

E-LEARNING IN MATHEMATICS EDUCATION: A BIBLIOMETRIC ANALYSIS (2012-2022)

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ABSTRACT

This study aims to create a comprehensive bibliometric map of published scientific articles on e-learning in mathematics education (ME). We used Web of Science (WoS) database to analyzed 341 articles published by 1018 authors representing 79 countries between 2012 and 2022. In this context, we examined scientific articles in terms of scientific production, network analysis, trend topics, thematic change, and conceptual structure. Bibliometric analysis was performed in the study. According to findings, the number of published articles differ according to the years, but the number of citations is constantly increasing. Albano, and Dello Iacono are the most prolific authors. The most productive institutions are Salerno and Black Sea Technical Universities. China, USA, and Russia lead the countries of the corresponding authors. According to the network analysis, the journals of Computers & Education and Computers in Human Behavior form strong links. The most used keywords are students, technology, and mathematics. The pandemic, covid, reality, and process are trend topic titles. It determined that the best size reduction obtained in the conceptual analysis constituted approximately 31% of the total variability. We presented some suggestions based on the findings obtained at the end of the research.

Keywords: Bibliometric analysis, e-learning, mathematics education, Web of Science (WoS) database.

INTRODUCTION

As information and communication technologies (ICTs) continue to develop, the priorities of social development and the roles expected from individuals differ. Therefore, in the digital transformation era, it is essential to be a society that produces information rather than consuming it but also to raise individuals who use technology consciously and effectively (European Commission-EACEA-Eurydice, 2019). The continuity of unpredictable progress, especially in the internet and access to information, necessitates nations to keep up with the digital transformation. Along with this progress, the widespread and effective use of information technologies in different fields is also increasing. Undoubtedly, one of the areas where ICTs is widely used in education. The interaction between technology and learning environments is increasing exponentially daily, and technology is essential for all levels of education (Wang et al., 2017). Although technological developments take their place in education, it is also essential that an education approach integrated with innovations is sustainable. Because knowledge is a significant value that needs to be constantly updated for educational institutions and individuals, it is the most effective way to respond to necessities of the age. With this understanding, raising individuals integrated with technological competencies is shown as one of the main goals in the curriculum of many nations, and strong steps are being taken in this direction (Common Core State Standards Initiative [CCSSI], 2016; European Commission-EACEA-Eurydice, 2011; Ministry

of National Education [MoNE], 2018; National Council of Teachers of Mathematics [NCTM], 2016; Organization for Economic Co-Operation and Development [OECD], 2022). The most important reason for this situation is that education is now associated with technology, and the importance of technology for an effective learning environment is increasing (Bal, 2015). Because it has become inevitable for 21st-century individuals to face a learning approach with technological equipment and resources (Gulbahar, 2022; NCTM, 2000; Wang, 2011). In particular, the fact that ICTs encourage innovative pedagogical actions and facilitate the creation of new learning areas has also caused nations to turn more towards the co-operation of education and technology (Garrote-Rojas, 2018).

Not only in the curricula but also in the reports published by many institutions and organizations, emphasizing the importance of education and technology, the necessity of equipping future generations with technological competencies is frequently stated. In the report published by the OECD in 2019, skills positioned on technology have been compiled for the digital business world, skills for the digital society, and learning in the digital environment. Therefore, the importance of integrating digital tools into the teaching process to develop the skills individuals will need in the future has been clearly emphasized (OECD, 2019). The fact that technology offers attractive opportunities for new approaches to teaching and therefore, to learning across the curriculum necessitates the increasing digitalization of education and the more efficient use of technology in the learning environment (Cullen et al., 2020; Mishra & Mehta, 2017; MoNE, 2018; NCTM, 2014; Pierce et al., 2007). In the report published by the International Society for Technology and Education [ISTE] in 1998 and revised in 2007 and 2008, it was stated that the importance of using technologies in educational environments should be transferred to the learning environment (ISTE, 2008). Similarly, the framework published by the Partnership for 21st Century Skills (P21) includes learning outcomes, including information-media-technology skills, and emphasizes the importance of information-communication-technology literacy (P21, 2019). The digital technological competencies of individuals were discussed within the scope of the project, which started with the Learning and Technology World Forum organized in 2009 with the cooperation of Cisco, Intel, and Microsoft (Scardamalia et al., 2012). The Assessment and Teaching of 21st Century Skills (ATC21S) project aims to encourage schools to help students gain qualifications necessary for their careers, modern life, and working life (Lamb et al., 2017). Among the 21st-century skills determined in the ATC21S project, information-communication technologies literacy was evaluated under a separate heading, and its importance between technology and learning environments was stated (Binkley et al., 2012). In the report published by the World Economic Forum (WEF) in 2016, it was stated that students need more than traditional academic education in order to develop further in the century we live in and that students' information-communication-technology skills should be at a sufficient level (WEF, 2016).

Effective and widespread use of technology, a reality of today, is essential in mathematics education (ME) in many disciplines. Since mathematics plays a vital role in the educational and developmental wishes of any country worldwide, the importance of the relationship between mathematics and technology is increasing day by day (Ahn & Edwin, 2018; Moreno-Guerrero et al., 2020). It is also essential that such a valuable branch of science establishes good relations with technology. Aware of this situation, many countries have made radical changes in their mathematics programs, placing technology at the center of their curriculum and shaping their programs in this direction (CCSSI, 2016; MoNE, 2018; NCTM, 2014). Moreover, they have opened the door to a short evolution towards new generation learning understandings with technology content in their curricula. In this context, it is noteworthy that countries focus on approaches to create more qualified educational environments (Jamali et al., 2022; Juan et al., 2012; Hung et al., 2014). So much so that in visionary statements that focus on the idea that technology has the potential to support mathematics teaching, it has been stated that ICTs plays functional roles in improving mathematics learning (OECD, 2019). Because the use of technological resources is a very convenient discipline especially for ME (Oksuz & Ak, 2010). Drawing attention to this situation, NCTM emphasized the importance of using technological tools in ME and school mathematics principles and standards; it stated that "technology is essential in teaching and learning mathematics, it affects the mathematics taught and improves student learning" (NCTM, 2000, p. 11). Therefore, digital technologies provide valuable contributions to learn mathematics effectively. With the efficient use of mathematical e-learning, the taught subject can be more exciting, and students can understand mathematics better (Ahn & Edwin, 2018). Thanks to this learning technology,

a more functional understanding of learning can be developed from a static mathematics teaching that changes rapidly. The e-learning approach is progressing by renewing itself day by day and keeping up with the changes.

In the digital age, which we are only living in the first quarter, although skills based on performances come to the fore, digital technology literacy makes itself felt more distinctly unlike other century skills (Trilling & Fadel, 2009). So much so that today “digital technology has changed the very notion of what being a human means” (Borba et al., 2016, p. 589). Together with The Fourth Industrial Revolution (4IR), today’s focus is on organizing tools based on artificial intelligence (AI), machine learning (ML), and algorithms (Chaka, 2020). Therefore, today’s education systems need to be reorganized and developed (Gonzalez-Perez & Ramirez-Montoya, 2022). In this context, ICTs have provided invaluable contributions to the continuation of educational activities, especially during the pandemic (Almarzooq et al., 2020). Considering the increase in studies on ICTs, knowing what to expect in future research is possible by understanding current research trends. Therefore, studies on the transfer of technological tools to learning environments are essential sources of information for future research. In this study, the e-learning approach in ME was discussed, and related literature were examined in detail. Thanks to the study aim to create a valuable resource for the related field and present new ideas to researchers who will work on this subject.

E-LEARNING AND USE IN MATHEMATICS TEACHING

In the face of the dizzying speed of ICT, the concept of e-learning is constantly renewing itself. As digital platforms have become a part of our lives, some concepts have been given different meanings by adding the suffix “e-” (e-academy, e-commerce, e-government, e-school, e-campus etc.), which is the first letter of the word electronics (Gokdas & Kayri, 2005). This situation corresponds to electronic learning (e-learning) in the education sector. E-learning approach; a method that adds diversity to learning environments and has the practicality of being accessible from anywhere. Unlike traditional teaching approaches, this approach, a trend in recent years, offers individuals more opportunities for learning experiences, lacks control and implementation mechanisms and allows individuals to learn independently (Wang, 2011, 2014). There are no time and place restrictions in this learning style, and the same learning outcome can be repeated more than once. It includes many advantages in terms of reducing the cost of learning and providing diversity in the content type. The beginning of these advantages is that teachers and students in different locations can communicate actively, students have the opportunity to take lessons from educational institutions in many different countries, and students develop a collaborative working environment (Altıparmak et al., 2011). E-learning, which also supports lifelong learning, includes technology in a broad perspective, such as radio, TV, CD-ROM, DVD, computer-assisted education, video conferencing, virtual and online education networks. It is also a roof concept as it includes many innovative approaches (mobile-smart learning, etc.). In this learning style, knowledge and skills expected to be acquired by individuals are transferred to the recipient with the help of technological tools. Computers, intranets, and internet (local and wide area networks), www (world wide web) and ftp internet services, TV and radio (telecommunication tools), and satellite broadcasting tools used in audio and video transmission are some of the technological tools used for e-learning (Gulbahar, 2022). In short, e-learning; is the process of learning knowledge and skills at any time and place with the help of media such as the internet, intranet, audio, video tapes, television broadcasts, and CD-DVD (Govindasamy, 2002). In this way, it aims to continue teaching activities through internet technologies without requiring instructors and participants to be simultaneously in the same environment.

Today, the speed of access to information is an essential need for educational institutions. Educational institutions that provide access to information in the fastest and most reliable way go one step ahead and have a say in directing change. These systems are also one of the most effective and quick ways to acquire knowledge. In particular, thanks to the widespread use of mobile phones, tablets, laptops, the strengthening of the internet network structure, the cheapening of the internet cost, and the ongoing developments in communication and information technologies, individuals and institutions can access information more quickly and reliably, and disseminate information to large masses (Gonzalez-Perez & Ramirez- Montoya, 2022). In addition, the e-learning ensures that teaching activities are based on ICTs and provides students with equal opportunities with their peers from elsewhere in the world, accessing different types of materials and meeting with instructional information technologies (Ekesionye & Okolo, 2011). Thanks to e-learning,

since the contents are easily accessible, learning environments can be created without the need to distribute physical materials, and the learner can determine the appropriate time for learning activities and provide flexibility to the instructors (Cheong, 2002; Hung et al., 2014; Wang, 2014). With e-learning, it allows access to all data, not only to the registered student group but also to all segments of society, from anywhere (Altiparmak et al., 2011). E-learning is a digital process and a social phenomenon based on interactions between individuals. Therefore, the rapid dissemination of e-learning environments today requires getting to know the characteristics of individuals studying in these learning environments and organizing online learning environments efficiently (Kurnaz & Ergun, 2019). Because the e-learning method can prevent individuals from being motivated and determined by creating a spatial and temporal gap (Cerezo et al., 2020; Hung, 2012; Moubayed et al., 2020). Also the fact that the use of information technologies is not as common as in developed countries, e-learning may not have the desired effect on educational learning (Karkar et al., 2020; Yaniawati et al., 2020). There may also be some disadvantages, such as problems with an internet connection, limited level of direct discussion, students having to look at digital tools constantly, and problems in working time and maintaining self-discipline (Altiparmak et al., 2011; Pujiasih, 2020). Therefore, such negativities may cause individuals to have low skills, especially in applied courses that require skills such as mathematics (Rohendi et al., 2023).

Many essential online teaching tools have been developed and implemented using digital infrastructure in mathematics teaching (Umoh & Akpan, 2014). For example, printed media, special digital publications, TV programs, radio, e-mails, computer-assisted teaching applications (power-point, CD-ROM, lecture videos, DVD, animated videos, simulation graphics, lecture applications, video conferencing, e-journals, e-books, enriched course materials, e-smart book, interactive interfaces, e-library, e-encyclopedia, e-text, etc.), web extension or teaching tools including virtual learning environments (Modular-Object-Oriented-Dynamic-Learning-Environment [MOODLE], Blackboard-Learning-Management-Systems [BLMS], MEI, WEBCT, MUMIE, WebALT, software [Google Meet, Microsoft Teams, Zoom, Skype, WebEx, etc.], Home-Work-System, MatLab, Mathwiki, Open-Courseware) have been made available to students in order to provide information flow to individuals (Albano, 2012; Awodele et al., 2010; Ayanda et al., 2012). In addition, Web 2 tools (Matific, Geogebra Software, Daum-Equation-Editor, MyScript Calculator, MathManiac, KidsMath, MathFormulary, MathPractice Flash Cards, Kids Numbers, MathLite etc.) are used in teaching mathematics. Mathematics e-learning is making mathematics teaching more functional by using hardware, software or the internet (Juan et al., 2012; Ozyurt et al., 2013). In this respect, many different instructional tools, including mathematics e-learning, have been made available to students today, and progress is continuing.

REVIEW OF RELEVANT LITERATURE

Depending on technological developments, the content and number of studies on e-learning are increasing. Especially with the Covid-19 epidemic, which has affected the whole world, many countries have made serious investments in e-learning. Significant steps have been taken in many areas, from changes made in curricula to improvements in technological infrastructure. Many countries are making serious efforts to make digital learning platforms more functional, both to prevent future generations from falling behind in teaching activities and to provide them with skills required by the age (Gonzalez-Perez & Ramirez-Montoya, 2022). In this age, where time is flowing towards digital learning, valuable studies are also carried out on e-learning. When the studies in the literature, which were carried out similar to the study are examined, it is seen that the effect of e-learning and design studies in mathematics teaching have gained weight (Bali et al., 2022; Bringula et al., 2021; Kramarski & Gutman, 2006; Kumari, 2021; Moreno-Guerrero et al., 2020; Mutlu et al., 2019; Ozyurt et al., 2013). In these studies, it has been reported that e-learning developed students improve their problem-solving and strategies (Sacristan, 2017; Kramarski & Gutman, 2006), improve their math manipulatives production (Sulistyaningsih et al., 2019), increase their participation in the lesson, deep learning, attention to the lesson, success, attitude, motivation, creativity, communication, performance, self-efficacy, and self-control (Allen et al., 2004; Bernard et al., 2014; Borba, 2012; Hung et al., 2014; Lin et al., 2017; Mulqueeny et al., 2015; Uzunboylu et al., 2020; Uzel & Ozdemir, 2012; Yaniawati et al., 2020). On the other hand, there are study findings that students are inadequate in terms of ICTs skills, test anxiety and software limitations of mathematical symbols (Bringula et al., 2021; Irfan et al., 2020; Umoh & Akpan, 2014).

When the findings of studies conducted in a similar direction are looking, the research findings differ in specific periods. For example, in Djeki et al. (2022), 12,272 articles on e-learning between the years 2015-2020 were examined. While USA, Spain, England and China are the most productive countries in e-learning, the most represented journals are *Computers in Human Behavior*, *Computers & Education*, and *International Journal of Emerging Technologies in Learning*. The countries of the corresponding authors are generally reported to be England, USA and China. It was determined that the cooperation between universities and countries on e-learning is weak and the pandemic has an impact on e-learning. Tibana-Tibana-Herrera et al. (2018), 39,244 scientific studies indexed in the Scopus and SCImago Institutional Rankings databases were analyzed. The study covers the years 2003-2016. In studies with e-learning content, it was determined that USA produced most of the works at the country level and had the largest international cooperation. The University of Hong Kong was determined to be the most productive institution. National Taiwan University of Science and Technology was determined to have the most extensive cooperation. Chen et al. (2021b) examined 555 scientific articles on innovative learning from the Scopus database. It was determined that while China is the most productive country in smart learning, Tsinghua University is the most productive institution. It has been reported that the main research topics include mobile learning, blended learning for smart learning, internet of things (IoT), cloud-computing, environmental-intelligence, and ecosystem. In the study by Goksu (2021), 5167 mobile learning-related studies in the WoS database as of September 2019 were examined. The research covers the years 2015-2019. In the research, it has been reported that the trending topics are generally educational technologies. It has also been reported that more specific trend topics are tablets, mobile phones and learning strategies. Hwang G. J. was determined to be the most influential researcher, and the National Taiwan University of Science and Technology was the most productive. It has been reported that the most preferred research topics are augmented reality, higher education, and mobile learning with a smartphone focus. The journals that contributed the most were *Computers & Education*, the *British Journal of Educational Technology*, and *Educational Technology & Society*. Cheng et al. (2014) 324 articles and proocedig published between 2000 and 2012 were analyzed. According to the findings of the research, e-learning themes came to the fore in continuing education, professional development, health sector, social media and knowledge management. In the study conducted by Delen (2021), 475 postgraduate theses on e-learning in Turkiye were examined. It has been reported that academic achievement, creation of e-learning environments and students' attitudes towards these learning environments are the leading issues associated with e-learning. In another study, trends in e-learning research in Turkiye were examined. In the study conducted by Parlakkilic and Gulduren (2019), it was reported that the research subjects are mostly tool and content-oriented applications. It was determined that the studies were mainly carried out in university institutions. In another study by Hung (2012), the longitudinal trends of e-learning research using text mining techniques were discussed. Between 2000 and 2008, 698 articles and papers were retrieved from the SCI-SSCI database and reviewed. In the study, it was reported that there was an increase in the number of e-learning studies between 2000 and 2008, and computer science and education subjects were dominant. England, USA, Taiwan, and China were the most productive countries. The most productive journals on e-learning are *Lecture Notes in Computer Science*, *Computers & Education*, the *British Journal of Educational Technology*, and *Educational Technology & Society*. The prominent topics were the systems and models, teaching and learning strategies, and factors and case studies. Today, e-learning tools offer many alternatives for teaching systems, such as distance, mixed, synchronous, or asynchronous online education models, increasing their impact and prevalence with each passing minute (Allen et al., 2004; Bernard et al., 2014; Wang, 2014). One of the goal of e-learning is to ensure that education and training programs are of higher quality, to serve more people, to increase accessibility to education, and to offer education opportunities independent of place and time (Gurcan & Ozyurt, 2020). Therefore, it is essential to examine the studies on e-learning in more depth and know the trends in the field. Although there are many studies on e-learning in the related literature, it is evident that more studies are still needed. Because in the face of the progress of technology, learning environments should progress at a similar pace and offer a safer education and understanding of the future by catching up with technology.

IMPORTANCE OF THE STUDY

The changes in the 21st-century information age bring a series of innovations. There is a rapid evolution in the education, health, industry, commerce, and information sectors, especially in working life. Technology has an unavoidable impact not only on the industry but also on individuals. Access to information is realized quickly, and the capability to respond to the needed knowledge and skills quickly and effectively necessitates different learning approaches. The fact that it is more economical and sustainable in terms of cost and time increases the need for e-learning environments. One of the main reasons why e-learning is getting more and more attention day by day is the rapid spread of information with the effect of globalization and the desire of individuals to access information faster. Therefore, the spread of e-learning is inevitable due to increased education demands. Due to the increase in the population in need of education, the problems experienced in classrooms and learning materials accelerate the need for e-learning. Due to the crowded classrooms, the interaction between the student and the teacher remains limited. Thanks to digital learning platforms such as e-learning, limitations that seem difficult to overcome are eliminated, and the interaction between students and instructors increases (Altıparmak et al., 2011). Therefore, it is essential to know the existence of learning tools such as e-learning at a time when the whole world is transforming towards technology. It is essential to know how the studies in this field have changed and the trends in the field.

Undoubtedly, scientific studies conducted in many disciplines have significant benefits in the relevant field. In the improvement and development of today's education programs, the outputs of scientific studies are taken into account, and steps are taken in this direction. Therefore, to predict how educational research will evolve in the future, studies focusing on the past and present of educational studies should be conducted first (Pring, 2013). Because past experiences are a good guide in the construction of the future. In the bibliometric analysis studies conducted similarly to our study, prominent scientific publications, frequently preferred research topics, productive authors, publications and citations by years, productive institutions, and countries were revealed. However, bibliometric studies must be continuously improved according to the innovative approaches brought by the age. Therefore, it is essential to follow the studies carried out in specific periods and to know the international view of the field. Thanks to bibliometric studies, different and current study subjects are also noticed by researchers. This study adopts a current issue, such as e-learning, based on innovative approaches in educational research. One of the critical starting points of the research is that no current study in the literature deals with the content of scientific studies related to e-learning in ME. The need for a more detailed study on developments, changes, trends, and processes in e-learning in ME reveals the necessity of this research. In order to make a good prediction about the future change in e-learning in ME, it is necessary to know which subjects have been studied in previous years (Chang et al., 2010). This study aims to determine the current profile of e-learning use in ME and contribute to creating a sustainable learning approach. Unlike other studies, it is aimed to create a more comprehensive assessment of the use of e-learning in ME by giving more weight to structural analysis. In this context, bibliometric analysis of 341 scientific articles that were accessed from the WoS database in accordance with the purpose of the research was conducted.

PURPOSE OF THE STUDY

This study aims to create a comprehensive bibliometric map of published scientific studies on e-learning in ME. The WoS database analyzed 341 articles published by 1018 authors representing 79 countries between 2012 and 2022. Scientific and technological developments experienced at a dizzying pace today significantly impact the determination of researchers' interests and fields of study. Knowing the past and present products in a study that centers on technological approaches such as e-learning in ME provides us with valuable clues about how future studies should be. In particular, it is essential for the researchers who will work on this subject to know the most productive authors, the most cited scientific studies and scientists, and the collaborations between authors, institutions, and countries. Therefore, this study will be a valuable resource for researchers working on this subject. In addition, this research is essential in guiding and making a difference in the research to be done within the scope of e-learning in ME. The research sought answers to the following research questions (RQs) within the scope of ME:

- RQ 1. What are the patterns of articles with e-learning content according to years and citation count?
- RQ 2. What authors, institutions, and countries have contributed the most to e-learning research?
- RQ 3. Which authors and journals are closely linked to the topic of e-learning?
- RQ 4. Which authors and countries are involved in collaborative research on e-learning?
- RQ 5. How is the distribution of keywords and co-occurrence in researches on e-learning?
- RQ 6. What are the trending topics and thematic changes in e-learning research?
- RQ 7. How do the conceptual structure and thematic map in e-learning research change?

METHOD

Research Design

This study presents a descriptive, cross-sectional-retrospective bibliometric analysis conducted through the analysis of published scientific documents on the use of e-learning in ME in the period 2012-2022. Bibliometrics was used because scientific literature and the authors who produced them were examined according to statistical procedures. This type of analysis allows readers and researchers to gain a holistic view of the research topic determined within a certain period of time and quantitative analysis of scientific publications (Chen et al., 2019; Gokhale et al., 2020). In addition to being functional, bibliometric analysis is an effective method for defining the relevant field (Donthu et al., 2021; Grzybowska & Awasthi, 2020; Pesta et al., 2018). In bibliometric analysis, a detailed evaluation can be made of sources and document types by making descriptive and performance analyses. Also, document matching can be examined with the help of scientific mapping and network analysis. Bibliometric assessment has two strengths. These are the dynamic and structural analysis phases (Chaparro & Rojas-Galeano, 2021). In dynamic analysis, impact values such as the number of publications and citations, timeline of authors, general trends/changes of terms, keywords frequency, distribution of keywords, and h-index are examined (Jamali et al., 2022). The structural analysis section examines indicators such as word dendrograms, conceptual and thematic maps, co-occurrence networks, collaboration, and standard citation networks (Jamali et al., 2022). The research framework proposed by Arksey and O'Malley (2005) was used as a guide in conducting the study. Accordingly, defining the research question(s), determining the relevant documents, deciding on the study selection, creating the data set, analyzing the data set, making a summary, reporting, and discussion processes according to the findings were followed. By following these processes, it was tried to increase the reliability of both the data set and the study.

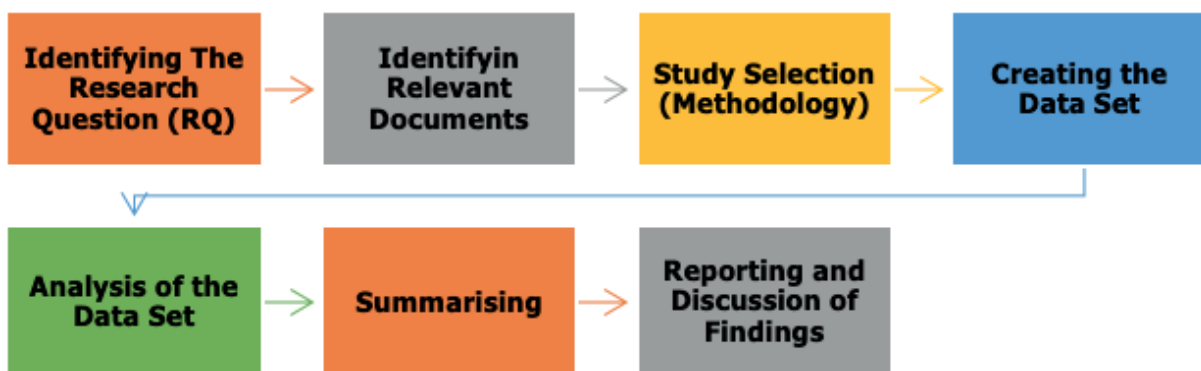


Figure 1. Process followed in the study

Data Collection and Procedure

The Web of Science™ Core Collection database was used to create a source database for e-learning in ME. The WoS database is a database of many disciplines within Clarivate Analytics. Among the significant reasons for choosing the WoS™ database is the presence of a large number of subject categories, the possibility of accessing peer-reviewed full-text available versions, the presence of prestigious journals that are accepted in the world, the

presence of publisher business partners and a large number of reference information (Web of Science Group [WoSG], 2023). Especially the significant increase in scientific studies makes it difficult for researchers to follow the literature related to their fields of interest (Aktoprak & Hursen, 2022). Therefore, the WoS database, which includes accepted and qualified studies in the field, was preferred. Bibliometric methods were used to explore the determined field's basic structure (Donthu et al., 2021). In this context, the title, keywords, and summary sections are among the primary criteria taken into account in creating the data set. While the keywords consist of article-specific terms that give an idea about the research, the part that is most read by the readers and represents the whole of the study is the summary section (Tosun, 2022). Firstly, scientific records with e-learning content in ME were searched. In this context, a pre-scan was made by typing [Title-Abs-Key (“e-learning”) AND (“math*”)] in the WoS search all fields module, and 3334 documents were reached. After this pre-scan, 1185 documents were reached by scanning again as searches title, abstract, author keywords, and keywords plus. After this search, the publication years were limited to 2012-2022, and 873 documents were reached. Of these documents, 475 (54.4%) were proceeding papers, 341 (39.1%) articles, 21 (2.2%) book chapters, and 36 (4.2%) other documents (review article, early access, editorial material, meeting abstract etc.). Finally, the article was selected as the document type, and final data were obtained with 341 articles. In order to obtain more data, no language restrictions were applied in the selection of publications. The 341 articles in the dataset were written in eight different languages (307 English, 14 Russian, 11 Spanish, 3 Bulgarian, 2 Turkish, 2 Ukrainian, 1 French and 1 Portuguese). Articles suitable for the content of the research were saved in the “Plain Text” format from the WoS database. The files downloaded in Plain Text format were then uploaded to VOSviewer and RStudio applications. With the help of the obtained data set, bibliometric analyzes were performed. The following figure shows the structure created by the PRISMA 2020 flowchart guidelines (Figure 2). Thanks to this flow diagram used in systematic reviews, the stages of improvement in the data set are shown (Haddaway et al., 2022).

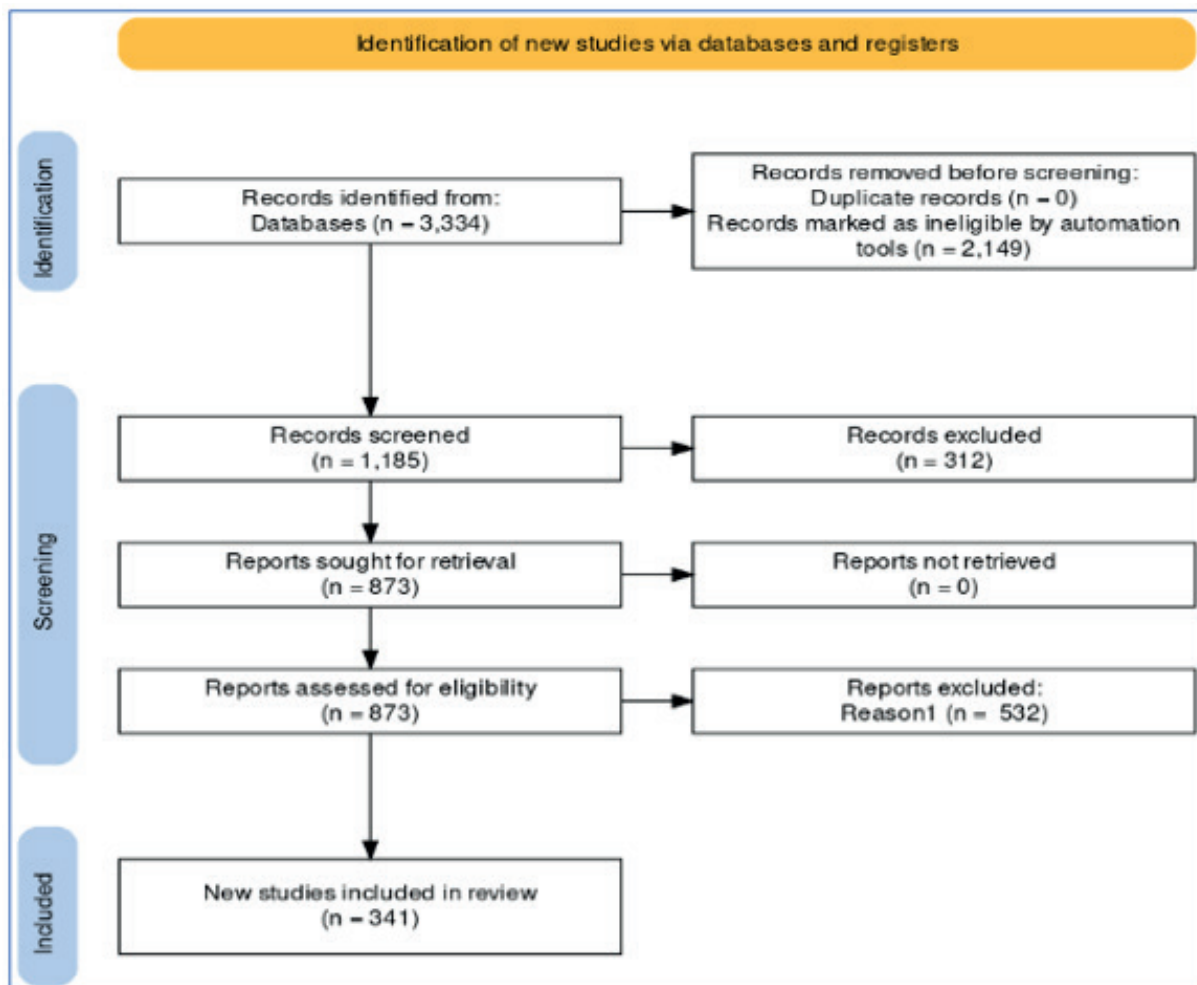


Figure 2. Flow diagram of the process of selection of scientific articles on e-learning in ME

Data Analysis

Traditional literature searches are generally conducted based on the researchers'/institutions' own skills, efforts and opinions, and the findings are presented with the help of limited analysis techniques (Andres, 2009; Grabowska & Saniuk, 2022; Wang et al., 2017). However, in this study, bibliometric analysis was preferred, which helps to understand how the knowledge structure and research areas in written documents have developed (Pritchard, 1969). Bibliometric analysis helps to perform statistical and quantitative analysis of documents such as author, subject, citation, sources, and publications. In this way, it reveals the general structure of many disciplines and the determined discipline. Bibliometric analysis is structured as descriptive and scientific mapping. Descriptive analysis and scientific mapping techniques were used to evaluate the data set. Within the scope of descriptive analysis, the main features of the data set, such as journals, authors, and documents, were examined. Within the scope of scientific mapping analysis, comprehensive analyzes were made through visualization methods such as network analysis, three-field plots, and thematic maps. In the study, VOSviewer 1.6.18 software was used to visualize the similarities of the data set in dynamic and structural analysis (Van Eck & Waltman, 2010). In addition, the R-tool 4.2.2 software of the Bibliometrix package, which was designed for quantitative-bibliometrics-research, was also used to analyze the data set (Aria & Cuccurullo, 2017). The data set analysis started with descriptive analyses of the WoS database. The relationships between the articles and the VOSviewer program were used to analyze the findings on the strength of the relationships. The visualizations created with the help of this program carry out the collaboration of authors, institution(s) and countries, and related research topics, as well as the association of publications on the data obtained from the WoS database (Yuan et al., 2021). Researchers in bibliometric analysis frequently prefer VOSviewer software. This open-access software can be downloaded and used for free (<https://www.vosviewer.com>). With the help of the VOSviewer program, large bibliometric maps can be viewed and interpreted directly, making it easier to understand large data sets (Van Eck & Waltman, 2010). In this way, the visualization of scientific studies is provided. In particular, journals, researchers, co-citations, publication networks, bibliographic matching, co-authorship relationships, and words used in documents can be configured.

On the other hand, with the help of the R-tool program, the conceptual, intellectual, and social structures of the data set were examined, as well as the general analysis of the authors and documents. Thanks to the RStudio software included in the Bibliometrix application, quantitative analysis applications related to the research subject are carried out. This open-source software is free to download and use (www.rstudio.com). In this software, items are defined as objects of interest. Elements and links represent network entities and clusters. In addition to the topics researched in these analysis studies, keywords, distribution of publications by years, citations to studies, words used in the abstracts, productive authors, institutions, countries, and the most cited authors are frequently used.

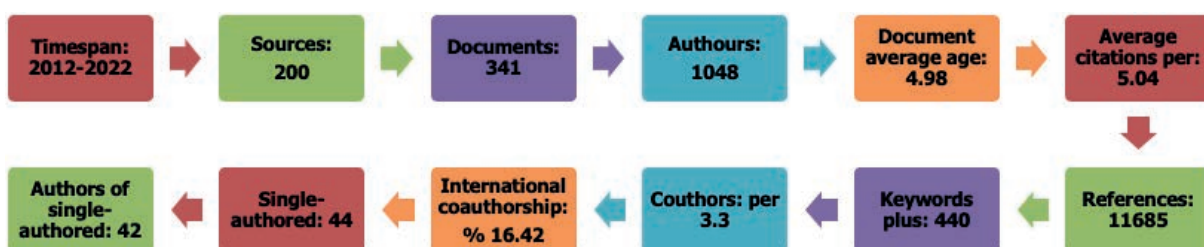


Figure 3. Statistical data of the descriptive main information in the articles reviewed

As Figure 3 indicates, 341 scientific articles were handled by 1048 authors in the study's data analysis. Generally, studies with multiple authors have been carried out. The number of articles with a single author is 44. While the collaboration index between the authors is 3.3, the percentage of international collaboration is 16.42%. Thematic and strategic diagram analyses were also included in the analysis of scientific studies between 2012-2022. Thanks to this structure created by Law et al. (1988), dynamic cluster formations can be determined by analyzing keywords or same-axis words. Thanks to these formations, the general view of e-learning in ME can be more detailed. Conceptual maps detail the conceptual structure of the research topic by dividing the content determined by the researcher into information sets (Wetzstein et al., 2019).

Validity, Reliability and Ethics

The process was explained in detail both to increase the validity of the research and to clarify how the data were obtained. In addition, the collection date of the data set, which modules were used in the WoS database, which restrictions were made and how the evaluation was made during data analysis process was explained. Also, explanations of the methods used in the data collection and analysis processes were included. In order to ensure the reliability of the research, the findings were presented without comment. The consistency between the data was kept in the foreground, and the data reached were discussed in the context of the relevant literature. All the operations done in the writing processes of the research are specified, and detailed information on how the data set was accessed (internet access addresses) is given. The research does not require ethics committee approval as it is based on documents obtained from the WoS™ Core Collection database. In addition, all the rules specified in the Council of Higher Education (CoHE) 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 of the data, and no damage has been done to the data set.

FINDINGS

In this section, the results obtained in accordance with the sub-problems of the research are presented. First of all, the distribution of scientific articles published on e-learning by years, and the number of citations is presented. Afterward, descriptive results about the authors, institutions, and countries that contributed the most to e-learning within the scope of ME were included. In the next step, findings about the journals closely related to e-learning in ME and the authors, institutions, and countries involved in the collaborative work are presented. Immediately after, cluster distributions are given according to author matching. Finally, conceptual structure and thematic maps related to trending topics and keywords in e-learning in ME are presented. Findings section; scientific production, network analysis (co-citation, collaboration, keywords, co-occurrence, clustering network of authors), trending topics and thematic evolution, conceptual structure, and thematic maps are presented below.

Scientific Production on E-Learning in Mathematics Education

The figure below shows annual publications and citations on e-learning in ME between 2012 and 2022. According to the data obtained from the WoS database, the annual production and annual citation numbers related to the study subject are indicated with a different color.

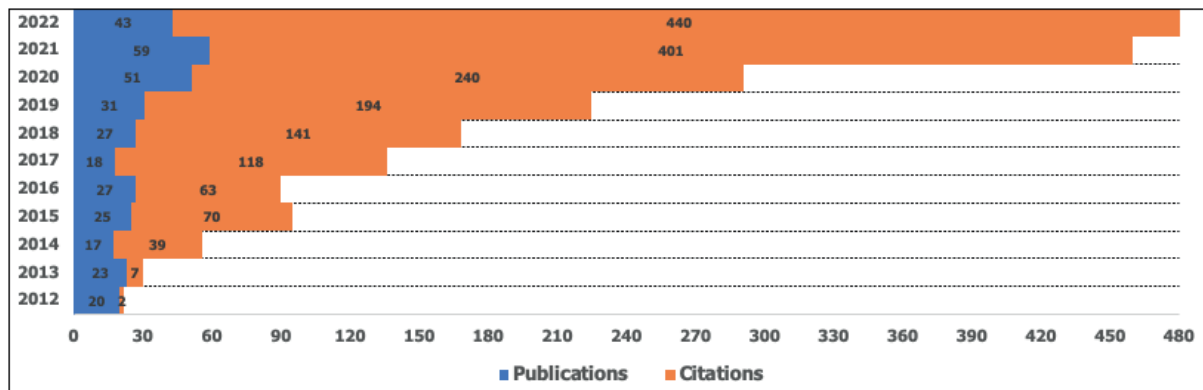


Figure 4. Annual scientific production and citation on e-learning in ME

Figure 4 shows the data of scientific outputs published on e-learning in ME. Accordingly, the annual publications increased in 2020 (51 articles) and 2021 (59 articles). The minimum number of publications was in 2014 (17 articles). Similarly, fewer articles were published in 2017 (18 articles), 2012 (20 articles), and 2013 (23 articles). Similarly, fewer articles were published in 2017 (18 articles), 2012 (20 articles), and 2013 (23 articles) compared to other years. Although there is a decrease in the number of publications in 2022 (43 articles), the number of published articles will continue in the coming years. The number of annual citations increases every year. It is noteworthy that those citations were made in 2021 (401 citations) and 2022 (440 citations). Below are the findings about the authors who published the most in this field.

Table 1. Most productive authors on e-learning in math education

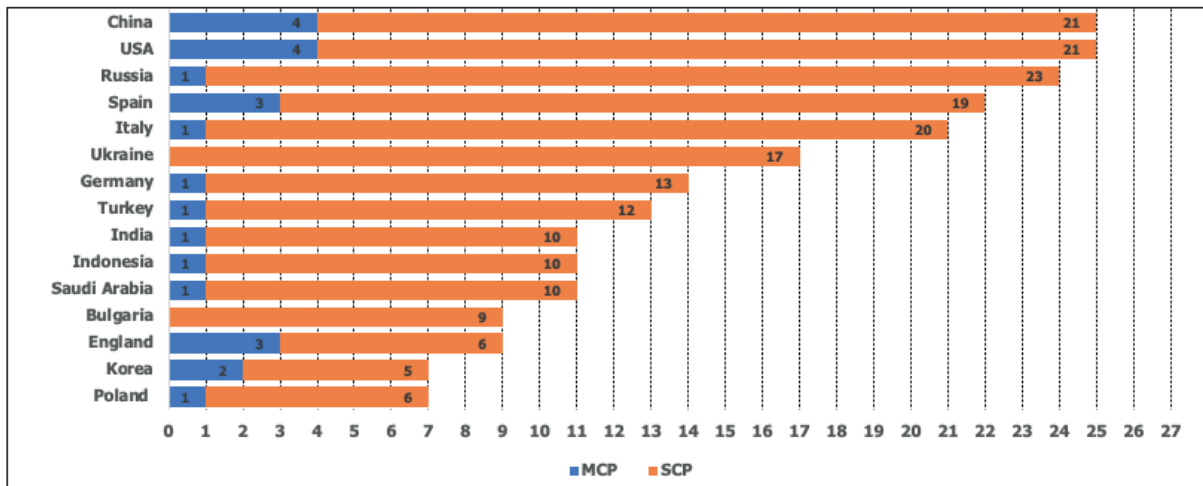
Authors	Articles	Articles Fractionalized
Albano, G.	7	3.20
Dello Iacono, U.	5	1.70
Baki, A.	4	1.03
Ozyurt, H.	4	1.03
Ozyurt, O.	4	1.03
Bakaric, M. B.	3	1.00
Bardelle, C.	3	2.50
Guven, B.	3	0.70
Juric, P.	3	1.00
Mandal, S.	3	1.33
Matetic, M.	3	1.00
Mikhailova, E. A.	3	0.78
Naskar, S. K.	3	1.33
Pierri, A.	3	0.87
Post, C. J.	3	0.78

Table 1 shows the authors who have contributed the most to e-learning in ME in the last ten years and their respective publications. Data in the table are limited to authors with at least three publications. Accordingly, Albano, G. (7 articles), Dello Iacono, U. (5 articles), Baki, A. (4 articles), Ozyurt, H. (4 articles), and Ozyurt, O. (5 articles) are the authors who contributed the most to this field. On the other hand, with three publications each, Bakaric, M. B., Bardelle, C., Guven, B., Juric, P., Mandal, S., Matetic, M., Mikhailova, E. A., Naskar, S. K., Pierri, A. and Post, C. J. other authors who contributed to this field. The table below provides information on the annual total number of citations of the articles.

Table 2. Most cited articles (by total citation per year) on e-learning in ME

Papers	Doi	Total Citations	TC per Year	Normalized TC
Wang, T. H., 2014	10.1016/j.compedu.2013.12.002	92	9.20	7.86
Borba, M. C., 2016	10.1007/s11858-016-0798-4	61	7.63	6.10
Ozyurt, O., 2013	10.1016/j.eswa.2012.12.008	44	4.00	4.32
Fabian, K., 2016	10.1007/s40692-015-0048-8	44	5.50	4.40
Farhan, M., 2018	10.1016/j.future.2017.09.037	38	6.33	5.32
Lin, H. C. K., 2014	10.1016/j.chb.2014.09.052	36	3.60	3.08
Ozyurt, O., 2013	10.1016/j.chb.2012.11.013	35	3.18	3.44
Warin, B., 2016	10.1109/TE.2015.2462809	30	3.75	3.00
Jasute, E., 2016	-	29	3.63	2.90
Arias, J. J., 2018	-	28	4.67	3.92
Yilmaz, F. G. K., 2016	10.1016/j.compedu.2016.01.006	27	3.38	2.70
Sarwar, S., 2019	10.1007/s11042-019-08125-8	24	4.80	6.39
Thongsri, N., 2020	10.1080/14703297.2019.1585904	23	5.75	5.56
Junus, K., 2001	10.3390/educsci11030139	21	7.00	6.91
Moreno G. A. J., 2020	10.3390/math8050840	20	5.00	4.83

Table 2 shows the fifteen most cited reference information among 341 articles on e-learning in ME. The most cited articles in the table are Wang, T. H. (9.20 citations per year), Borba, M. C. (7.63 citations per year), Ozyurt, O. (4.00 citations per year), Fabian, K. (5.50 citations per year), Farhan, M. (6.33 citations per year), Lin, H. C. K. (3.60 citations per year), Ozyurt, O. (3.18 citations per year), Warin, B. (3.75 citations per year), Jasute, E. (3.63 citations per year), Arias, J. J. (4.67 citations per year), Yilmaz, F. G. K. (3.38 citations per year), Sarwar, S. (4.80 citations per year), Thongsri, N. (5.75 citations per year), Junus, K. (7.00 citations per year) and Moreno, G. A. J. (5.00 citations per year). Below is the distribution of the corresponding authors by country.



Notes: MCP = Multiple Country Publications; SCP = Single Country Publications

Figure 5. Corresponding' author's country on e-learning in ME

When Figure 5 is examined, it is noteworthy that the responsible authors working on e-learning in ME are primarily from one country. Corresponding authors are mostly China (n=25), USA (n=25), Russia (n=24), Spain (n=22), Italy (n=21), Ukraine (n=17), Germany (n=14), Turkiye (n=13), India (n=11), Indonesia (n=11), Saudi Arabia (n=11), Bulgaria (n=9), England (n=9), Korea (n=7) and Poland (n=7) countries. One of his remarkable findings is that all of the articles related to Bulgaria and Ukraine include a single-country author. The figure below shows the distribution of authors who have assumed a dominant role in e-learning in ME over the years.

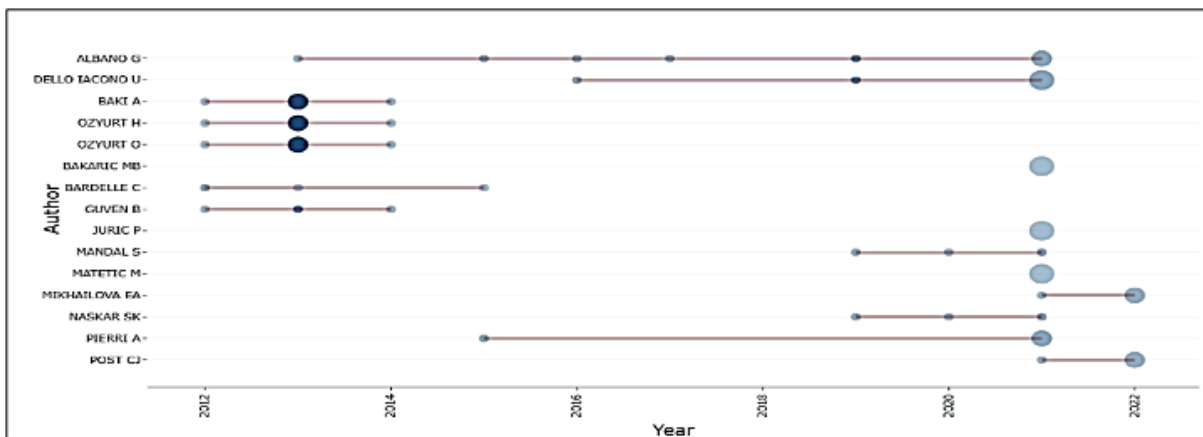


Figure 6. Authors' production over time on e-learning in ME

Figure 6 shows the authors who assumed the dominant role over time. The dominance factor is a measure that calculates author dominance by dividing the number of articles with multiple authors in which the author is the first author by the total number of articles with multiple authors (Kumar & Jan, 2014). Analyzing the figure, the dominant roles of Albano authors from 2013 to 2021, Dello Iacono from 2016 to 2021, and Pierri from 2015 to 2021 can be seen. Apart from these, some authors have assumed the dominant roles of the period. For example, Baki, Ozyurt, and Ozyurt stand out as dominant authors between 2012 and 2014. Similarly, Bardelle is the dominant author from 2012 to 2015, Guven from 2012 to 2014, Mandal from 2019 to 2021, and Mikhailova and Post from 2021 to 2022. Information about institutions that are more productive in e-learning in ME is given in the figure below.

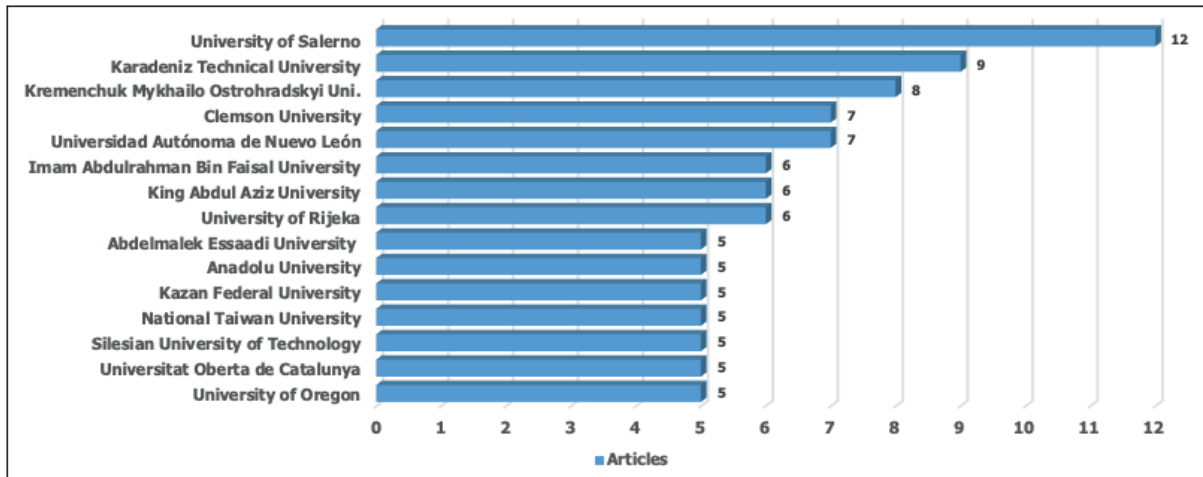


Figure 7. Most relevant affiliations over time on e-learning in ME

When Figure 7 is examined, it is seen that the most productive institution regarding e-learning in ME is the University of Salerno (12 articles). This is followed by Karadeniz Technical (9 articles), Kremenchuk Mykhailo Ostrohradskyi National (8 articles), Clemson (7 articles), Universidad Autonoma de Nuevo Leon (7 articles), Imam Abdulrahman Bin Faisal (6 articles), King Abdul Aziz (6 articles), Rijeka (6 articles), Abdelmalek Essay (5 articles), Anatolia (5 articles), Kazan Federal (5 articles), National Taiwan (5 articles), Silesian Technology (5 articles), Oberta de Catalunya (5 articles) and Oregon (5 articles) follow the universities. Below is information about the countries with the most references to e-learning in ME.

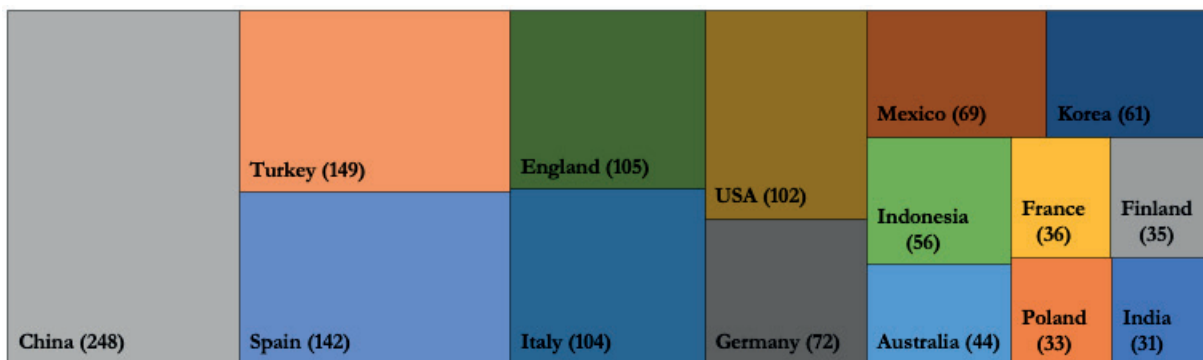


Figure 8. Most cited countries on e-learning in ME

When the tree map in Figure 8 is examined, China (n=248) is one of the most cited countries. This is followed by Turkiye (n=149), Spain (n=142), England (n=105), Italy (n=104), USA (n=102), Germany (n=72), Mexico (n=69), Korea (n=61), Indonesia (n=56), Australia (n=44), France (n=36), Poland (n=33), Finland (n=35) and India (n=31) respectively. The following section presents network analysis, trend topic, and thematic evolution information about articles published on e-learning in ME.

Network Analysis on E-Learning in Mathematics Education

This section includes network analyses of scientific studies on e-learning in ME between 2012 and 2022, trend topics, and thematic evolution. The following figure shows the co-citation analysis. Co-citation analysis is defined as the frequency of citing two studies together. This analysis technique shows the citation frequency of two different analysis units in the same study (Bagis, 2021, p. 100). In other words, it is a visualization of the frequency of citing two studies together. The network visualization of co-citation analysis is included in the context of the cited authors in the figure below.

Co-Citation Networks Analysis on E-Learning in Mathematics Education

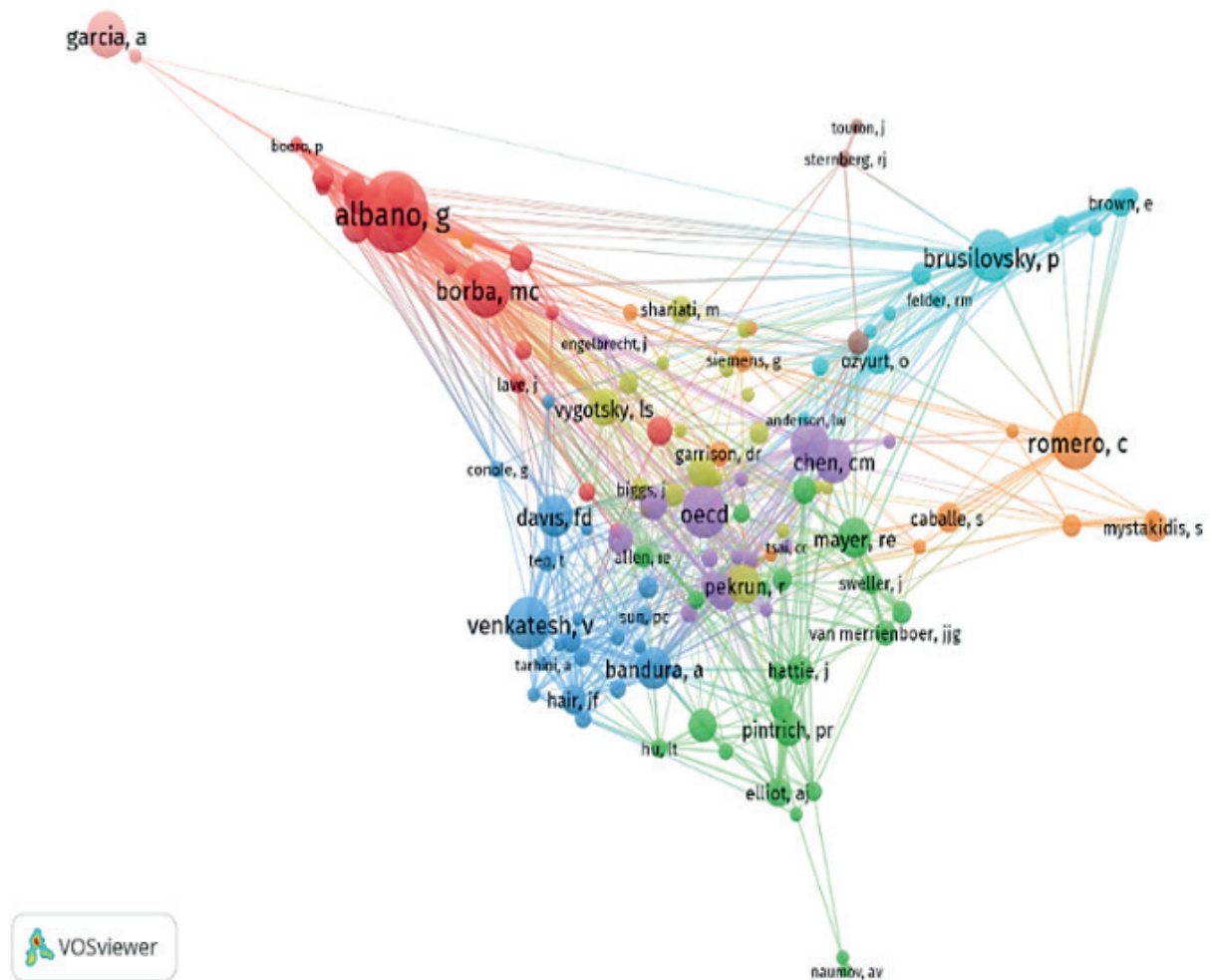


Figure 9. Co-citation network analysis in the context of authors

In Figure 9, co-citation network analysis is given in the context of the authors. In e-learning in ME, preference was made so that a quoted author should have at least five citations. According to this threshold value, the total number of authors cited for their studies in the data set in which the analysis was made is 9383, and the number of cited studies meeting the threshold value is 157. It is seen that authors with different connection strengths come to the fore depending on the colors used. The cluster in red includes authors such as Albano, Borba, Bardelle, and Duval. In this cluster, Albano [connections: 1384, total connection strength: 4524] is central. The green-colored cluster includes authors such as Mayer, Hattie, Pintrich, Elliot, and Marsh. Mayer [number of connections: 40, total connection strength: 130] is central in this cluster. The blue-colored cluster includes authors such as Venkatesh, Bandura, Davis, and Hair. Venkatesh [number of connections: 20, total connection strength: 198] is central in this cluster. The cluster turquoise includes authors such as Brown, Brusilovsky, Ozyurt, and Felder. Brusilovsky [number of connections: 34, total connection strength: 190] is centrally located in this cluster. The purple cluster includes authors and institutions such as Chen, OECD, Hwang, and Zimmerman. The OECD [number of connections: 53, total connection strength: 165] is central in this cluster. In the orange cluster, Romero [number of connections: 30, total connection strength: 82] is the central author. Co-citation network analysis is included in the context of the journals cited below.

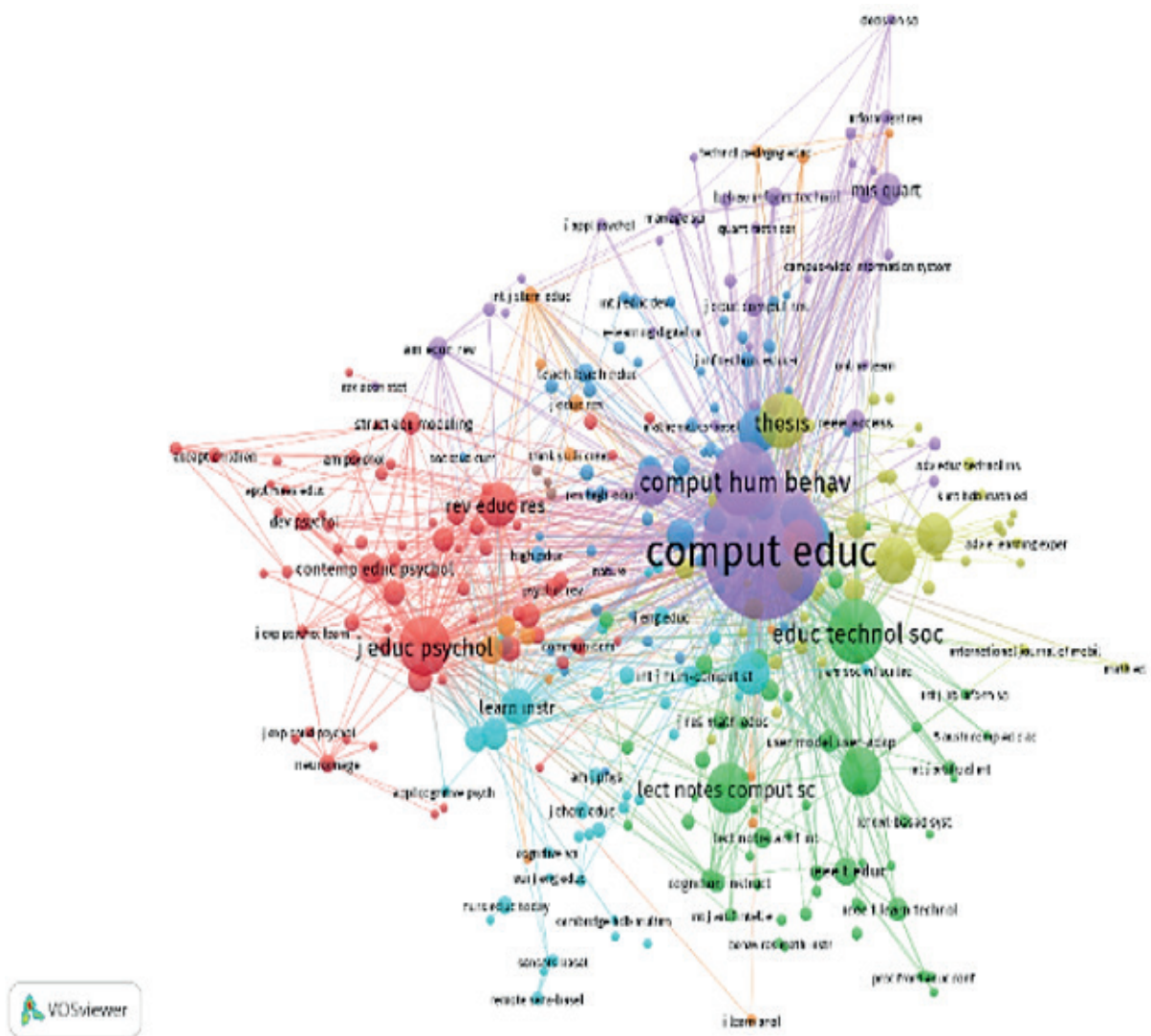


Figure 10. Co-citation network analysis in the context of journals

In Figure 10, a co-citation network analysis in the context of journals is given. In ME, preference was made so that the minimum number of citations of a cited journal on e-learning was five. According to this threshold value, the total number of documents cited in the data set in which the analysis was made is 6646, and the number of cited studies meeting the threshold value is 327. It is seen that journals with different connection strengths come to the fore depending on the colors used. Journal of Educational Psychology and Review of Educational Research stand out in the red cluster. Computers & Education and Computers in Human Behavior journals stand out in the purple cluster. ZDM Mathematics Education and Educational Studies in Mathematics journals dominate the yellow cluster. Educational Technology & Society and Expert Systems with Applications journals have stronger links in the green cluster.

Collaboration Networks Analysis on E-Learning in Mathematics Education

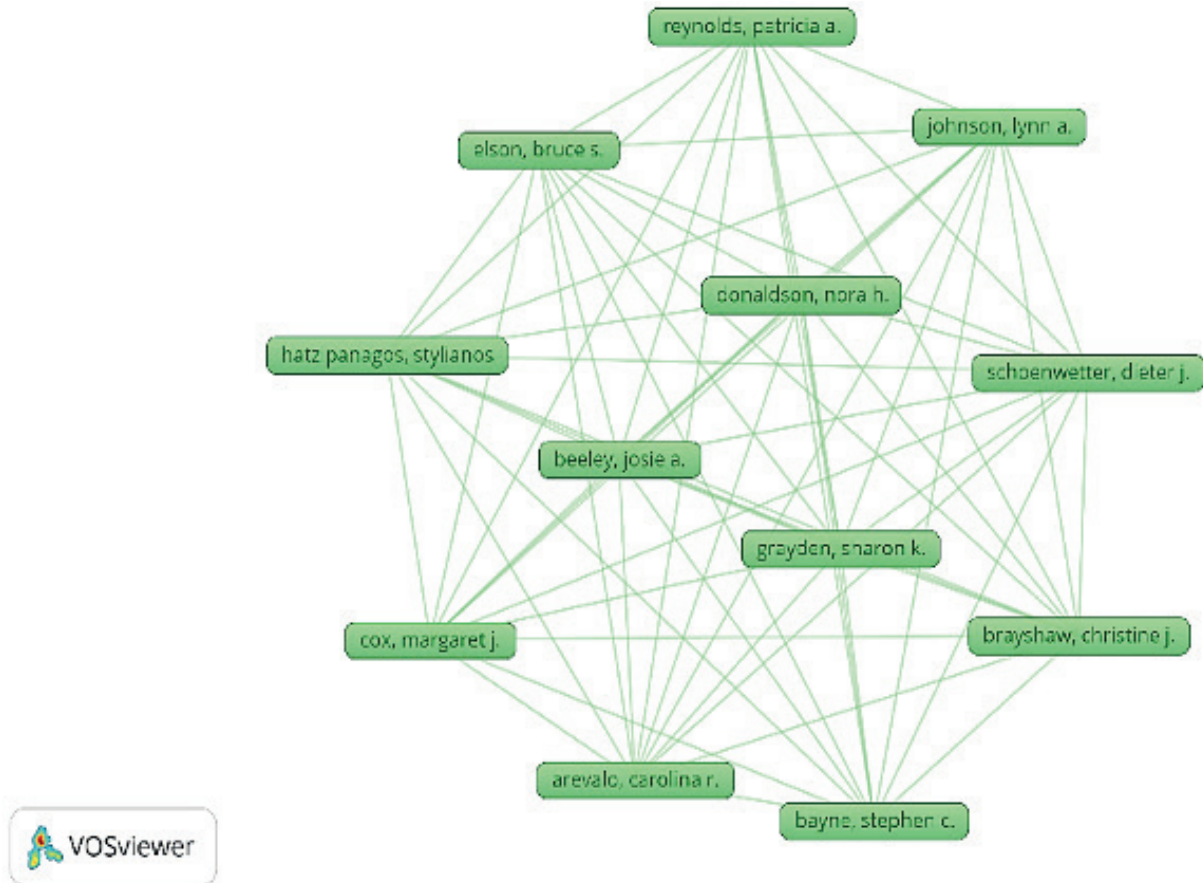


Figure 11. Co-author network analysis in the context of authorship

Figure 11 shows the co-author network analysis results in the authorship context. From the figure, the collaborations between the authors on e-learning in ME are quite limited. Accordingly, it is seen that there is a collaboration between Arevalo, C. R., Beeley, J. A., Bayne, S. C., Brayshaw, C. J., Grayden, S. K., Cox, M. J., Hatzipanagos, S., Schoenwetter, D. J., Donaldson, N. H., Elson, B. S., Johnson, I. A., and Reynolds, P. A. authors in a single cluster. Below is a co-author network analysis in the context of countries.

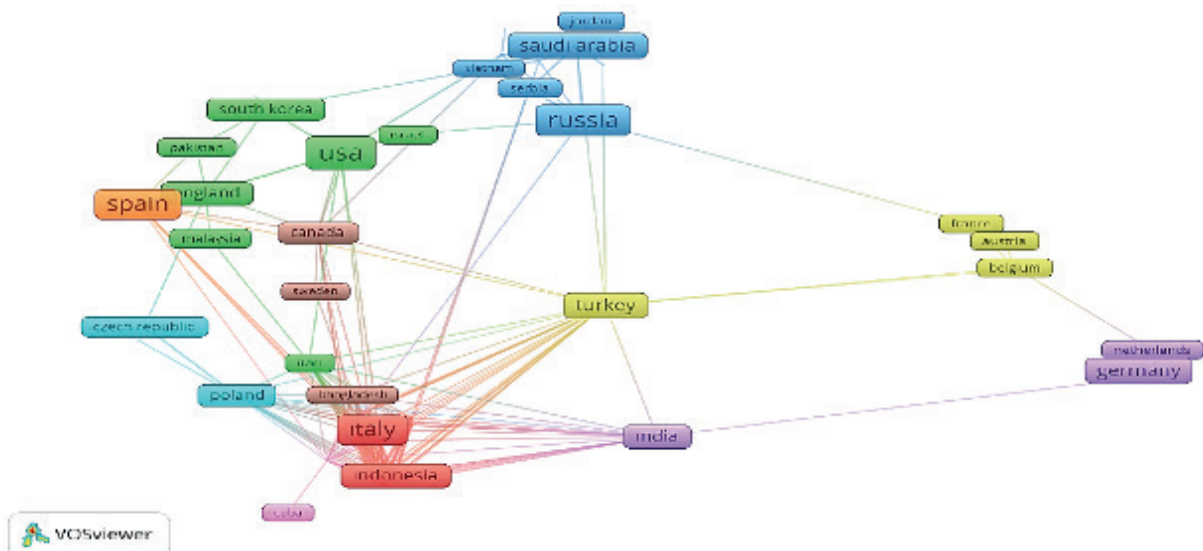


Figure 12. Co-author network analysis in the context of countries

Figure 12 shows the co-author analysis by country. According to the network analysis of 79 countries, it is seen that countries such as Italy, USA, Turkiye, Spain, Germany, and Russia are more prominent. The yellow cluster includes Turkiye, Algeria, Belgium, Peru, France, and Austria. The intensity of cooperation between countries such as the green cluster USA, Iran, England, Malaysia, Pakistan, South Korea, and Israel draws attention. The red cluster includes countries such as Italy, Indonesia, Mexico, Portugal, Romania, Slovenia, Arab Emirates, Brazil, and Chile. The purple cluster includes countries such as Germany, India, Netherlands, Norway, and Sudan. The blue cluster includes collaborations between Russia, China, Saudi Arabia, Serbia, Vietnam, Egypt, and Jordan. The turquoise cluster includes countries such as Czech Republic, Poland, and Slovakia. The world cooperation network is shown below.



Figure 13. Authors' world collaboration network on e-learning in ME

Figure 13 shows the cooperation between countries more clearly. According to the figure, the relations between Brazil with South Africa, China with Saudi Arabia, China with Serbia, Greece with Finland, Indonesia with Hungary, Italy with Australia, Italy with Slovenia, Mexico with Brazil, Mexico with South Africa, Poland with Czech Republic, Saudi Arabia with Egypt, Saudi Arabia with Serbia, Turkey with Brazil, Turkey with Mexico, Turkey with South Africa, USA with Canada, USA with China and USA with Korea are noteworthy. There is a certain level of partnership between these countries, although not at an intense level.

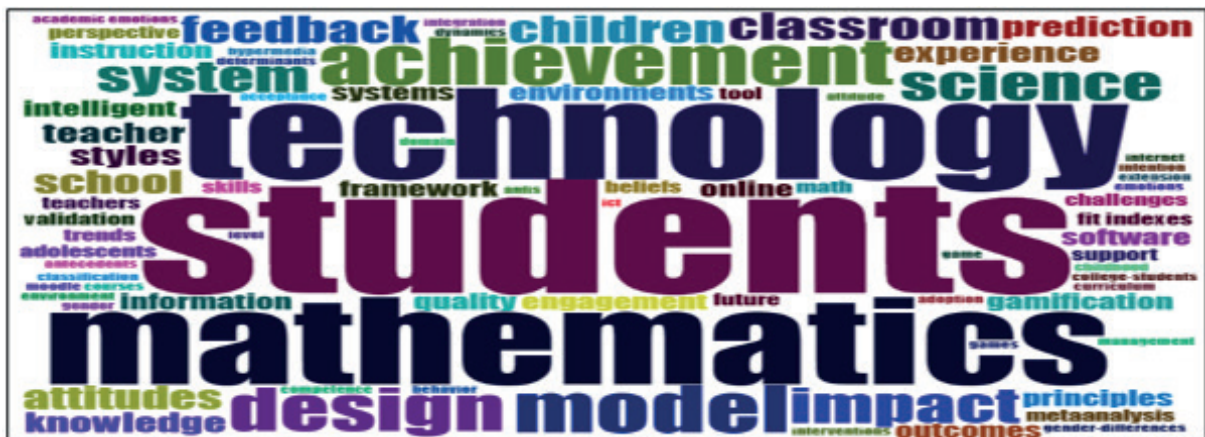


Figure 14. Word cloud for e-learning in ME

Figure 14 shows the keywords plus involved in studies on e-learning in ME. According to the figure, it is seen that the frequently preferred keywords are “students”, “technology”, “mathematics”, “education”, “performance”, “achievement”, “model”, “design”, “impact”, “motivation” and “science”. The co-word network analysis was examined to determine better how often the keywords are used in the same document. In this context, the co-occurrence of the keywords created by the authors was examined. In this way, in the following figure, the co-word network analysis, in other words, the occurrences between the keywords, are shown.

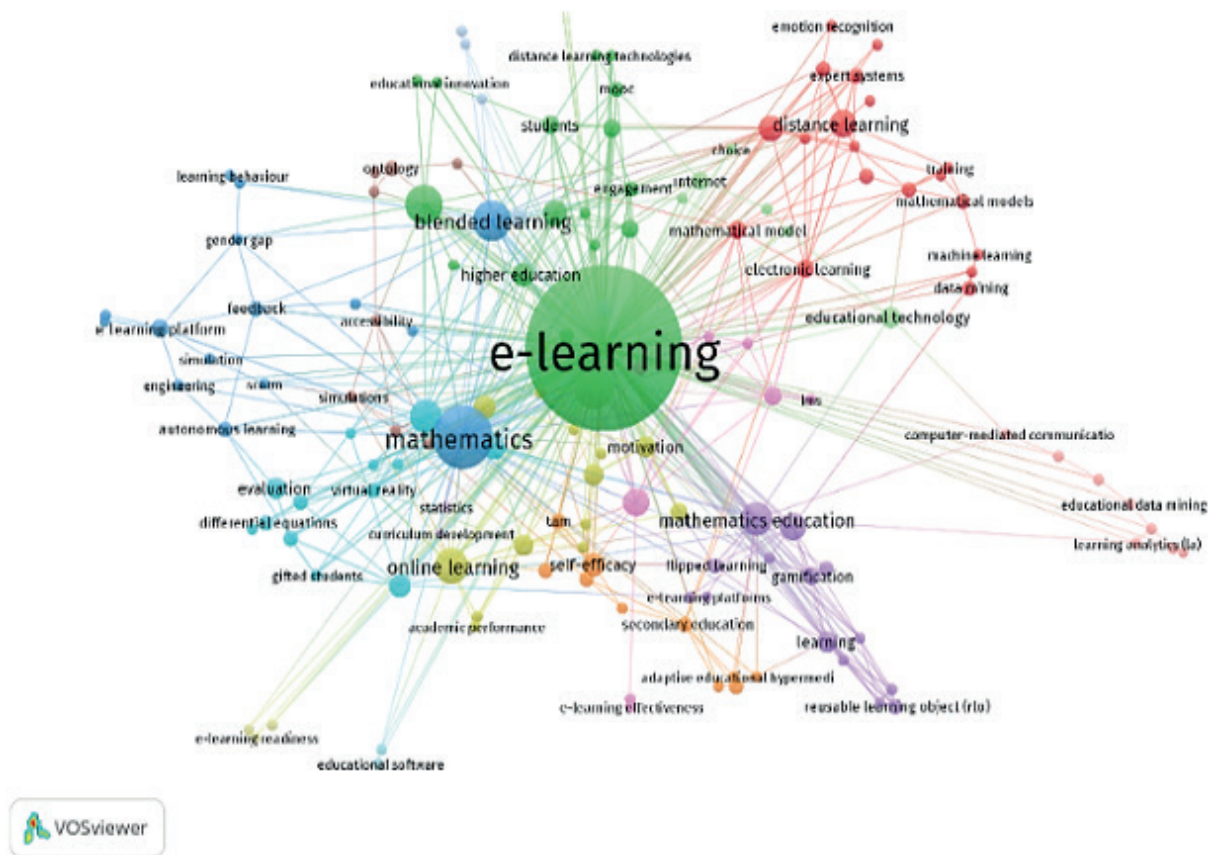


Figure 15. Co-word network analysis in the context of author keywords

In Figure 15, co-word network analysis is given in the context of author keywords. Studies on e-learning in ME were preferred, so the number of citations was at least two. According to this threshold value, the total number of documents cited from the studies in the data set in which the analysis was made is 1217, and the number of cited studies meeting the threshold value is 149. When the figure is examined, the words “e-learning”, “mathematics”, “mathematics education”, “online learning”, “blended learning”, “educational technology”, “distance learning”, “evaluation” and “higher education” come to the fore more dominantly. In the figure below, in the three-domain diagram, also known as the Sankey diagram, the links to each other as keywords (left), authors (middle), and institutions (right) are discussed to contextualize the flow trend of scientific studies on e-learning in ME.

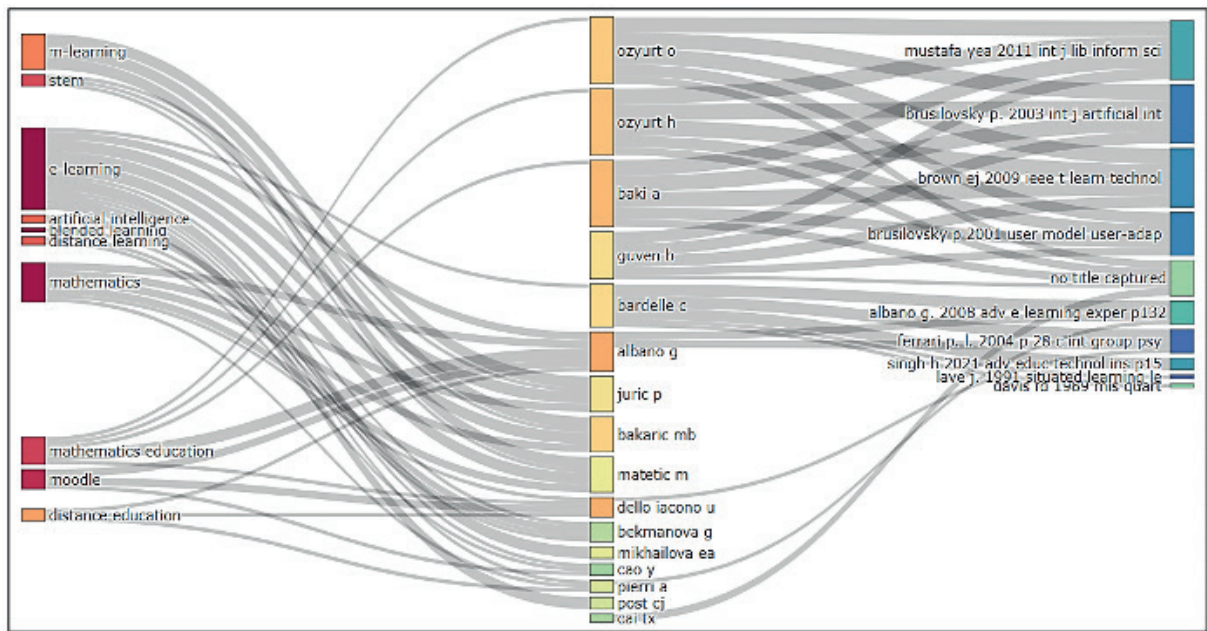


Figure 16. E-learning in ME Sankey Plot (keyword- author-affiliation)

When Figure 16 is examined, the boxes' size is proportional to the number of links (keyword, author, or institution). According to the figure, it is seen that the margin widths of the keywords “e-learning”, “mathematics”, “mathematics education”, “m-learning” and “moodle” are larger than the other keywords. The large margins show that many authors use keywords in their publications. On the other hand, it is noteworthy that the authors of Ozyurt, O., Ozyurt, H., Baki, A., Guven, B., Albano, G., Juric, P. and Bakaric, M. B. are used in a wide list. It can be said that a comprehensive keyword list reflecting the diversity of the studies is used based on the interaction between institutions, keywords, and authors.

Trending Topics and Thematic Evolution on E-Learning in Mathematics Education

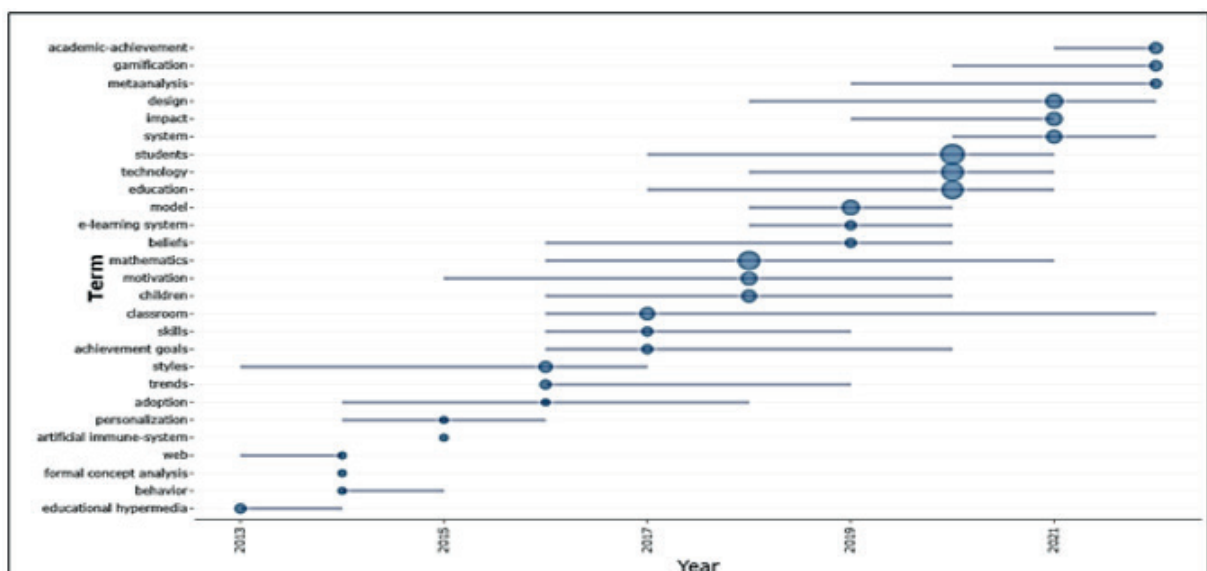


Figure 17. E-learning in ME trending topics map (keywords plus)

Figure 17 contains trending keywords in e-learning in ME. Keywords are one of the essential steps that reflect the content of research. According to the trend topic map, “students” and “education” (2017-2021),

“technology” (2018-2021), “mathematics” (2016-2021), “model” (2018-2020), “design” (2018-2022), “motivation” (2015-2020) and “impact” (2019-2021) keywords seem to be more preferred. In addition, the keywords “system” (2020-2022), “classroom” (2016-2022), “children” (2016-2020), “styles” (2013-2017), “academic achievement” (2021-2022) is also frequently preferred. Keywords from the study offer clues over the years and in identifying trends. The explosion or increase in keywords in scientific studies is a leading indicator of study potential (Qian et al., 2019). It helps researchers to see the changes in the study content. It also offers valuable opportunities and ideas for work to be done in a similar direction. The trend topic map determined according to e-learning topics in ME is shown below.

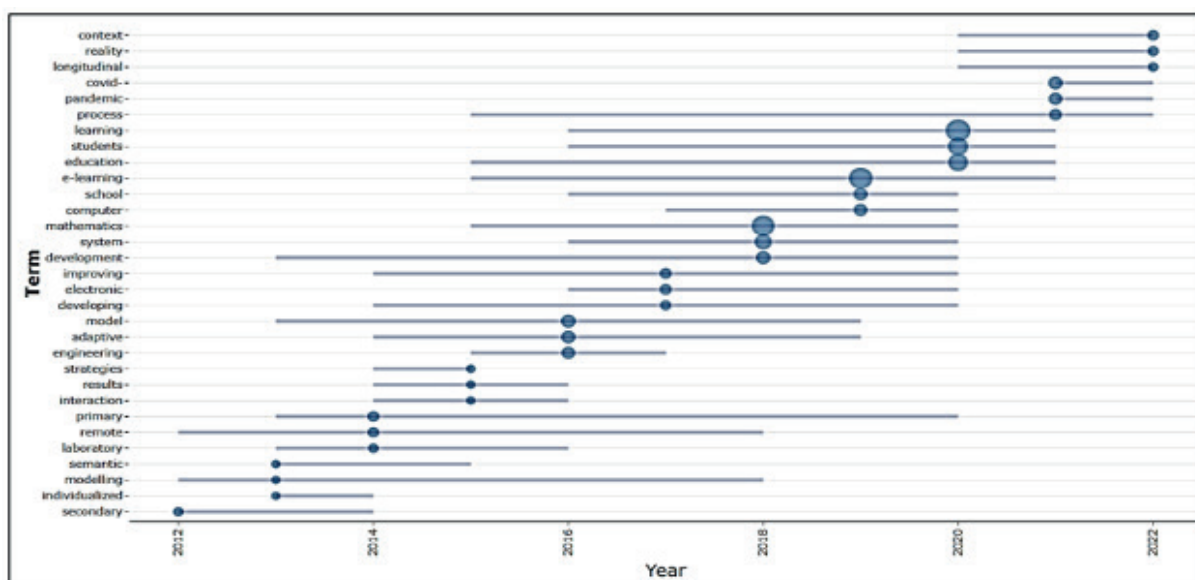


Figure 18. E-learning in ME trending topics map (titles)

Figure 18 includes trending article titles on e-learning in ME. According to the trend topic map, “learning” and “students” (2016-2021), “e-learning” and “education” (2015-2021), “mathematics” (2015-2020), “system”, “school”, “children” and “electronic” (2016-2020), “model” (2013-2019), “development” and “primary” (2013-2020), “adaptive” (2014-2019), “covid”, “pandemic” and “academic achievement” (2021-2022) article titles are mostly preferred. In addition, “engineering” (2015-2017), “computer” (2017-2020), “styles” (2013-2017), “process” (2015-2022), and “improving” (2014-2020) articles titles are also available is often preferred. Such topics can be considered trending topics/hotspots in scholarly publications on e-learning in ME because trending topics often represent hotspots or emerging themes in a particular research area (Chen et al., 2021a; Mostafa, 2020). The thematic change over the years is shown below.

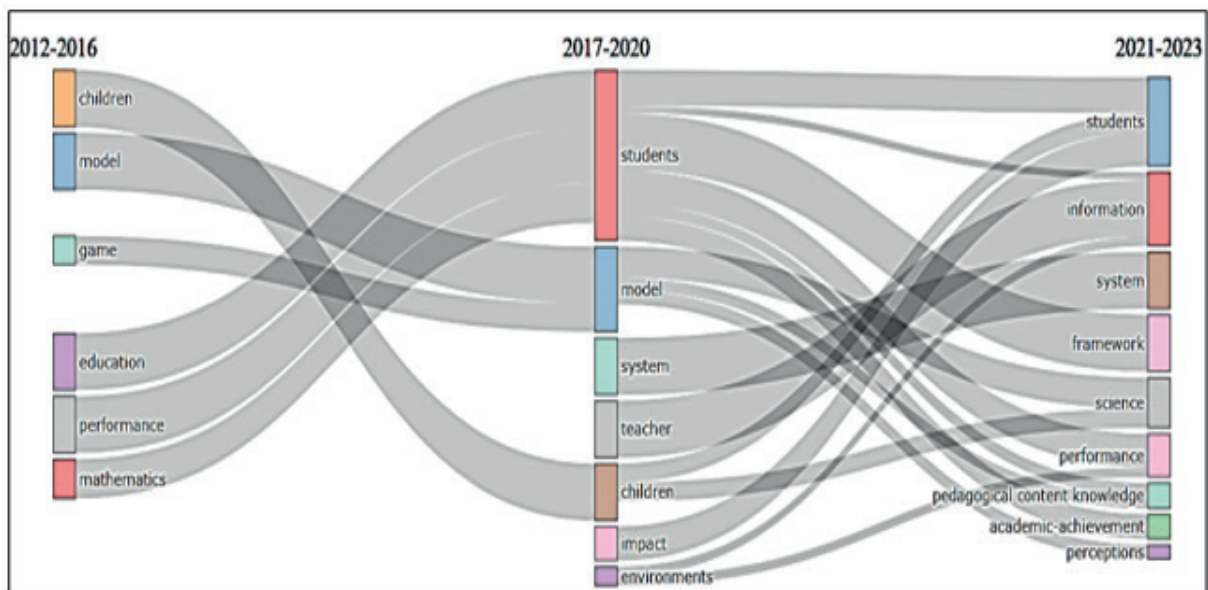


Figure 19. Thematic evolution indicator on e-learning in ME by years

Figure 19 shows the thematic changes in e-learning in ME over intermittent years. According to the figure, the keywords “children”, “model”, “game”, “education”, “performance” and “mathematics” stand out between 2012 and 2016. According to the size of the boxes, the keywords “students”, “model”, “system”, “teacher”, “children”, “impact and “environments” are more dominant between 2017 and 2020, respectively. The keywords “students”, “information”, “system”, “framework”, “science”, “performance”, “pedagogical content knowledge”, “academic achievement” and “perceptions” come to the fore according to the size of the boxes between 2021-2023 years, which is the closest time period to today.

Conceptual Structure and Thematic Maps on E-Learning in Mathematics Education

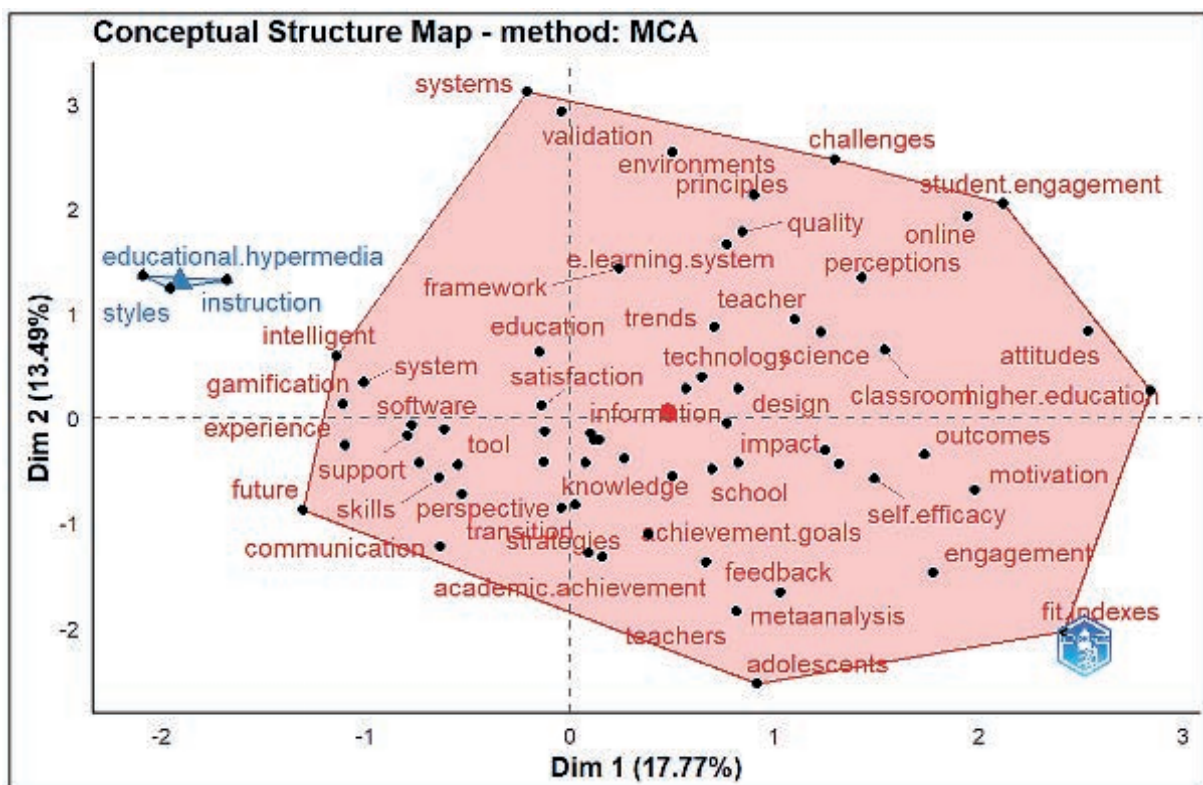


Figure 20. E-learning in ME conceptual structure map (MCA method)

In Figure 20, the MCA was run on the keywords presented by the authors on e-learning in ME. This resulting map reveals the conceptual structure of e-learning in ME between 2012 and 2022. According to the graph, the best size reduction obtained for the first two dimensions of the MCA accounts for approximately 31% of the total variability. The closer the points are to each other in this graph, the more similar the profile they represent, with each cluster of points representing distinctive profiles (Mostafa, 2020; Wong et al., 2021). In the graph, the depth of the red-colored structure is greater than the blue-colored structure. For example, the red-colored cluster “information”, “e-learning”, “knowledge”, “design”, “school”, “technology”, “self-efficacy”, “achievement”, “education” and “outcomes” highlight keywords that highlight methods. The blue-colored cluster contains keywords such as “educational”, “styles”, “hypermedia” and “instruction”. The thematic/strategic map is given below.

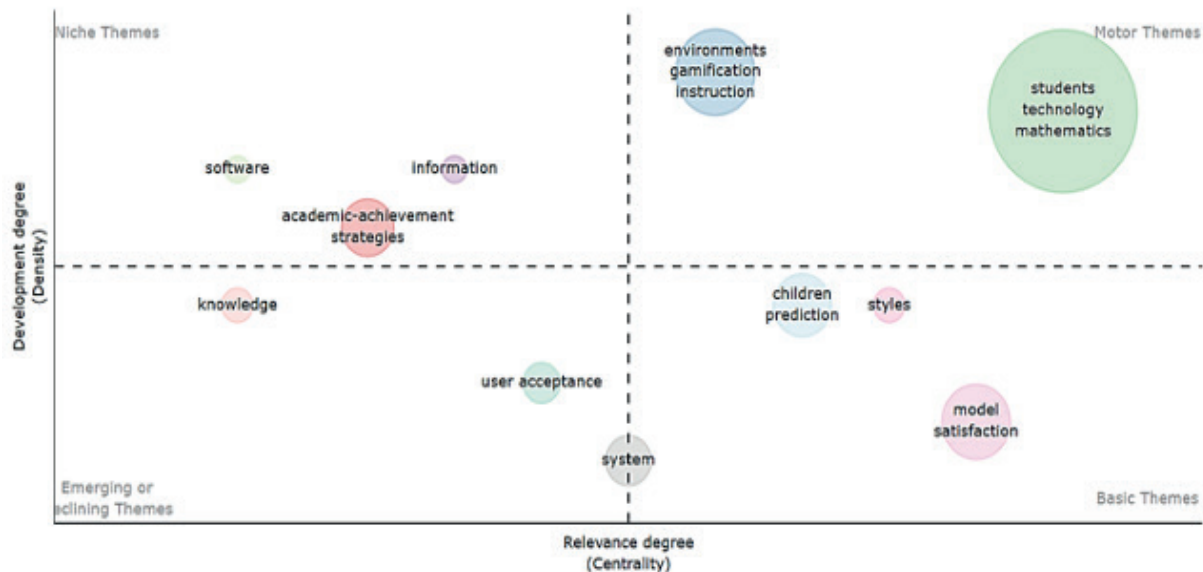


Figure 21. E-learning in ME thematic map

Figure 21 shows the thematic/strategic map of e-learning in ME according to keywords plus. Walktrap is used as a clustering algorithm in thematic/strategic mapping. The minimum cluster frequency (per thousand docs) value of twelve was chosen to reduce cluster contiguity. The map in the chart is represented by a dotted line dividing it into four quadrants. Both axes represent mean values. Each dial in this chart represents a different theme. Bubble size is determined in proportion to the frequency of studies using keywords. The first quarter of the chart (motor themes) is well developed both internally and externally as it is formed with high density and centrality (Cobo et al., 2011). (Cobo et al., 2011). These themes, which include e-learning in ME are “students”, “technology”, “mathematics”, “environments”, “gamification” and “instruction”. These themes are current themes and point to current trends. On the other hand, the second quarter is known as Niche themes, which are very developed and isolated. This theme exhibits a high density and low centrality structure. The content of this much is based on the fact that while it is well developed internally, it is of little importance externally. Niche themes, including e-learning in ME are “academic-achievement”, “strategies”, “information” and “software”. The themes in the third quarter include low density and low centrality. Weak ties at the inner and outer levels characterize the themes in this quadrant. Such themes indicate potential hotspots in research on interactive learning environments. Examples of these themes are “knowledge” and “user acceptance”. Finally, the core and cross themes quarter (low density-high centrality) includes poorly developed themes in terms of interconnections. However, they are characterized by significant external bonds. These simple themes that include e-learning in ME include are “model”, “satisfaction”, “styles”, “children” and “prediction”.

DISCUSSIONS AND CONCLUSION

This study tried to determine the comprehensive view of the scientific articles published on e-learning in ME between 2012 and 2022. In this context, 341 scientific articles were accessed from the WoS™ Core Collection database, and bibliometric analysis was performed. First, scientific articles related to the study subject were examined according to their years and citation counts. According to the findings, scientific studies on e-learning in ME have entered an increasing trend since 2018. Although there has been a decrease in the number of studies published in 2022, this situation is closely related to the emerging global epidemic. It was determined that there is a continuous increase in the number of citations on this subject. It is noteworthy that there has been a significant increase in the number of citations due to the increase in the number of studies. Accordingly, the popularity of e-learning in ME has increased, especially in recent years. The number of citations made in the last two years is relatively high. This situation, which has emerged both in the number of publications and citations, shows that e-learning in ME is becoming an essential field of study with increased visibility. Considering that approximately 45% of the world's population has access to the internet, technological terms such as mobility, online courses, touch technology, and massive open online courses (MOOCs) are now frequently used by mathematics educators (Borba et al., 2016). Therefore, it is inevitable that studies with digital technology content will increase day by day, and intensive studies should be carried out in this direction. In a similar study conducted by Hung (2012), it was determined that the number of studies on e-learning between the years 2000-2008 increased compared to the previous years. The findings of the study by Djeki (2022) also indicate that studies on e-learning are increasing. However, there has been a significant increase in e-learning in ME, especially in recent years, as in other disciplines, the development of e-learning needs studies.

When the articles based on the WoS database are examined, Albano, G., Dello Iacono, U., Baki, A., Ozyurt, H., Ozyurt, O., Bakaric, M. B., Bardelle, C., Guven, B. and Juric, P. authors stand out. Looking at the general working profiles of these authors, it is seen that they have qualified publications on e-learning in ME. According to WoS author information, the universities of Salerno (Italy), Karadeniz Technical (Turkiye), Rijeka (Croatia), and Milan (Italy) come to the fore when looking at the institutions where these authors work. These pioneering authors' works occupy an important place in the field and contain valuable information in guiding the field. The article "developing an assessment-centered e-learning system for improving student learning effectiveness" published by Wang in *Computers & Education* journal in 2014, has been the most cited work. In the study, the teaching of the speed unit within the scope of the math course was considered. In the study conducted with sixth-grade students, four learning environments were created according to the e-teaching model. Personalized e-learning is significantly more effective in facilitating learning achievement and improving misconceptions, especially for students with low prior knowledge. In another study by Borba et al. (2016), it was the most cited publication. In the study, it was tried to determine what the latest developments in digital technology research in the field of ME are. In ME, "blended learning", "e-learning" and "mobile learning" constitute the main research topics of the study. In the study, the effects of digital technologies on ME practice were discussed, and some suggestions were made for future research. Another study conducted by Ozyurt et al. (2013) aimed to learn and teach permutation-combination-binomial expansion and probability at the secondary school level by designing an intelligent web-based e-learning system called UZWEBMAT. Another most cited study was done in 2016 by Fabian et al. In the study, research findings related to mobile mathematics technologies were synthesized. Within the scope of the study, the effects of mobile use on student perceptions, attitudes, achievements, and commitment were investigated. It was determined that student attitudes toward mobile use are primarily favorable. It was determined that the interaction and participation of students with other students increased in general. In terms of success, it was determined that there was an effect size of .48. Among the common features of the most cited studies is that they contain content about how e-learning can be in ME at a time when the subject is just beginning to take shape. In this respect, these studies have gained an important place in the field and have guided researchers in e-learning. Notably, the posts about its practical use in ME have been met by other researchers. It is seen that there is an increasing trend in the number of studies on the use and effectiveness of digital technologies in ME in recent years (Chen et al., 2021b; Djeki et al., 2022; Hung, 2012).

When the countries of the responsible authors in the studies were examined, it was determined that the countries of China, USA, Russia, Spain, and Italy came to the fore more. It is noteworthy that the study's responsible authors are usually single-country authors. On the other hand, there are no authors from other countries among the corresponding authors in Ukraine and Bulgaria. When the prolific authors' findings were examined yearly, it was determined that the authors named Albano, G. between 2013 and 2021, Dello Iacono, U. between 2016 and 2021, and Pierri, A. between 2015 and 2021 were the dominant authors. Apart from this, it was determined that there are also dominant periodical authors. For example, authors Baki, A., Ozyurt, H., Ozyurt O, and Guven, B. acted as dominant authors between 2014 and 2021. Similarly, between 2019 and 2021, Mandal S. impacted this field. The most productive institution in e-learning in ME has been the University of Salerno (Italy). This institution is followed by Karadeniz Teknik (Turkiye), Kremenchuk Mykhailo Ostrohradskyi (Ukraine), Clemson (South Carolina), Universidad Autonoma de Nuevo Leon (Mexico), and Imam Abdulrahman bin Faisal (Saudi Arabia). The most important reason for these institutions to come to the fore is that most of the authors who publish scientific studies on e-learning in ME work in these institutions. Although this finding is an expected result, it can be said that the authors put the institutions they work into the fore. When the findings of the most cited countries were examined, it was determined that China, Turkiye, Spain, England, USA, and Germany were more active in this field. Similar findings were obtained in studies conducted in previous years. For example, Djeki et al. (2022), USA, Spain, England, and China were determined as the most productive countries. Tibana-Herrera et al. (2018), USA comes to the forefront as a productive country. According to Chen et al. (2021b), China was the most productive country based on the Scopus database. In another study by Hung (2012), England, USA, Taiwan, and China were determined as the most productive countries. Therefore, it is seen that the countries that were productive in the past on the e-learning approach still have a say today. Similarly, the countries of the responsible authors are more prominent in e-learning, and these authors place their countries at the top of e-learning.

Another finding from the study was from co-citation analysis in the context of authors. It is stated that specific authors are in the central position when a cited author's minimum number of citations is selected as five. Authors Albano, Borba, Bardelle, Romero, Brusilovsky, Venkatesh, Chen, and Brown are prominent authors in the co-citation analysis. In particular, the connection knots of Albano, Borba, and Brusilovsky authors with other authors are thick and frequent. These authors united and discussed the axis of a common subject. Another finding from the study was from co-citation analysis in the context of authors. It is stated that specific authors are in the central position when a cited author's minimum number of citations is selected as five. Authors Albano, Borba, Bardelle, Romero, Brusilovsky, Venkatesh, Chen, and Brown are prominent authors in the co-citation analysis. In particular, the connection knots of Albano, Borba, and Brusilovsky authors with other authors are thick and frequent. These authors united and discussed the axis of a common subject. These similarities that emerge in bibliometric analyses indicate intradisciplinary or thematic similarity (Jiang et al., 2019). Authors central to the cluster on e-learning in ME tend to influence other communities. In addition, these authors significantly impact other researchers as they control and promote content related to the study topic (Mostafa, 2020). Therefore, these authors are considered influential authors with the subject of study. In the context of journals, *Computers & Education* and *Computers in Human Behavior* journals come to the fore in co-citation network analysis. These journals are pioneer journals, and the subject of study has strong links. At the same time, these journals contain many studies with the subject of study. The fact that these journals focus on technology and technological tools is among the first references in studies conducted similarly. Journals that are pioneers on the subject of the study have gained a significant position both in getting more citations and in determining the trends in the relevant field.

On the other hand, one of the remarkable features of these journals is that most of the authors working in this field have publications in these journals. One of the remarkable findings of the study was obtained from co-author network analysis in the context of authorship. Accordingly, it was determined that the cooperation between the authors remained at a limited level. In the co-author network analysis in the context of countries, it was determined that there were connections between 79 countries, such as Italy, USA, Turkiye, Spain, Germany, and Russia. It was determined that cooperation between countries remains limited in terms of

the number of connections and the power of the connection nodes. In the analysis made according to the geographical atlas, it was determined that although cooperation exists between countries such as USA, China, Turkiye, Australia, Brazil, and Mexico, this is at a limited level. According to Djeki et al. (2022), in the study covering the years 2015-2020, it was determined that while the journals *Computers in Human Behavior*, *Computers & Education*, and *International Journal of Emerging Technologies in Learning* came to the fore, similar journals are still at the forefront in ME today. Especially on the subject of common, *Computers & Education* and *Computers in Human Behavior* journals have been the journals in which more studies in this field have been published. The studies in these journals make significant contributions to the field and pioneer innovative approaches/approaches in e-learning.

The study's other finding was obtained from word cloud analysis reflecting the contents of e-learning in ME. According to the findings, the keywords "technology", "students" and "mathematics" stand out. Keywords are one of the essential building blocks of a study. Due to their abstract nature, they provide valuable clues in obtaining a general idea about the study (Chen et al., 2021a). The co-occurrence network of keywords was also examined to determine how often keywords coexist in the same document in e-learning in ME. According to the findings, it was determined that the words "e-learning", "mathematics", "mathematics education", "online learning", "blended learning", "educational technology", "distance learning", "evaluation" and "higher education" are frequently preferred. It was determined that these keywords are located in the center of the clusters they are in, and in other words, they act as core words. The margin widths of the keywords "e-learning", "mathematics" and "mathematics education" were found to be larger than the other keywords in the Sankey three-stage diagram. Similarly, in a similar study by Goksu (2021), topics such as augmented reality, higher education, and smartphone-oriented mobile learning were preferred. Technology-oriented keywords and topics are essential information in reflecting the content of the e-learning topic. Therefore, it plays a critical role in spreading the e-learning approach to wider audiences and attracting more attention from researchers. While the concepts of systems and models, teaching and learning strategies, and factors and case studies have come to the fore in studies on e-learning in the past years, it is seen that more technical concepts are preferred in new studies (Hung, 2012). Therefore, as technology advances, changes in the content of the studies are inevitable. The diversity of technological tools affects researchers, which is felt in the studies.

When the findings about trend keywords and titles in e-learning in ME are examined, it was determined that certain keywords are dominant in specific years. It was determined that current research words such as "academic-achievement", "gamification", "meta-analysis", "design", "impact" and "system" are preferred more frequently, especially as we approach the present day. According to these changes, there is a transformation from formal, conceptual structures to a technology and skill-oriented phase. When we look at the thematic changes in e-learning after 2021, there is a shift towards skill-based approaches such as performance, pedagogical content knowledge, information, and perception. The evolution towards a more student-centered understanding of e-learning draws attention. In the past years, as the e-learning approach, which is game and model-centered, approaches today, information, system, and framework-oriented structures have dominated. A better understanding of how students learn mathematics, combined with the practical application of e-learning, can improve meaningful mathematics learning and make the subject more exciting (Ahn & Edwin, 2018). In addition, studies show that the use of the e-learning method in mathematics teaching has positive effects on students' motivation, autonomy, participation, and understanding of mathematical concepts (Moreno-Guerrero et al., 2020). When the conceptual structure related to e-learning in ME was examined, it was determined that two clusters were formed between 2012 and 2022. The best size reduction achieved for these two dimensions accounted for approximately 31% of the total variability. Key highlighting different learning methods, especially "information", "e-learning", "knowledge", "school", "technology", "self-efficacy", "design", "achievement", "education" and "outcomes" it was determined that the words were frequently included in the studies. Looking at the thematic map of e-learning in ME, the concepts of "students", "technology", "mathematics", "environments", "gamification"

and “instruction” indicate current trends. Therefore, these themes are both internally and externally well-developed and trending themes. These structures, also known as motor themes, show how the field of study has changed, and the subject of many studies today has developed in this direction (Cobo et al., 2011). As the benefits of e-learning, whose popularity is increasing day by day, are understood, it is seen that the studies in this field continue without slowing down. Although e-learning is an approach intertwined with technology, it has a structure immediately affected by the change in technology. So much so that the changes in technology make themselves felt immediately in the e-learning environment (Wang, 2014). Therefore, conducting more studies on e-learning in mathematics teaching is essential. In order to prepare for the future with a more prepared and equipped education approach, we need technology and education together more than ever (European Commission/EACEA/Eurydice, 2019; NCTM, 2016; OECD, 2019). In this context, it is necessary to increase technological diversity by giving more weight to technology-based studies in mathematics, as in other fields.

Recommendations and Further Research

Within the scope of the study, the subject of e-learning in ME was taken as the basis. In studies to be carried out in a similar direction, all types of digital content can be addressed. In addition, research on e-learning environments can be conducted not only for the discipline of mathematics but also for many other disciplines. WoS database was used to select scientific articles published on e-learning in ME. In order to reach more data sets in similar studies, Scopus, Eric, Ulakbim, Ebsco etc. databases can also be used. In addition, changes can be made in the search criteria in similar studies to be carried out. BKCI-SSH, BKCI-S, SSCI, SSCI Expanded, ESCI, A&HCI, and CPCI-S indexes were preferred in the study. By making changes in WoS categories, only SSCI, A&HCI, or SSCI-Expanded can be preferred. Only articles were chosen in the study as the document type. All documents (proceeding paper, book chapters, early access, review article, meeting abstract, editorial material etc.) can be selected for similar studies. In addition, changes in language and WoS category selections can narrow or expand the scope of work on structures. In this way, the study’s findings can be considered and discussed with a larger-scale set. Future studies may continue to analyze published research articles on e-learning in ME after 2023. This way, changes in e-learning can be better monitored over the years. Finally, comprehensive analyses can be carried out with the help of content analyses, not only bibliometric analyses, at the point of the dynamic changes that occur over time in e-learning. This study discusses scientific productivity, network analysis, conceptual structures, thematic maps, and trends. Therefore, a more in-depth process can be followed with the help of systematic or descriptive analysis.

Limitations

The study has some limitations as well as many contributions to be made to the studies on e-learning. Among the most critical limitations of the study is that only the WoS database is preferred for accessing articles published on e-learning in ME. Another limitation of the study is that the scientific articles included in the study have e-learning content. Other digital competencies should have been included in the study. In addition, articles were selected as the document type in the study. The study did not include other document types such as early access, review article, proceeding paper, book review, and editorial material. Therefore, the contents of document types may differ.

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