship are presented in Figure 11 below. This diagram reveals the limited collaboration among authors on 21st century skills within the context of MSE. Furthermore, alongside the authors identified as Aris, B., Mohammed, H., and Abdullah, Z., it is clear that Susoni, H., Lestari, U., Susilo, H., Mahanal, S., and Setiawan, D. are collaborating within a distinct cluster.

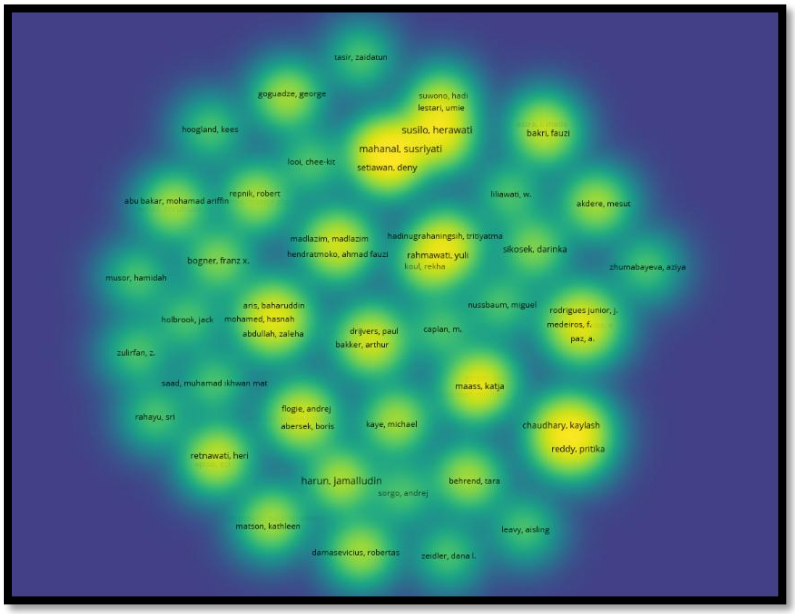

Figure 10. Co-Authors Network Analysis in the Context of Authorship

In addition to these, on the below, Figure 11 represents the co-author network analysis with respect to the countries. The analysis of co-authorship by country is illustrated in Figure 11. This network examination, encompassing 56 nations, reveals that certain countries, such as Australia, Canada, Turkey, the United States, and Indonesia, hold a more significant position within the network. The turquoise cluster comprises Turkey, Australia, Ireland, and Norway, while the dark blue cluster includes England, Switzerland, Ireland, and New Zealand. Notably, the collaboration among nations like the Philippines, Singapore, Canada, and Indonesia is highlighted within the green cluster. Additionally, the purple cluster features countries such as the United States, Turkey, Brazil, and Germany, whereas the red cluster consists of the Netherlands, South Africa, and Thailand. The subsequent representation illustrates the global collaboration network.

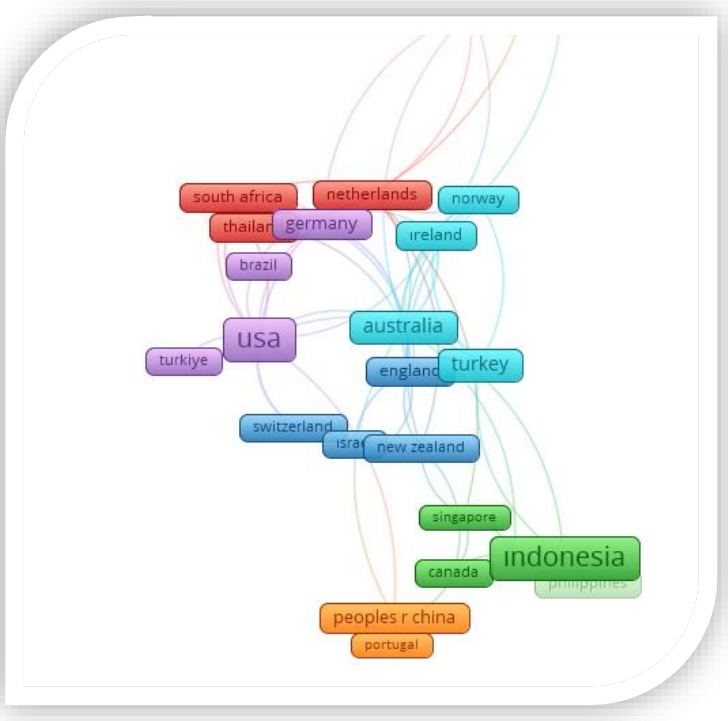

Figure 11. Co-authors Network Analysis with Respect to Countries

Figure 12 offers a more distinct representation of the collaborative efforts among various countries. This illustration emphasizes the significant connections among the United States, Turkey, Brazil, Germany, the Netherlands, South Africa, Thailand, and Indonesia, alongside the interactions involving the United States, Turkey, Canada, Australia, and Indonesia, as well as Canada, Singapore, the Philippines, and the United States. One could contend that while these nations exhibit some level of collaboration, it is not particularly robust.

In the context of MSE research focusing on 21st century skills, Figure 13 presents a visual representation of the most frequently employed terms associated with these skills, including technology, mathematics education, assessment, computational thinking, project-based learning, critical thinking, science, and creativity. To gain a more nuanced understanding of the frequency with which these keywords appear together, we conducted a co-word network analysis. This analysis specifically examined the co-occurrence of terms as articulated by the authors, thereby illustrating the relationships and interactions among the keywords in the accompanying graphic.

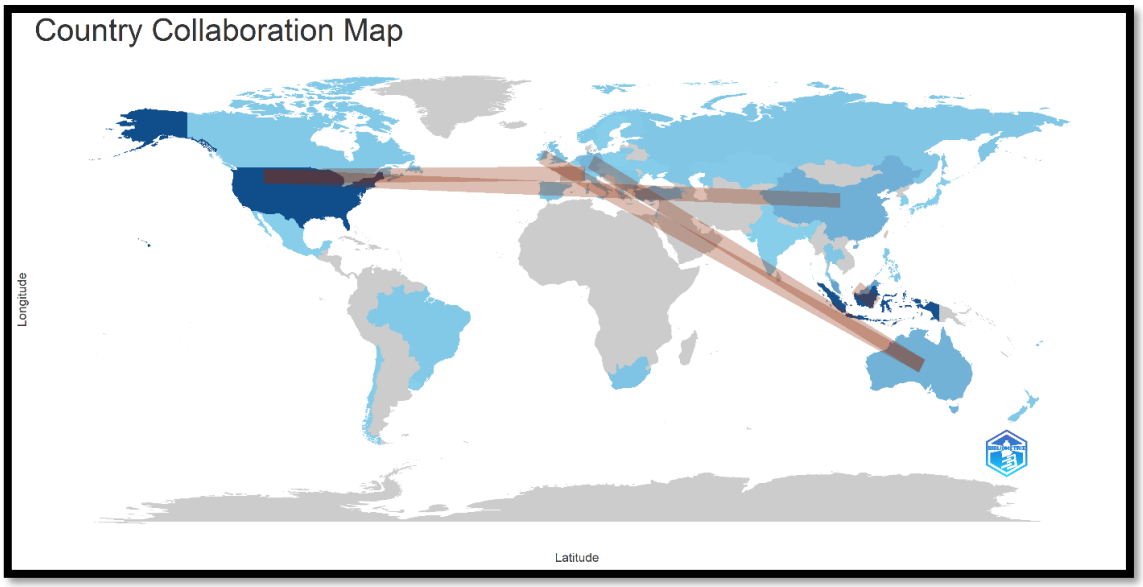

Figure 12. Authors' World Collaboration Network on 21st Century Skills in MSE

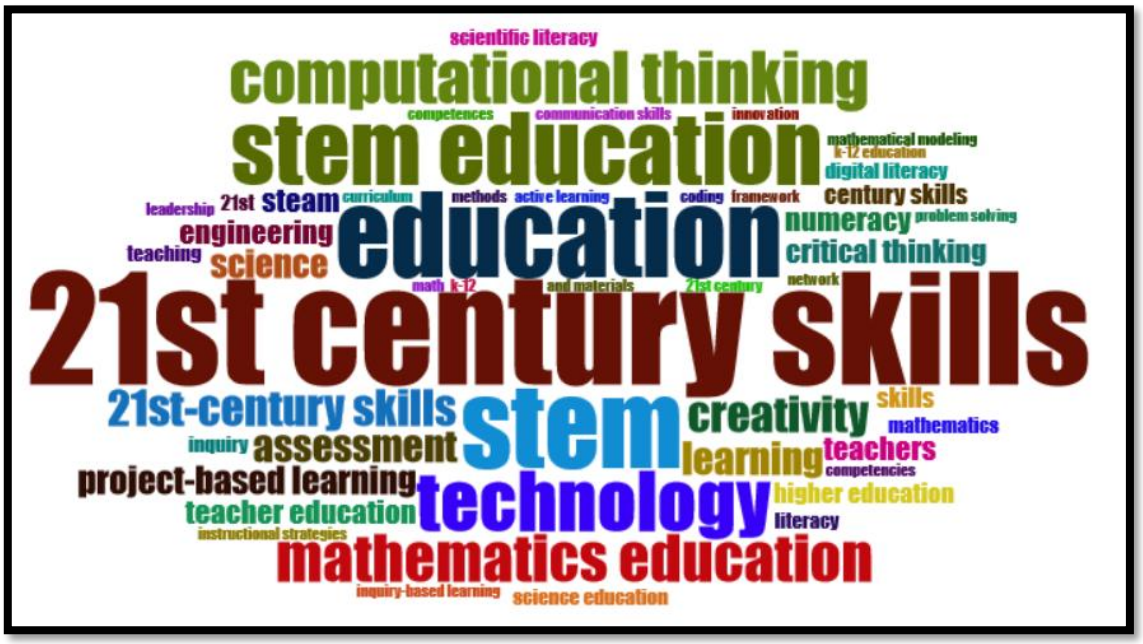

Figure 13. Word Cloud for 21st Century Skills in MSE

The analysis of co-word networks is presented concerning author keywords, as illustrated in Figures 14a and 14b. Given that the focus of the studies pertains to 21st-century skills within the context of MSE, a minimum citation count of two was established. This criterion reveals that a total of 843 papers were referenced from the studies included in the dataset utilized for this research, with 103 of these cited works meeting the established threshold. Upon examining the figure, terms such as "critical thinking," "science," "creativity," "21st century skills," "technology," "mathematics education," "education," "STEM," "computational thinking," "assessment," "project-based learning," and "STEM education" emerge as increasingly significant. The relationships among keywords (on the left), authors (in the middle), and institutions (on the right) are depicted in a three-domain diagram,

commonly referred to as a Sankey diagram, which serves to illustrate the flow trends of scientific literature concerning 21st-century skills in MSE.

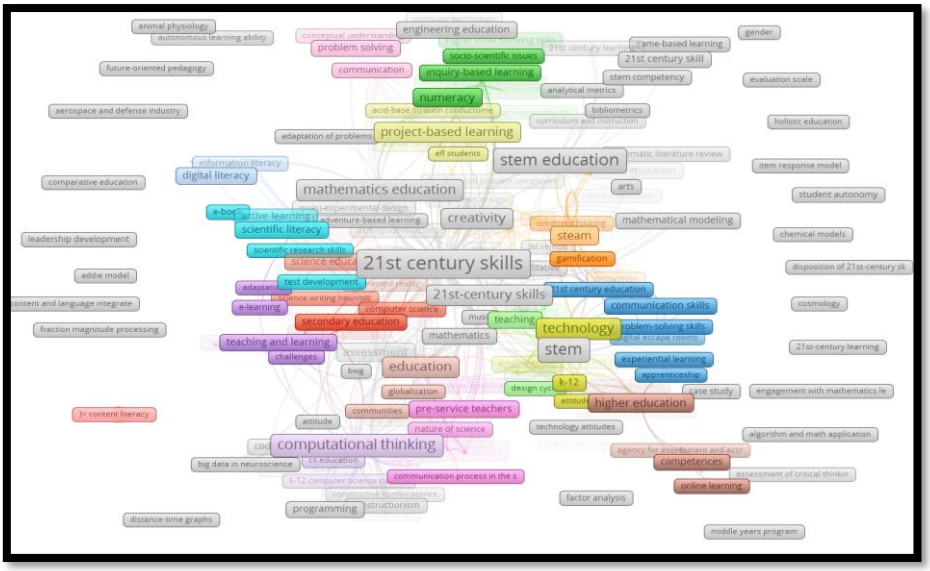

Figure 14a. Co-Word Network Analysis in the Context of Author Keywords

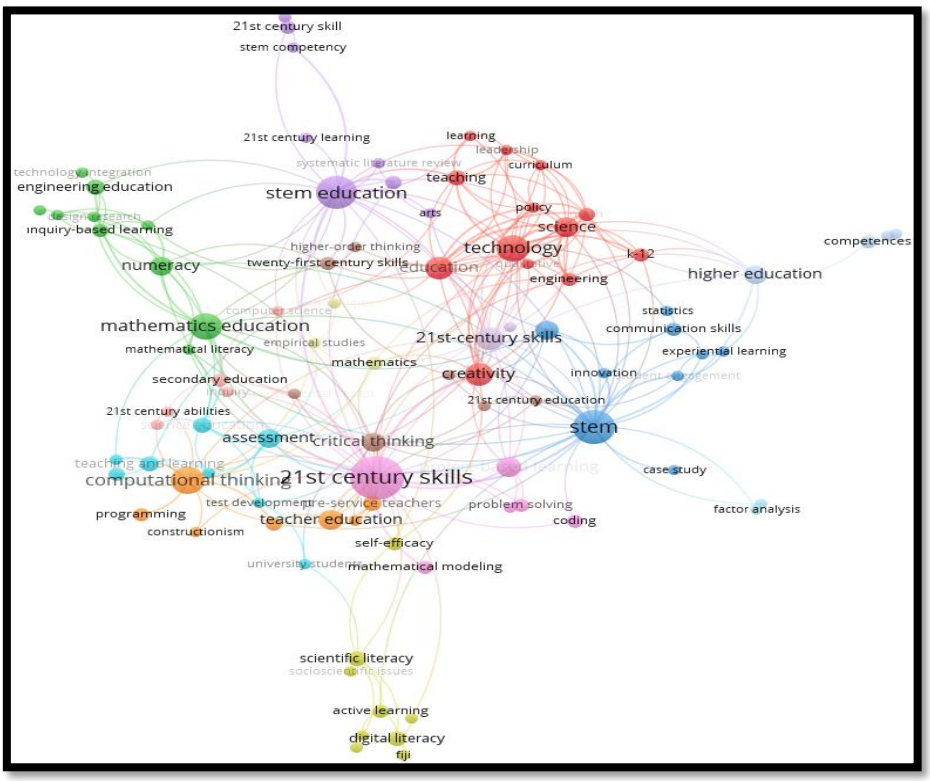

Figure 14b. Co-Word Network Analysis in the Context of Author Keywords

An analysis of Figure 15 reveals a correlation between the dimensions of the boxes and the number of associated linkages, which may include keywords, authors, or institutions. The keywords "stem education," "project-based learning," "steam," "creativity," and "21st century skills" exhibit larger margins compared to other terms, as

illustrated in the figure. The presence of substantial margins indicates that many authors incorporate these keywords into their works. It is particularly significant to note that a considerable number of authors, including Gieger, V., Gravemeijer, K., Voogt, J., and Binkley, contribute to a comprehensive array of keywords, reflecting the breadth of the research landscape through the interconnections among authors, keywords, and institutions.

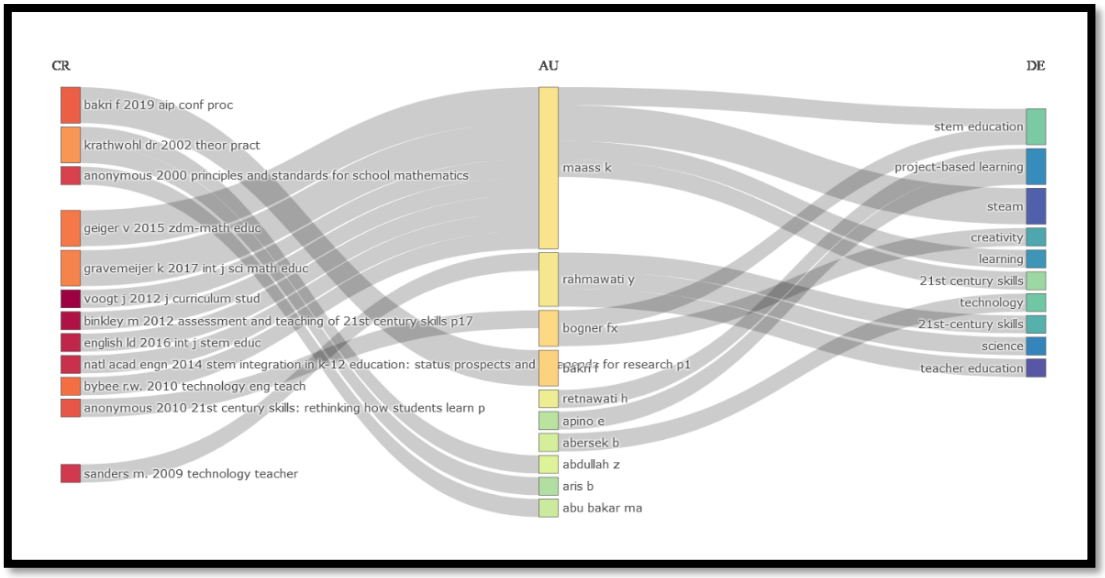

Figure 15. 21st Century Skills in MSE in Sankey Plot (Keyword- Author-Affiliation)

Figure 16 illustrates the co-word network analysis pertaining to author keywords, employing the tree-map technique for visualization. The analysis reveals that the most frequently utilized keyword is "education," which accounts for 10% of the total occurrences, appearing 32 times. Following this, "students" is noted with a frequency of 27 occurrences, representing 8% of the total. The keyword "science" appears 24 times, constituting 7%, while "skills" is mentioned 15 times, making up 5%. Lastly, "technology" is recorded 13 times, corresponding to 4% of the total keyword usage.

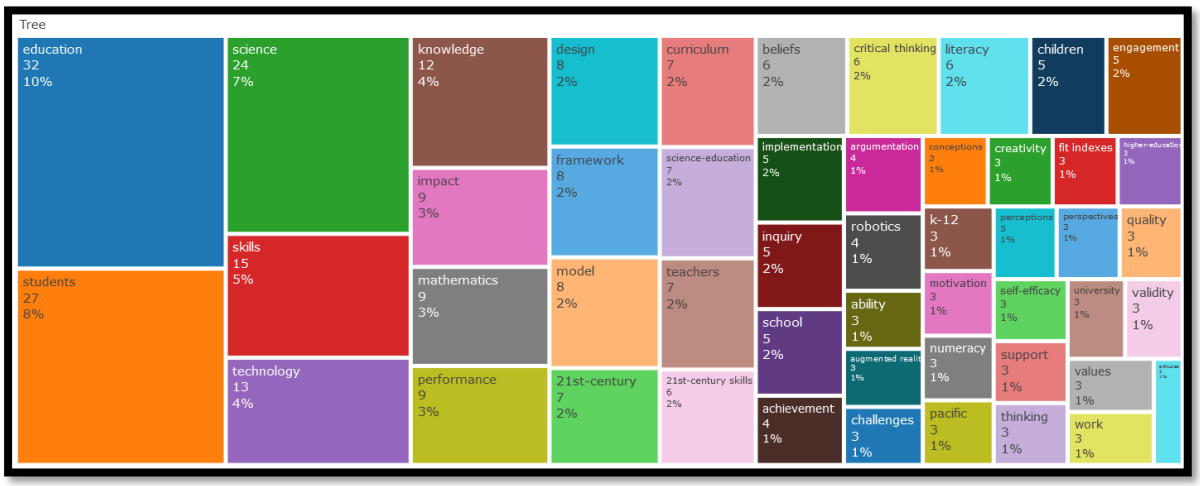

Figure 16. Co-Word Tree-Map Network Analysis in the context of Author Keywords

Trending Topics and Thematic Evolution on 21st Century Skills in MSE

The analysis of trending keywords associated with 21st-century skills within the context of MSE is illustrated in Figure 17. A pivotal aspect of this research involves the selection of keywords, which significantly reflects the core of the study. The trend topic map reveals a preference for terms such as "knowledge" (2021–2023), "skills" (2021–2023), "students," and "education" (2019–2021), along with "science," "technology," and "science education" (2019–2021), and "21st-century skills" (2022–2023). In contrast, the terms "impact" (2022–2023) and "curriculum" (2022–2023) are less favored. The examination of study keywords over time offers insights into emerging patterns and facilitates the tracking of content evolution in research endeavors. This analysis not only highlights significant trends but also presents valuable opportunities and recommendations for future investigations within the same domain. The following trend topic map, derived from the titles, underscores the findings related to 21st-century skills as identified through MSE.

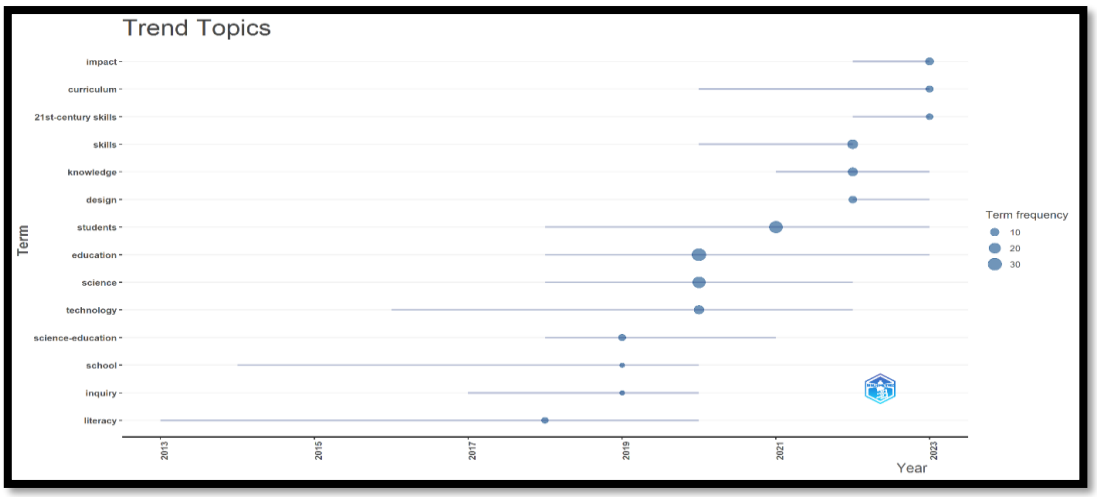

Figure 17. 21st Century Skills in MSE Trending Topics Map (Keywords Plus)

Figure 18 illustrates the popular article titles related to 21st century skills within the context of MSE.

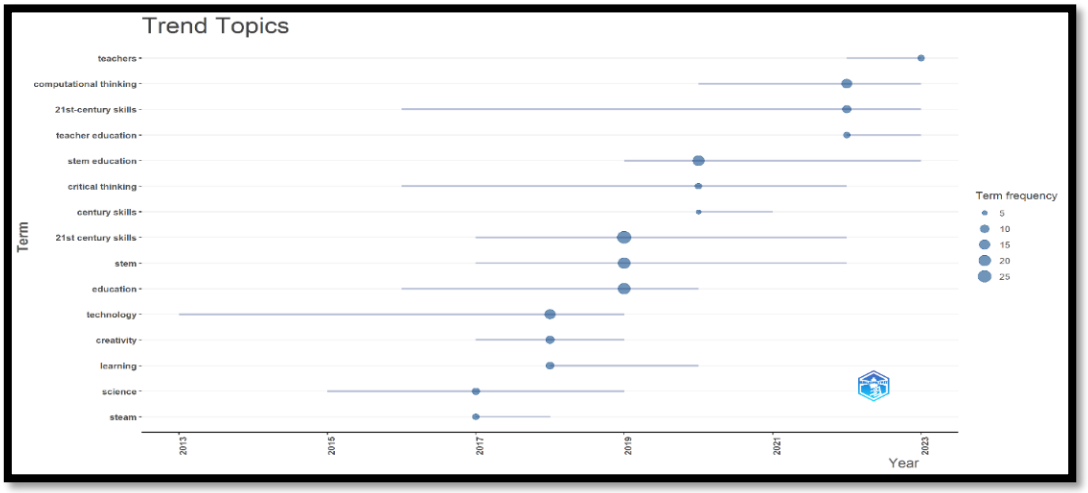

Figure 18. 21st Century Skills in MSE Trending Topics Map (titles)

The trend topic map reveals a preference for titles associated with "21st century skills," "education," and "STEM" from 2018 to 2020, as well as "technology," "creativity," and "learning" from 2017 to 2019. Additionally, titles focusing on "science" and "STEAM" from 2015 to 2019, along with "system," "school," "children," and "electronic" from 2016 to 2020, are notable. The term "model" has been prevalent from 2013 to 2019, while "critical thinking" has gained traction from 2016 to 2022. These topics can be identified as significant areas of interest or emerging themes in academic literature concerning 21st century skills in MSE, as trending topics often signify key issues within a specific academic domain. The subsequent section provides an overview of the thematic evolution over the years.

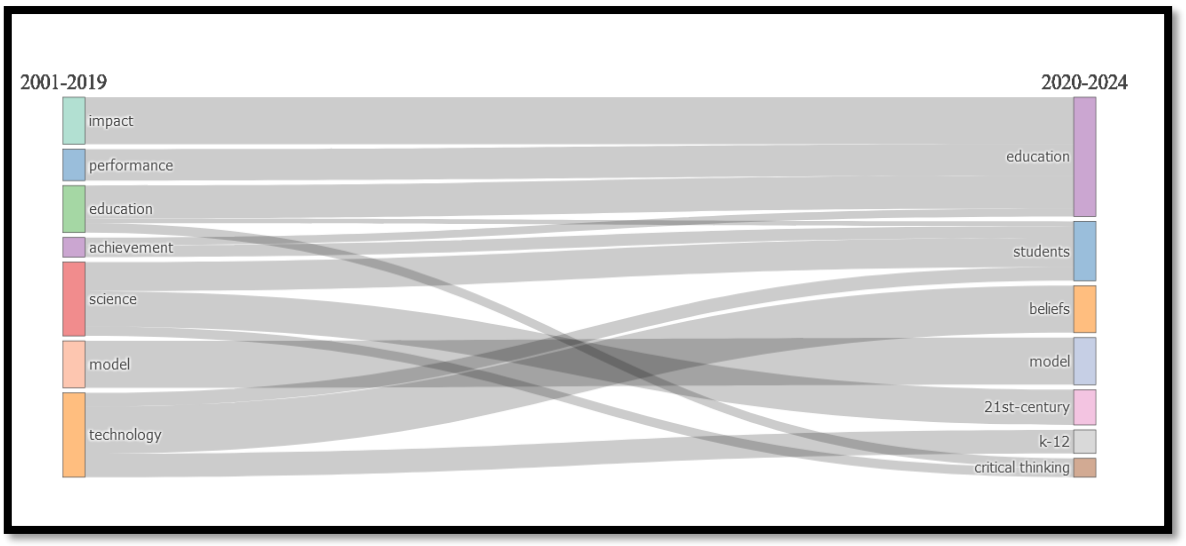

Figure 19. Thematic Evolution Indicator on 21st Century Skills in MSE

The evolution of thematic elements related to 21st century skills in MSE is illustrated in Figure 19. The data reveals that between 2001 and 2019, there was a notable emphasis on the terms "technology," "science," "model," and "education." In contrast, the period from 2020 to 2024 shows a significant increase in the prominence of keywords such as "education," "students," "beliefs," and "21st century skills."

Conceptual Structure and Thematic Maps on 21st Century Skills in MSE

The multiple correspondence analysis (MCA) presented in Figure 20 illustrates the authors' compilation of terms pertinent to 21st-century skills in the context of modern MSE. This visual representation encapsulates the conceptual framework surrounding these skills, drawing on data collected from 2001 to 2024. The graph accounts for approximately thirty percent of the overall variability, effectively demonstrating the optimal size reduction for the initial two dimensions of the MCA. Each cluster of points within the graph signifies a unique profile, with proximity among points indicating greater similarity in the profiles they represent (Mostafa, 2020; Wong et al., 2021). The clusters highlighted in red, including "21st century skills," "rethink," "critical thinking," "knowledge," "curriculum," "teachers," "implementation," "motivation," "inquiry," "self-efficacy," and "career," underscore the keywords that predominantly reflect methodological emphasis, as evidenced by the pronounced depth of the red structure within the graph. Following this analysis is the strategic/thematic map.

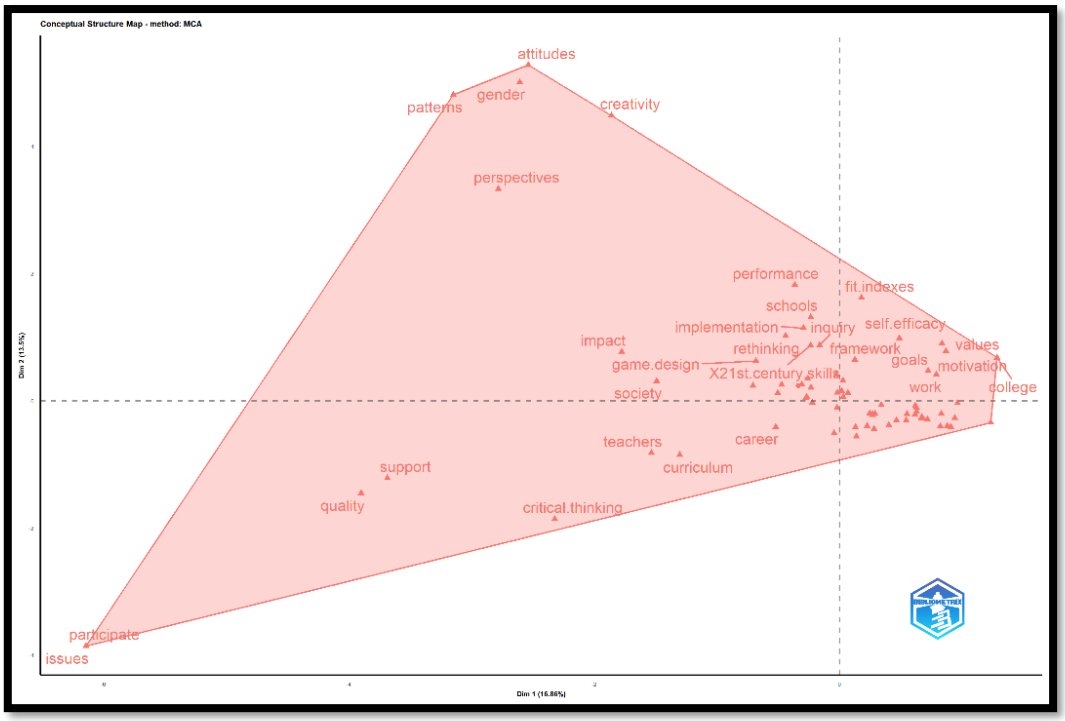

Figure 20. 21st Century Skills in MSE Conceptual Structure Map (MCA method)

The thematic and strategic map illustrating 21st century skills in MSE, as shown in Figure 21, is constructed using the keywords plus methodology. In this mapping process, the walktrap algorithm serves as a clustering technique, with a threshold of twelve minimum cluster frequencies per thousand documents implemented to reduce the contiguity of clusters.

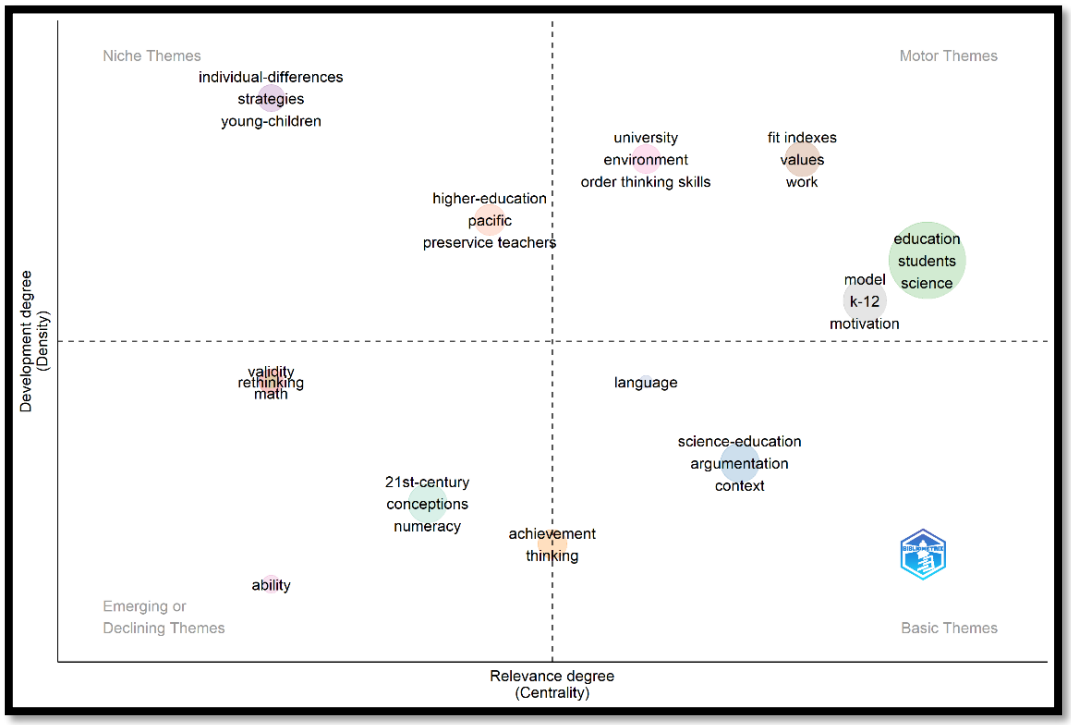

Figure 21. 21st Century Skills in MSE Thematic Map

The resulting map is divided into four quadrants, delineated by a dotted line, with mean values represented on both axes. Each bubble on the chart corresponds to a unique topic, with its size reflecting the frequency of research associated with specific keywords. The first quadrant, characterized by high density and centrality, encompasses the motor themes, which are well-developed both internally and externally, as noted by Cobo et al. (2011). The prominent themes within this quadrant include "students," "education," "science," "model," "k-12," "motivation," "university," "environment," and "high order thinking skills," all of which align with contemporary trends. Conversely, the second quadrant identifies niche themes that are distinctly developed yet isolated, exhibiting low centrality and high density. This suggests that while these themes, such as "higher education," "pacific," "pre-service teachers," "individual differences," "strategies," and "young children," are robust internally, they lack broader significance. The third quadrant is marked by themes that display both low density and low centrality, indicating weak internal and external relationships, and these themes point towards potential avenues for future research in interactive learning environments, including topics like "rethinking," "21st century," "conceptions," and "validity." Finally, the fourth quadrant, which encompasses core and cross themes, is characterized by low density and high centrality, suggesting that while these themes may be underdeveloped in terms of relationships, they hold significant potential for further exploration. These simple themes that include 21st century skills in MSE consist of “science education”, “argumentation”, “context” and “language”.

Discussion and Conclusion

The aims of this research was to carried out a bibliometric analysis of studies focused on 21st century skills in MSE. In this purpose, a total of 312 studies that have been published between the 2001 and 2024 years, about the topic of 21st century skills in MSE, in different kinds of scientific journals were analyzed using bibliometric analysis with the help of the R-Studio program. The data analysis took into account the following factors: the distribution of studies by year, the quantity of quotes, the most published authors, citation bursts, country-specific publications, highly cited articles, collaborations, word clouds, and word trees.

Results have also showed that the number of studies on 21st century skills in MSE have increased after 2016. In particular, the studies at the highest rate were published between 2016-2021. Most studies (n=40) on 21st century skills in MSE were conducted in 2017. It was also found that the most published authors that have made the most contributions to this field are Susilo, H. (5 papers), Harun, J. (4 articles), Mahanna, S. (4 articles), and Zubaidah, S. (4 articles). However, additional writers who have made contributions to this topic include Bakri, F., Bogner, F.X., Chaudhary, K., Maass, K., Rahmawati, H., Sharma, B., and Sikosek, D., each of whom has three publications. When it comes to the most cited countries, USA is among the most mentioned nations (n=730). Subsequently, Germany (n=205), Indonesia (n=163), Netherlands (n=162), Chile (n=148), Sweden (n=117), Australia (n=99), Turkey (n=79), Malaysia (n=78), Spain (n=77), Korea (n=44), Thailand (n=42), Mexico (n=34), New Zealand (n=33), China (n=32), Israel (n=19), Fiji (n=17), Slovenia (n=17), Cyprus (n=15), UK (N=15), Russia (n=12), Finland (n=11), Canada (n=10), Czech Republic (n=9), and South Africa (n=9) follow. When it was examined the nations' collaboration, it can be understood that they represent more distinct collaboration between each other. The relationship between USA, Turkey, Canada, Australia, and Indonesia, as well as those between USA, Turkey, Brazil, Germany, the Netherlands, South Africa, and Thailand, are remarkable. Though

not at a very high level, it may be said that other nations also have some degree of relationship.

On the other hand, in MSE, it was preferred that a cited publication on 21st century skills have a minimum of two citations. This threshold value indicates that there were 6407 total papers mentioned in the data set used for the study, and 1312 cited studies met the threshold value. The journals Computers & Education and Computers in Human Behavior are particularly notable, while the journals Educational Technology & Society, ZDM Mathematics Education, International Journal of Science Education, and Educational Studies in Mathematics all follow the same trend. Two citations or more were required since studies on 21st century skills in MSE were selected. Based on this cutoff point, 843 papers were mentioned overall from the studies in the data set used for the study, and 103 of those cited studies satisfied the cutoff point. Examining them, it becomes clear that terms like "critical thinking," "science," "creativity," "21st century skills," "technology," "mathematics education," "education," "stem," and "computational thinking" are more widely used. Therefore, these themes are well-developed both within and outside and are currently in trend. These structures, which are sometimes referred to as motor themes, demonstrate the evolution of the area of study and the direction in which it has grown in the present. Studies in this area are evidently continuing unabated as more people become aware of the advantages of 21st century talents, whose demand is growing continuously. Even though 21st century skills are a technology-infused approach, its structure has been directly impacted by the shift in educational focus toward technology. Thus, it is imperative to carry out further research on 21st century competencies in science and math education. We need technology and education to work together more than ever in order to better prepare for the future through a more prepared and equipped educational approach. In this environment, it is imperative to broaden the scope of 21st century skills studies by prioritizing studies in mathematics and science education, as well as other subjects, that are technology-based, project-based, creative, and thinking skills centered.

Recommendations

The topic of 21st-century skills in MSE was chosen as the basis for the study. All kinds of digital material can be studied in research that goes in the same direction. Furthermore, studies on 21st century skill settings may be carried out for several other subjects in addition to science and math. The scientific publications published on 21st century skills in MSE were chosen using the WoS database. You may also use databases such as Scopus, Eric, Ulakbim, Ebsco, etc. to access more data sets in related research. Furthermore, modifications to the search parameters can be made for comparable studies that need to be conducted. The study's favored indices were BKCI-SSH, BKCI-S, SSCI, SSCI Expanded, ESCI, A&HCI, and CPCI-S. The only WoS categories that can be chosen are SSCI, A&HCI, or SSCI-Expanded. In the research, only articles were selected as the kind of material. For comparable research, any document—including book chapters, editorial material, review articles, meeting abstracts, and proceeding papers—may be used. Furthermore, the area of work on structures can be restricted or expanded by alterations in language and the choice of WoS categories. The results of the research can then be examined and debated with a wider group of people. After 2024, research publications on 21st century skills in MSE may still be analyzed for the future studies. In this manner, it will be easier to track developments in 21st century skills research throughout time. Finally, content analyses—rather than just bibliometric analyses—can assist in conducting thorough assessments at the point when 21st century skills undergo dynamic changes

throughout time. Scientific productivity, network analysis, conceptual structures, thematic maps, and trends are all included in this research. Thus, systematic or descriptive analysis might be used to support a more thorough procedure.

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