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Transforming Education with Augmented Reality, Metaverse and Virtual Reality Technologies in the 21st Century*

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ABSTRACT

This study aims to analyze the articles published on augmented reality (AR), metaverse, and virtual reality (VR) in the 21st century based on the Web of Science (WoS) database. In this study, we evaluated 2203 scientific documents in the education category. We examined the data set obtained from the WoS database within scientific productivity, network analysis, trend topic, thematic change, conceptual structure, and thematic map. We analyzed the distribution of articles by year and number of citations, core authors, most cited articles, productive institutions, dominant authors by years, and productive countries within scientific productivity. The network analysis determined cooperation between authors, institutions, and countries, keyword cloud, and co-occurrence networks according to keywords. In the last stage of the research, we examined trend topics, thematic change, conceptual structure, and the formation of thematic maps. The research analyzed scientific documents with 71,050 reference information, representing 87 countries and published by 5781 authors. According to the findings, the number of articles and citations published on AR, metaverse and VR has increased significantly, especially in the last ten years. Hwang, G. J., Makransky, G., and Tsai, C. C. stand out as core authors. Prolific institutions include the National Taiwan Normal University and the National Taiwan University of Science and Technology. China, USA, Spain, Türkiye, and United Kingdom are among the leading producing countries. While emphasizing the technological infrastructure as thematic change, the best size reduction representing the conceptual structure accounts for approximately 58% of the total variability. We shared some thoughts on the future of AR, metaverse, and VR as suggestions.

Keywords: Augmented reality (AR), bibliometric, metaverse, virtual reality (VR), Web of Science (WoS)

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1. INTRODUCTION

Technology has an important place in the information society of the 21st century, the first quarter of which we live. While the technology ecosystem, which is the holistic representation of the digital age, takes its place widely in the life of humanity, it also necessitates change and transformation in many areas of life. It is possible to find traces of technological tools, the existence of which is needed more and more every day in many areas, from health to art, from space science to justice, from architecture to sports, from security to energy, from agriculture to trade, from communication to transportation, from industry to tourism, from the religious sciences to social services, from economy to education. We witness the effects of technological advances and developments every minute, even every second. In the face of these irresistible changes and advances, our lifestyle, needs, and future expectations constantly change. Although the subject of how our future life will evolve and what kind of development will be achieved through technology is frequently discussed, research on the effective use of information and communication technologies (ICT) continues at a dizzying pace (Yılmaz & Şimşek, 2023). Unlike in other centuries, versatility and sustainability are becoming the most critical indicators, and the needs for individual differences are increasing. Because in the century we live in, the roles expected from individuals differ significantly, and there is a greater need for a performance-based understanding of skills. Therefore, it is now inevitable for countries to continuously improve their scholarly outputs and equip them with the knowledge, skills, and competencies required by the age.

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

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In today's world, to better adapt to the changing individual profiles, the transformative function of technology is felt in educational environments, as in many other fields (Baran Bulut & Güveli, 2023; Trilling & Fadel, 2009). So much so that it has become almost impossible to think of technology and teaching independently of each other, and ICT has become an integral part of education. Learning environments enriched with ICT pave the way for the new generation, called the digital generation, to think multi-dimensionally and offer valuable opportunities. In this direction, the structure of education standards in many countries is shaped by the understanding of acquiring 21st-century skills (career, initiative, creativity, communication, flexible thinking, critical thinking, technology literacy, *etc.*) that individuals will need throughout their lives rather than knowledge (International Society for Technology in Education [ISTE], 2016; Organization for Economic Co-operation and Development [OECD], 2022; Partnership for 21st Century Learning [P21], 2019). According to the World Economic Forum (2018), it is stated that individuals will need more technological knowledge, competence and skills to overcome the uncertainties they will face in the future. Therefore, individuals are expected to produce innovative ideas, develop insights into the needs of life, offer solutions to problems with different perspectives, keep up with changes, respond to requirements, and, most importantly, transform the potential of ICT into the welfare of humanity.

With the acceleration of digital transformation and the emergence of the internet of things (IoT), the sharp evolution in the social model necessitates the multi-faceted training of individuals. In this respect, many nations act with an effort to make them more dynamic and functional by putting the innovations offered by technology at the centre of their curriculum (ISTE, 2016). In particular, technological innovations improve individuals' learning experiences, provide interactive learning environments that help more profound learning, and lead program makers to more technology (Shute, Rahimi & Emihovich, 2017). One of the essential benefits of the technological world is that it allows the virtual world and the real (physical) world to be presented together. Technology-based applications such as augmented reality (AR), metaverse and virtual reality (VR) go far beyond the concepts of time and place by adding a different dimension to learning understandings. These innovative technologies offer valuable advantages to learning environments in seemingly impossible situations by easing the barriers to learning. In this context, AR, metaverse and VR technologies, which are directly related to each other within the scope of the study, were preferred as research topics. Although the content that deals with the convergences between the virtual world and the real world, which is increasingly popular in our age is discussed under separate headings, there is also a need to evaluate scientific studies involving AR, metaverse and VR from a wider perspective. No study in the related literature has been conducted in a similar direction in which AR, metaverse and VR technologies are evaluated together. In this respect, our study aims to fill this gap in the related field.

1.1. Augmented Reality, Metaverse and Virtual Reality

Today, technology-based applications such as web 2.0 tools, mobile technologies, artificial intelligence (AI), cloud computing, hologram, 3D printers, digital platform, second life and smart board have become integral to education. However, the widespread use of developing technological content and the understanding of the super-intelligent society (society 5.0) has integrated virtual and physical environments more. These innovative-style developments have accelerated the incorporation of AR, metaverse, VR and mixed reality (MR) technologies into teaching environments. The wave of technological change is felt firmly not only in education but also in many other fields. Especially in the 21st century, while AR, metaverse and VR technology come to the fore more due to their benefits, there is an increasing interest in its transfer to the educational environment (Chang & Hwang, 2018; Dwivedi et al., 2022; Hwang & Chein, 2022). Among the important reasons for this situation are the promising technological applications such as AR, metaverse and VR, their fast-sensing capabilities, their compatibility with mobile devices and their advanced computing capacity, and the increasing diversity of usage areas in real-life (Chao & Chang, 2019; Lee, 2012). AR and MR, the types of artificial reality, transform the real world into a virtual experience. At the same time, VR includes the understanding of creating a completely virtual world different from real life. Similarly, the metaverse is designed to extend the internet, which is the product of a virtual reality understanding.

AR is a virtual reality, the art of combining/integrating computer graphics with the real world. In general, it is an environment in which digital media products are used instead of real-world objects (Milgram & Kishino, 1994). AR can be created by configuring and connecting innovative technologies (mobile devices, wearable computers, immersion technologies, *etc.*) (Wu, Lee, Chang & Liang, 2013). Therefore, the usage areas vary depending on the developing technological content. AR is a virtual reality that enhances the user's perception of the real world with a computer-assisted layer (Azuma, 1997). Unlike VR, symbols, effects and information can be transferred to the learning environment. This way, learning environments can be seen from different angles, and real-world perception can be approached more. AR uses a location-aware system and an interface consisting of layered network information into a technology that expands the real world outside the individual (Kye, Han, Kim, Park & Jo, 2021). It also can present complex realities and possible situations by incorporating other technologies (Rohendi, Septian & Sutarno, 2018). Although the environment in AR technology is real, it contains extended equipment with information and images from the system (Lee, 2012). In this respect, it creates an interactive bridge between the virtual and real world, allowing the use of multimedia materials such as pictures, videos, 2D or 3D animations, text and sound (Chang, Morreale & Medicherla, 2010; Wang, Jeong, Love & Kang, 2013). Therefore, AR offers an artificial reality experience by placing virtual objects in real life. AR does not necessarily require creating a realistic illusion; it can also be considered an extension of VR (Gutiérrez, Mora, Díaz & Marrero, 2017). In this respect, it also brings the imagination to the fore. Recently, the metaverse application has been attracting more and more attention from researchers, and its usage areas have become widespread. The term metaverse, derived from the combination of meta and universe, is a virtual ecosystem with a wide-ranging future space in the digital environment (Hwang, Shin & Lee, 2023). In the simplest meaning, it can be described as an internet extension that transforms our 2D experience into an interactive 3D virtual world (Hussain, 2023). The immersive metaverse facilitates the convergence between extended reality and internet and web technologies, blending the real world and digital (Lee et al., 2021). The metaverse establishes multi-sensory interactions between virtual ecosystems, physical entities and a virtual simulation of real-world objects, processes or systems (Mitra, 2023). In the metaverse, individuals can discuss a topic, collaborate in the development of a project, play games, experience and solve a series of problems, or benefit from spatially organized information or experiences by engaging in social interactions (Bourlakis, Papagiannidis & Li, 2009; Hwang & Chein, 2022; Park & Kim, 2022; Wu & Hao, 2023). Metaverse has three features: *shared, persistent,* and *de-centralized*, which require AI technology quite different from traditional AR or VR (Hwang & Chein, 2022). Thanks to these features, it stands out more as a new-generation internet extension that includes a 3D sandbox where users can interact with their avatars (Tas & Bolat, 2022).

VR consists of a virtual design that introduces users to a brand-new world, independent of real life and carries the traces of imagination. It is generally defined as "a generated state in a person's mind that can occupy varying degrees of one's awareness, similar to that in real settings" (Macpherson & Keppell, 1998, p. 63). In the VR system, individuals enter a virtual world regardless of their environment and are included in a virtual scenario. However, individuals can reach the closest experience of living independently of their actual physical existence (Bown, White & Boopalan, 2017) because this system includes real-time simulation of an environment that can be explored and interacted with using multiple senses (Lee & Wong, 2014). VR technology enables users to feel themselves in a real environment, even though it is a virtual environment, through 3D environments and objects, and creates curiosity and a desire to explore in individuals by activating more than one sensory organ (Chen et al., 2019). AR and VR systems are classified as immersive, semi-immersive and non-immersive (Bamodu & Ye, 2013). Suppose an immersive system creates the feeling of exploring a whole virtual world. In that case, "a semi-immersive (projection screen instead of glasses) or non-immersive system (computer screen) creates a degree of realism" (Gutiérrez et al., 2017, p. 475).

1.2. Augmented Reality, Metaverse and Virtual Reality in Education

Thanks to ICT emerging in education, revolutionary transformations are taking place in learning processes. Especially in the last two decades, the widespread use of digital technology for teaching, learning and evaluation has led to radical changes in education (Dwivedi et al., 2022). AR and VR based content are frequently encountered in learning environments. Similarly, metaverse content that has the potential to create a new educational environment, as it allows social communication supported by immersive learning experiences, has also started to become widespread in recent years (Kye et al., 2021). Many researchers believe that innovative types of approaches characterized by digital technology-based applications provide practical and numerous benefits to the development of didactic qualities and strengthening learning environments (Chang & Hwang, 2018; Hwang et al., 2023; Park & Kim, 2022; Rohendi et al., 2018; Wu & Hao, 2023; Yılmaz & Şimşek, 2023; Yuan, Liu, Han, Li & Zhao, 2023). Thanks to AR, metaverse and VR technologies, there are significant changes in the structure and time of teaching environments (Lee, 2012). In particular, developing current technologies is essential in increasing students' interest in learning and meeting their expectations from learning environments (Jee, Lim, Youn & Lee, 2011). This makes it essential to investigate technological contents such as AR, metaverse and VR, as they may cause different results in the outputs of learning environments (Cheng & Tsai, 2013). AR, metaverse and VR based technological applications are used in many environments, such as biology, physics, chemistry, mathematics, astronomy, geometry, literacy, foreign language, and space education, especially in medical education (Ali, Ullah, Khan, Rahman & Alam, 2023; Dutta, Mantri, Singh & Singh, 2023; Gutiérrez et al., 2017; Hussain, 2023; Hwang, 2022; Mitra, 2023; Wu et al., 2013; Yen, Tsai & Wu, 2013; Yılmaz & Şimşek, 2023). Thanks to AR, metaverse and VR technologies, which have been increasingly used in recent years, the inclusion of 3D content teaching materials in teaching environments also makes it easier for us to achieve learning goals (Dunleavy, Dede & Mitchell, 2009; Dutta et al., 2023; Hwang, 2022).

It is known that AR application increases students' project performance and learning motivation and improves their critical thinking disposition and group self-efficacy (Chang & Hwang, 2018). AR technology facilitates students' concept learning (Rohendi et al., 2018), encourages learning success (Akçayır & Akçayır, 2017), helps to understand by offering different perspectives (Chao & Chang, 2019), and provides experience (Shelton & Hedley, 2002), increasing cooperation (Yen et al., 2013) and improving problem-solving skills (Dunleavy et al., 2009). It also supports approaches such as authentic and inquiry-based learning (Yuen, Yaoyuneyong & Johnson, 2011), constructivist learning (Wojciechowski & Cellary, 2013), inquiry-based learning (Cheng & Tsai, 2013), design-based learning (Atadil-Kuzucu & Kartal, 2020; Bower, Howe, McCredie, Robinson & Grover, 2014), collaborative learning (Kaufmann & Schmalstieg, 2003) and immersive learning (Udeozor, Chan, Abegão & Glassey, 2023). According to Chavez and Bayona (2018) and Khamis (2015), AR based applications support permanent learning by adding visuals, sounds and videos to the learning content that help better understanding. It is stated that VR technology-based approaches improve learning success, a sense of belonging, critical thinking, and problem-solving awareness and contribute positively to students' experiences (Hwang & Chang, 2022). It has been determined that this system also affects students' learning motivation, methods and content (Laine, Korhonen & Hakkarainen, 2023). It has also been reported that it facilitates understanding students with low learning performance (Ali et al., 2023) and affects cognitive and affective development (Vesisenaho et al., 2019). Gutiérrez et al. (2017) highlight four main advantages of VR technology. This increases the motivation and participation of students, allows constructivist learning, is accessible and allows more interaction. Although it has positive aspects, it is also stated that interaction, interface, animation routines, motion and simulated virtual environments must be well organized for VR to be successful in the learning process (Chavez & Bayona, 2018).

One of the innovative applications that has started to be used in teaching environments is metaverse technology. The number of research on the reflections of this innovative trend in education has begun to increase, especially in the last three years. Thanks to the edu-metaverse ecosystem, education content is deepened, the cost of education is reduced, and the efficiency and quality of education increase (Wu & Hao, 2023). In addition, it is stated that the metaverse application contributes to developing students' creative cognition, problem-solving, and curiosity (Hwang, 2022). Among the essential benefits of using metaverse as a teaching tool is that it encourages students to research in a virtual environment and contributes to their creative thinking processes (Huang, Rauch & Liaw, 2010; Hwang et al., 2023; Kye et al., 2021). The use of metaverse in many areas, such as computer games and entertainment (Park & Kim, 2022), health service (Hwang & Chang, 2022), product experience (Bourlakis et al., 2009), engineering education (Díaz, Saldaña & Avila, 2020), language teaching (Yuan et al., 2023) and higher education (Hwang et al., 2023; Yen et al., 2013; Yılmaz & Şimşek, 2023; Yuan et al., 2023) is becoming increasingly common worldwide. For example, Yuan et al. (2023), a teaching model reflecting the wisdom of VR from a metaverse perspective, was developed to promote English learning. The empirical results showed that VR technology can help students master their language skills and overcome course deficiencies. Moreover, it has been determined that the feeling of authentic experience in the virtual environment increases the learning and teaching effect. Hwang et al. (2023), it was aimed to add empirical data to the developing metaverse learning and teaching field. The study examined undergraduate students' experiences on three metaverse platforms (ifland, Gather Town & Frame VR). At the end of the study, it was determined that the success of metaverse teaching depends on whether students see it as beneficial or not. The survey conducted by Yılmaz and Şimşek (2023) tried to determine the general views of biology and mathematics teacher candidates regarding using VR, AR and metaverse in education. Students stated that using VR, AR and metaverse in education is beneficial in increasing the quality of learning and improving teaching methodologies.

1.3. Literature Review on Augmented Reality, Metaverse and Virtual Reality Technologies

When we look at the studies conducted similarly to our research, it is noteworthy that bibliometric studies with AR and VR content come to the fore. For example, the past, present and future of AR and VR subjects in the WoS database were discussed by Cipresso, Giglioli, Raya and Riva (2018). It generated 21,667 recording datasets for VR and 9,944 for AR. As a result of the study, it was determined that there was a significant increase in the number of studies in the field of medicine, and countries such as USA, China, England and Germany came to the fore. In addition, it was determined that the University of Illinois, University of Southern California, and University of Washington institutions made significant contributions. In a systematic study conducted by Akçayır and Akçayır (2017), it was determined that research on AR has an increasing trend and encourages learning success. In the research conducted by Tas and Bolat (2022), a bibliometric analysis of the studies on the use of metaverse in education in the WoS database was performed. As a result of the research, it was determined that Computers & Education journal and Hwang G. J. author came to the fore regarding the number of publications. National Taiwan Normal University and National Taiwan University of Science and Technology have been identified as productive on an institutional basis. It was determined that while USA was the most productive country, China had the highest number of publications from other countries. AR, VR, and second-life terms were determined as frequently used keywords. In the study by Roda-Segarra, Mengual-Andrés and Martínez-Roig (2022), 1074 articles on VR use between 1990-2021 were analyzed bibliometrically. According to the findings of the data set accessed from the WoS database, it has been determined that there has been a rapid increase in the number of studies related to VR since 2015. While USA, China, Spain and the UK are the countries that produce the most documents, it has been determined that Computers & Education journal stands out in VR content. In the study conducted by Soto, Navas-Parejo and Guerrero (2020), AR and motivation were discussed in the context of education. Scientific articles published between 1998-2018 were obtained from the Scopus database. At the end of the study, it was determined that there was a significant increase in the number of studies from 1998 to 2018, and more studies were carried out in Computer Sciences. While USA, Spain, the UK and Taiwan stand out as productive countries, it has been reported that VR, interactive learning environments and simulation are frequently used in studies. In another study by Rojas-Sánchez, Palos-Sánchez and Folgado-Fernández (2023), articles about VR in education were analyzed with the help of bibliometric analysis using WoS, Scopus and Lens databases. 718 scientific documents published between 2010-2021 were evaluated. According to the study's findings, it has been determined that the number of studies with VR content has increased since 2015 and that China is the most productive country with 273 articles. Publications with VR content was mainly featured in the International Journal of Emerging Technologies in Learning and Computers & Education. In the co-citation analysis, a co-citation relationship was found between Lee and the authors of Merchant, Dalgarno, Smith, Mikropoulos, Davis and Bouman.

When the studies conducted in the same direction in the literature are evaluated in general, it is noteworthy that a single topic that mainly includes AR, metaverse and VR technologies or the prevalence of these systems specific to a branch of science is examined. For example, in the study conducted by Arici, Yildirim, Caliklar and Yilmaz (2019), the bibliometric results of the articles on the use of AR in science education were examined. 62 articles accessed from the WoS database were evaluated. According to the findings from the studies published between 2013-2018, Azuma, Dunleavy and Klopfer were determined to be the most cited authors. In addition, while Computers & Education, Journal of Science Education & Technology and Educational Technology were prominent journals, the most examined variables in the articles were academic achievement, motivation and attitude. In the study by Li, Li, Peng, Zhao and He (2022), bibliometric analysis of VR was performed in anatomy teaching between 1999-2022. 287 publications accessed from the WoS database were included in the research. While USA, Australia and China were more productive countries in the number of publications, it was stated that there was an increasing trend in the number of publications in 2011-2015. McMaster University and Bond University were determined to be prominent institutions.

In the study conducted by López-Belmonte, Moreno-Guerrero, López-Núñez and Hinojo-Lucena (2020), AR technology in education was analyzed with a scientific mapping technique according to the WoS database. As a result of the study in which 777 articles were analyzed, it was determined that there was an increase in the number of studies on AR between 1999-2019. Wu, Dunleavy and Di Serio were the most cited authors. It has been determined that the National Taiwan Normal University institution and Altınpulluk, H. author stand out in scientific production. While Spain is the most productive country, Wu et al. (2013) wrote the most cited document. It has been determined that Computers & Education journal is leading the production source for AR content. The study conducted by Menjivar Valencia, Sánchez Rivas, Ruiz Palmero and Linde Valenzuela (2021) examined VR in Scopus and WoS databases between 2016 and 2020 through bibliometric analysis. As a result of the research, it was determined that there is a significant interest in VR and educational studies. It has been determined that most of the institutions and authors are located in the North of Europe. It has been reported that China and Canada have shown an extraordinary increase in research, especially in recent years.

1.4. Statement of the Problem

Technological developments directly affect the education and training understanding of nations. In this respect, it is essential to adapt to the developments by closely following the innovative approaches required by the age. Especially at the beginning of the current century, the significant increase in research on AR, metaverse and VR applications necessitates knowing the tendencies and contents of these studies. At this point, bibliometric studies offer important support. Thanks to bibliometric analysis, analyses that help to better reveal the scientific quality in terms of statistics, such as the content of the subject, author, citation, reference, keyword, institution, country, indexing, and field content, are carried out. With the help of bibliometry, qualitative dimensions such as the importance, quality and effectiveness of the research subject in the relevant literature can be quantitatively evaluated (Zhao & Strotmann, 2015). Such studies provide qualified data to both researchers and readers by evaluating scientific studies in databases that are considered important. Therefore, it is crucial to monitor the reflections in the databases periodically to obtain detailed information about the general structure of the research subject. Because the general framework should be determined well in detecting the change, development and orientation of the determined research topic and revealing the gap in the field, in this respect, the starting point of our study is to determine the comprehensive view of AR, metaverse and VR topics by considering the trends of applications in education from a bibliometric perspective. Our study is to give a general idea and constitute an essential resource, especially for researchers working on similar content. In addition, it is expected to guide field experts in determining current issues by providing informative data on AR, metaverse and VR topics indexed in the WoS database. Another predicted output of the study is that it will accelerate the studies to be carried out in a similar direction in the field and contribute to the development of the area. The fact that no bibliometric study in which AR, metaverse and VR contents were evaluated together was found in the relevant literature is essential in demonstrating the study's necessity.

The study, which is handled from the perspective of bibliometrics, includes AR, metaverse and VR topics. The impact of these titles in learning environments is increasing exponentially with each passing day. Especially in the last three years, although it is a relatively new application area, the increase in the number of research on the subject of metaverse draws attention. Metaverse includes an understanding of a purely virtual world, such as a VR system, or a partially virtual world, such as the use of AR in real-world contexts (Avila, 2017). Therefore, while determining the content of the research topic, separate titles were used for the concepts of AR, metaverse and VR. Thus, they were evaluated holistically due to their close connections. The metaverse is not just a term but a general construct that includes much more than AR or VR (Park & Kim, 2022). In this context, it is essential to have an idea about the studies on AR, metaverse and VR applications that enable the transfer of innovative and designer approaches to learning environments. Among the strengths of the study are that it provides a deeper understanding of the effects of the studies done in the 21st century and provides an opportunity for future researchers to look at the traces of the past from a clearer perspective. Because knowing the effects of technology, which will have a say in shaping the future, on the educational environment is a valuable step for future teachings.

1.5. Purpose and Problem of the Study

This study aims to reveal a retrospective view of the articles listed on AR, metaverse and VR in the WoS database from 2000 to the present (22.06.2023). In this context, the information structure of the data set was evaluated in terms of performance, network analysis, conceptual structure and thematic mapping. 2203 scientific articles in the field of education category; the annual number of publications and citations, productive authors, most cited studies, countries of responsible authors, dominant authors, productive institutions, geographical distributions, co-citation, collaboration, word analysis, trend topic, thematic change, conceptual structure and thematic evaluated in the mapping headings. In the context of these criteria, the research questions (RQs) are as follows:

RQ 1. What is the distribution of scientific documents with AR, metaverse and VR content by years and citation numbers?
RQ 2. What are the authors, studies, institutions and countries contributing to AR, metaverse and VR?
RQ 3. Which authors and resources interact on AR, metaverse and VR?
RQ 4. What is the collaborative profile of authors, institutions and countries on AR, metaverse and VR?
RQ 5. What is the co-keyword and co-occurrence profile in AR, metaverse and VR studies?
RQ 6. What are the trending topics and thematic changes in AR, metaverse and VR research?

RQ 7. How is the conceptual structure and thematic map changing in AR, metaverse and VR research?

2. METHODOLOGY

This study aims to reveal a comprehensive retrospective view of the documents listed on AR, metaverse and VR in the WoS database from 2000 to the present (22.06.2023). A quantitative discovery was made with bibliometric analysis to reveal the information structure of the data set created with the study subject. This form of analysis allows the data set to be evaluated according to statistical procedures and to create a roadmap. Bibliometric methodology covers applying quantitative techniques to the data set (Pritchard, 1969). It helps to summarize large volumes of data to present the status of the research topic and emerging trends (Donthu, Kumar, Mukherjee, Pandey & Lim, 2021). Bibliometrics is widely used to analyze the overall representation levels of a set of bibliographic documents and to gain a more detailed understanding of the field of study. Thanks to this analysis, the qualitative and quantitative changes of a determined scientific research topic are determined. At the same time, the profile of the publications on the subject is displayed, and the direction of the trends in the discipline can be determined (Rey-Martí, Ribeiro-Soriano & Palacios-Marqués, 2016). Therefore, it provides more comprehensive and objective results than typical literature reviews (Ramos-Rodriguez & Ruiz-Navarro, 2004). Performance analysis, scientific mapping and enriched network analysis techniques were used as bibliometric analysis techniques in the study. Performance analysis includes contributions from research components, scientific mapping analysis includes relationships between research components, and network analysis includes network metrics, clusters, and visualization (Donthu et al., 2021). In performance analysis, it determines the authors of the structure that is the subject of the research and deals with metrics that contribute to the field, such as the number of publications and citations (Cobo, López-Herrera, Herrera-Viedma & Herrera, 2011). Scientific mapping analysis deals with the relationships between the structure's components and the research's subject (citation, collaboration, co-word, co-author *etc.*) (Baker, Kumar & Pandey, 2021). Combined with network analysis, these analyses effectively present the intellectual structure of the research topic with a broader perspective (Tunger & Eulerich, 2018). In the study, a bibliometric process of scientific production (annual number of publications and citations, prolific authors, most cited publications, countries of responsible authors, dominant authors, productive institutions, geographical distribution), scientific mapping (co-citation, collaboration, word analysis) and enriched relationship networks was followed in accordance with the research questions. In addition, evaluations according to keyword analysis, trend topic, thematic change, conceptual structure and thematic mapping were included, and the general lines of the research topic were tried to be revealed more clearly. The research framework was created according to the bibliometric analysis procedure and application guidelines designed by Donthu et al. (2021).

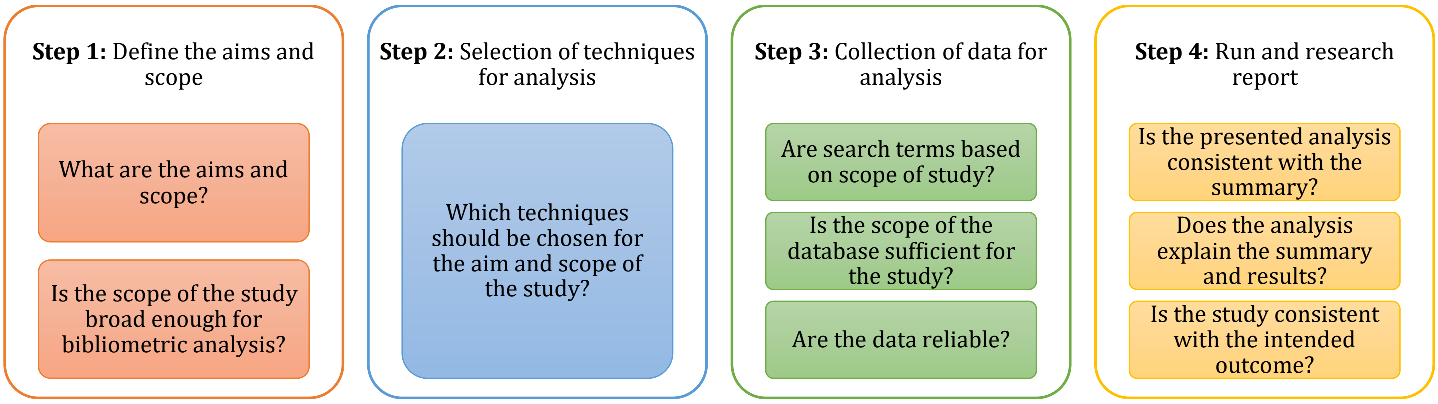

Figure 1. Bibliometric analysis procedure and application guidelines (Donthu et al., 2021, p. 295)

The first step of the bibliometric analysis procedure and practice guideline is to define the purpose and scope of the bibliometric analysis. Is the scope of the work broad enough to warrant the use of bibliometric analysis? search for an answer to the question. The second step is the selection of techniques for bibliometric analysis. The methods needed to meet the purpose and scope are determined. The third step is data collection. In this step, the suitability of the search terms to the scope of the study, the adequacy of the database for the study, the reliability of the data for error-free entries, and the bibliometric analysis techniques of the data set are considered. The bibliometric analysis and the study results are implemented and reported in the last step. In this step, attention is paid to the comprehensibility of the bibliometric summary for the readers, the compatibility of the study with the bibliometric summary, and the harmony of the study with the intended result (Donthu et al., 2021).

2.1. Data Collection and Procedure

The data used in the research were obtained from the Web of Science™ Core Collection database, which has the oldest and most comprehensive citation index records and a helpful analysis interface. The WoS™ database hosts many world-renowned scientific journals, providing detailed information and access to publications. Analytical information that includes 85.9 million records dating back to 1900, more than 21,000 high-quality journals with international access, 1.9 billion citation references, 254 topic categories, more than 300,000 conference papers, and 17.2 million open access records platform (Web of Science Group [WoSG], 2023). The most important advantage of the WoS™ database, which includes bibliometric indicators from many disciplines, is that it is transparent, accessible, organized, and consistent (Zhao & Strotmann, 2015). The WoS™ database, the world's leading information platform, provides access to more than one content information simultaneously and includes many online indexing databases. Social Science Citation Index (SSCI)-1900-present, Science Citation Index-Expanded (SCI-Expanded)-1900-present, Emerging Sources Citation Index (ESCI)-2005-present and Arts & Humanities Citation Index (A&HCI)-1975-present is the most important of the indexed databases (Yuan, Bie & Sun, 2021).

The title, keywords, and summary sections were determined as priority criteria in creating the data set. In this context, scientific records in the WoS™ database related to AR, metaverse and VR were searched. The processes followed during call recording are as follows: WoS™ Database: [TITLE-ABS-KEY ("virtual reality" OR VR OR metaverse OR "augmented reality" OR AR) AND TITLE-ABS-KEY (educat* OR learn* OR teach* OR class* OR innovat* OR student*) Refined by: Document Type: (Article), Language: (English) and Years of Publication: 2000-2023 (June) and Science Categories: (Education Educational Research) and Web of Science Index : (Social Science Citation Index (SSCI), Science Citation Index-Expanded (SCI-Expanded), Emerging Sources Citations Index (ESCI), Arts & Humanities Citation Index (A&HCI)]. During the search on research subjects, 2203 records were accessed. These data formed the final study set. Figure 2 shows the structure that reflects the criteria of the research.

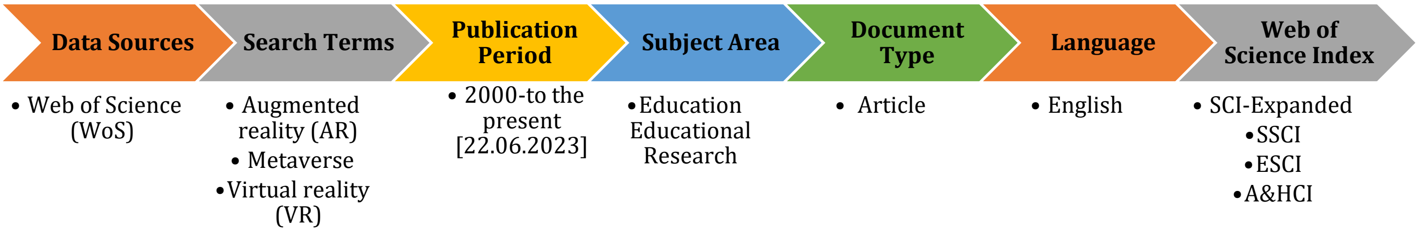

Figure 2. Search criteria performed in the WoS™ database

In the last step of the research, the data downloaded from the WoS™ database were saved in the "Plain Text" format. Since the WoS database allows downloading a maximum of 1000 records simultaneously, this process was repeated three times, and these three files were combined into a single file. Since the Plain Text format is compatible with VOSviewer and RStudio applications, it was used in evaluating documents, and bibliometric analyses related to research topics were carried out according to this format type. There are 1098 articles on AR, 31 on metaverse, and 1317 on VR. Some studies have more than one research topic in their content. A summary of the research strategy carried out in the WoS database is given in Figure 3.

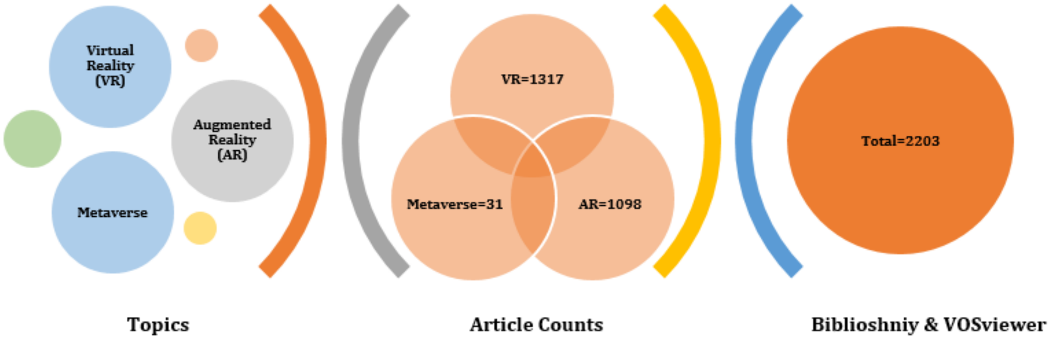

Figure 3. Search strategy summary in WoS database (*Note:* Some articles consist of more than one subject area)

The change is remarkable, considering the annual number of publications and citations of AR, metaverse and VR studies. It is seen that there are differences in AR, metaverse and VR from 2000 to the present. Accordingly, there has been an increase in the number of studies on VR since 2005. The interest in AR has started to increase since 2012. The number of studies on the subject of the metaverse has remained limited. Although there is a trend towards the metaverse in 2022 and 2023, interest in this subject will increase in the coming years, depending on technological advances. Figure 4 shows the change in the number of articles with AR, metaverse and VR content over the years.

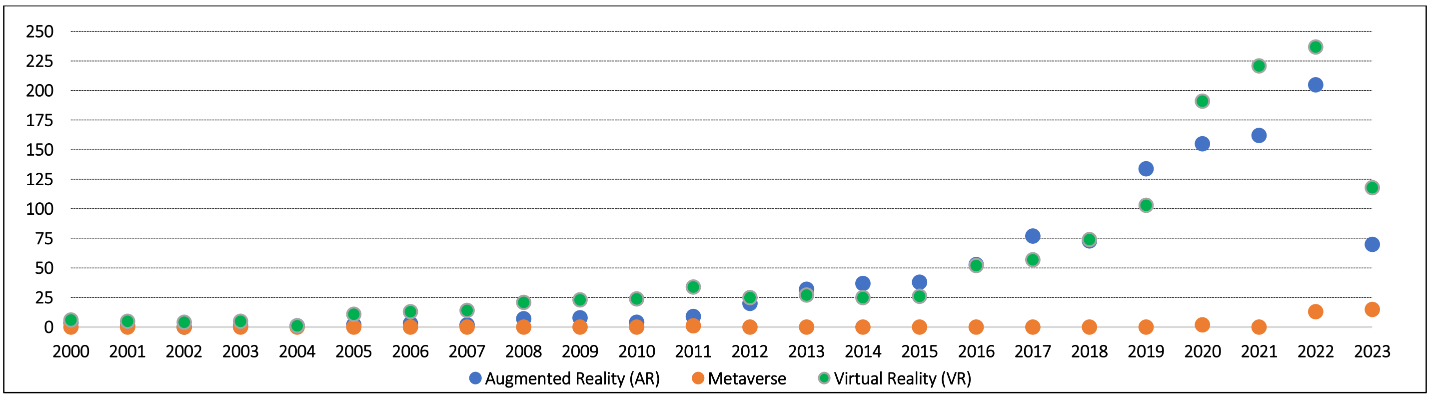

Figure 4. Number of articles by years on AR, metaverse and VR

2.2. Data Analysis Process

The study used scientific articles from the WoS™ Core Collection database to analyze the data. Within the scope of the research, bibliometric analysis was used to help determine the direction of the information structure in written documents and the change in the field (Pritchard, 1969). Since this analysis approach allows statistical and quantitative analyzes, the data set obtained on AR, metaverse and VR has been evaluated in detail. The bibliometric analysis of the data set was carried out in four stages. In the first stage, the data set was accessed to be able to evaluate according to the criteria. According to the research criteria, 2203 scientific articles created the data set. It was determined that the data set was reliable when it was checked whether there were erroneous or repetitive data. In the second stage, performance-based descriptive statistical analyzes of scientific documents were carried out. In this respect, the annual number of publications and citations, productive authors, the most cited articles, the distribution of responsible authors by country, the distribution of dominant authors by years, productive institutions, and productive countries are included. In the third stage, network analyses were carried out. The network analysis examined co-citation, co-author, geographical atlas, co- word, trend topic, and thematic changes. The last stage includes AR, metaverse and VR's conceptual formations and thematic changes. Figure 5 summarizes the steps followed in the analysis process.

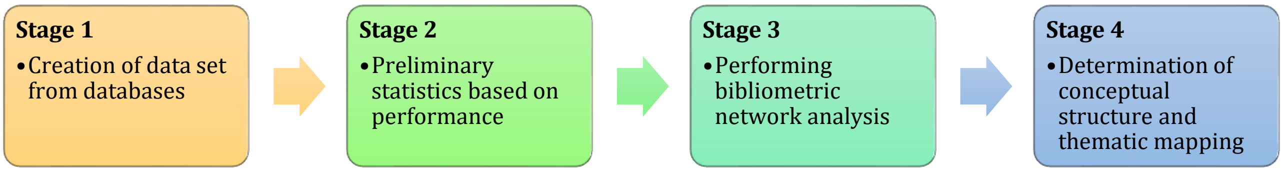

Figure 5. Stage followed in the analysis process

Performance, scientific mapping, and enriched network analysis techniques were applied to analyze the data set. VOSviewer 1.6.18 bibliometric software was used to visualize the similarities in the dynamic and structural analyzes of the data set (Van Eck & Waltman, 2010). VOSviewer software, which enables the pragmatic analysis of large volumes of data, significantly contributes to expanding scientific knowledge (Kumar, Lim, Pandey & Westland, 2021). The items included in the VOSviewer interface-based software are in the form of labels and circles. The circle's size indicates the item's weight and effectiveness in that cluster. In network analysis visualization, different hues are generated by the software and represent clusters of similar elements. The distance between these elements indicates the strength of the broadcasts (Yuan et al., 2021).

On the other hand, R-tool 4.3.0 software of the Bibliometrix package, designed for quantitative bibliometrics research, was used (Aria & Cuccurullo, 2017). This software determined the dominant authors, conceptual structure, thematic map, thematic change, geographical atlas, word cloud, Sankey Plot, trend topic, and countries' cooperation according to the years. VOSviewer [https://www.vosviewer.com] and R-tool [www.rstudio.com] software, frequently preferred in bibliometric analysis, are open-access and used for free. Biblioshiny software in RStudio is a tool that analyzes all the data identified in the literature, determines the main themes, and makes comprehensive evaluations of quantitative analyzes related to the research topic (Huber, 2002). Detailed explanatory information on the data set is given in Figure 6.

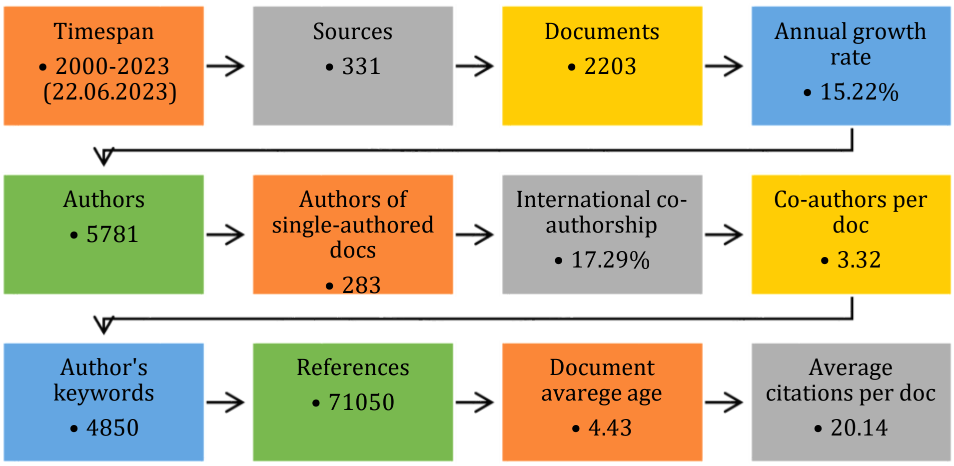

Figure 6. Descriptive main information on AR, metaverse and VR

According to Figure 6, 2203 scientific articles on AR, metaverse and VR were written by 5781 from 2000 to the present. While the number of articles with a single author is 283, the cooperation index between the authors is 3.32. The percentage of international cooperation is 17.29%, the annual growth rate is 15.22%, and the average number of citations is 20.14. The structure suggested by Law, Bauin, Courtial, and Wittaker (1988) was used for thematic and strategic diagram analysis in analyzing articles on AR, metaverse and VR. In the structuring of the map, dynamic cluster formations are determined by analyzing keywords or same-axis words (Gonzales-Valiente, 2019). Conceptual maps divide the content determined by the researcher into information sets, enabling the elaboration of the conceptual structure of the research subject and the interpretation of the content (Wetzstein, Feisel, Hartmann & Benton, 2019). It also contributes to determining an overall picture of the study area by helping to know the invisible patterns to reveal future research areas (Khan & Wood, 2016). Using thematic and strategic diagrams to gain in-depth information about the research subject is an important analysis technique for future research (Mostofa, 2022).

2.3. Validity and Reliability

Validity and reliability are among the essential criteria in the general analysis of scientific documents. Within the scope of the study's validity, the process of obtaining the data set is explained in detail. Preferred search terms for bibliometric analysis and information about the restrictions used in the search are presented respectively. In addition, it is stated how the data set was created, from which source it was obtained and in what period it was reached. To ensure the external validity of the research, the processes followed in the analysis of the data set were explained in stages. The criteria determined in the data selection, the method and technique used, and the software used in the data analysis are specified in detail. At the same time, it is aimed to contribute to the internal validity of the research by presenting general descriptive information about the 2203 articles that make up the data set. On the other hand, to ensure the reliability of the study, the results obtained from the data set through software are presented as they are without any comments. Attention was paid to the consistency between the data reflecting the research result and whether erroneous data was checked. In addition, information about the software used in data analysis is given, and web addresses are specified. In conclusion, the findings obtained are discussed per the literature and presented with suggestions for future research. Reliability was increased by including the software information used under the images containing each analysis.

3. FINDINGS

This section presents the findings related to the research questions determined for AR, metaverse and VR topics with their explanations. Results presented under sub-headings first start with performance analysis. Accordingly, the annual number of publications and citations on AR, metaverse and VR and the productivity of the authors, studies, institutions and countries that contributed the most were examined. Network analysis was performed at another stage, and co-citation and co-author analyses were included. Under the heading of trend topic and thematic change, trending keywords and titles of publications in AR, metaverse and VR were analyzed. Finally, the conceptual structure and thematic mapping of scientific articles published on AR, metaverse and VR were analyzed.

3.1. Scientific Productivity on Augmented Reality, Metaverse and Virtual Reality

The figure below shows the annual publication and citation numbers of the articles on AR, metaverse and VR from 2000 to the present. Since the starting point of our study is to deal with the studies on AR, metaverse and VR in the context of the 21st century, the year 2000 was taken as the starting date. In this direction, articles published on AR, metaverse and VR since 2000 were analyzed descriptively. According to the information obtained from the WoS database, the annual production and annual citation numbers are indicated in different colours.

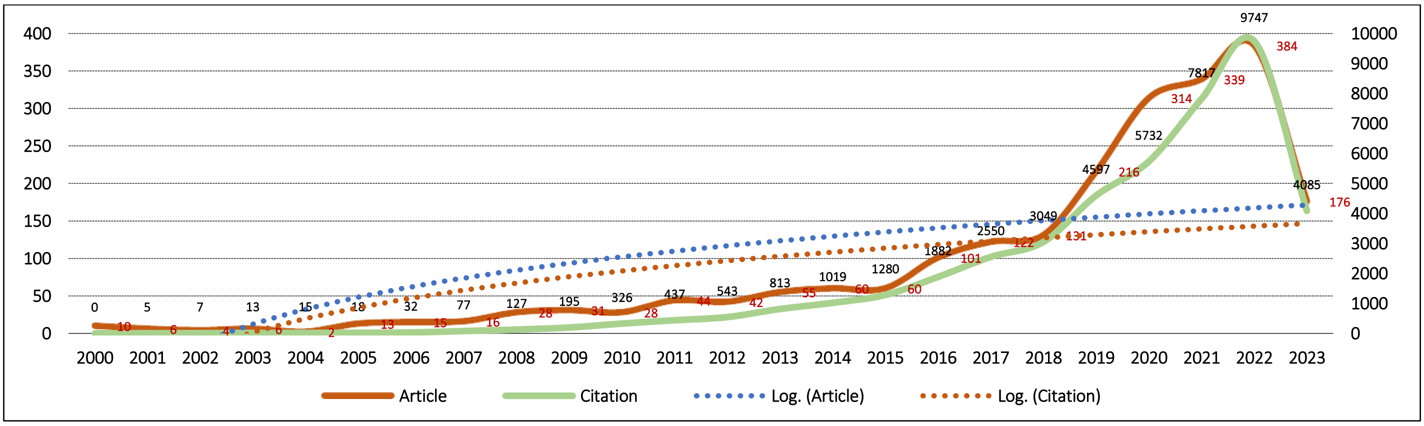

Figure 7. Annual scientific production and citation in AR, metaverse and VR

Figure 7 shows the results regarding the values of the AR, metaverse and VR studies. Accordingly, it is observed that there has been a marked increase in the number of publications, especially since 2015. There was an increase in the number of publications and citations compared to the previous year. Although there were few publications and citations in the first years of the 21st century, it is seen that the productivity towards these issues has increased in the last ten years. The changes in the annual number of citations show that the interest in AR, metaverse, and VR studies has increased. The number of citations has increased exponentially every year, especially since 2009. Table 1 includes information about prominent authors on AR, metaverse and VR.

Table 1.
Most Productive Core Authors on AR, Metaverse and VR

Authors	Publications	Publications Fractionalized
Hwang, G. J.	32	9.19
Makransky, G.	20	6.48
Tsai, C. C.	18	5.94
Ke, F. F.	15	6.33
Chen, C. H.	14	5.26
Cheng, K. H.	14	9.14
Jong, M. S. Y.	12	3.90
Yılmaz, R. M.	11	3.50
Chang, Y. S.	10	4.79
Chang, K. E.	9	2.00
Goktas, Y.	9	2.92
Sung, Y. T.	9	2.00
Chang, C. Y.	8	2.45
Chang, S. C.	8	2.50
Cochrane, T.	8	2.89
Pombo, L.	8	3.87

Table 1 shows the prolific authors on AR, metaverse, and VR, further explaining core authors. These authors have a strong influence on research issues. The core author varies according to the number of publications of the author who has done the most work. Core authors own about half of all publications in a research field. The core author group is formed if the core authors have published 50% of the articles on the same subject (Yeoh, Talburt & Zhou, 2013). According to Price Law in bibliometrics, core authors are determined by using the formula [$M=0.749*(N_{max})^{1/2}$ (M=minimum number of articles in the study subjects of the core authors, N_{max}=the number of articles of the most productive author in the study subjects)] that determines the minimum number of articles by the core author (Price, 1963). Accordingly, since the number of articles published by Hwang, G. J. is the highest, N_{max}=32. According to the formula, the minimum number of articles for an author to be a core author is five. Since there will be many author additions, the number of documents belonging to the author is limited to eight to make the table more understandable. Core authors comprise over half of published AR, metaverse and VR articles. According to the data in the table, Hwang, G. J. (32), Makransky, G. (20), Tsai, C. C. (18), Ke, F. F. (15), Chen, C. H. (14), and Cheng, G. H. (14) were the most productive in their study subjects stand out as writers. Table 2 contains information about the publications that stand out in the number of citations.

Table 2.
Most Cited Articles (by total citation per year) on AR, Metaverse and VR

Paper	Doi	Total Citations	TC per Year	Normalized TC
Wu, H. K., 2013	10.1016/j.compedu.2012.10.024	933	84.92	11.53
Hanus, M. D., 2015	10.1016/j.compedu.2014.08.019	763	84.78	14.69
Merchant, Z., 2014	10.1016/j.compedu.2013.07.033	656	65.60	11.03
Dunleavy, M., 2009	10.1007/s10956-008-9119-1	615	41.00	7.23
Di Serio, A., 2013	10.1016/j.compedu.2012.03.002	488	44.36	6.03
Makransky, G., 2019	10.1016/j.learninstruc.2017.12.007	385	77.00	18.01
Klopfer, E., 2008	10.1007/s11423-007-9037-6	371	23.19	7.01
Potkonjak, V., 2016	10.1016/j.compedu.2016.02.002	351	43.88	10.67
Lee, K., 2012	10.1007/s11528-012-0559-3	350	29.17	9.58
Huang, H. M., 2010	10.1016/j.compedu.2010.05.014	350	25.00	5.50
Annetta, L. A., 2009	10.1016/j.compedu.2008.12.020	344	22.93	4.05
Gavish, N., 2015	10.1080/10494820.2013.815221	317	35.22	6.10
Tuzun, H., 2009	10.1016/j.compedu.2008.06.008	290	19.33	13.41
Heradio, R., 2016	10.1016/j.compedu.2016.03.010	285	35.63	8.66
Wojciechowski, R., 2013	10.1016/j.compedu.2013.02.014	277	25.18	3.42

Table 2 shows information on the most cited articles. The most cited articles from the table are Hsin-Kai Wu et al. (2013) (84.92 citations per year), Michael D. Hanus and Jesse Fox (2015) (84.78 citations per year), Zahira Merchant et al. (2014) (65.60 citations per year), Matt Dunleavy et al. (2009) (41.00 citations per year), Ángela Di Serio et al. (2013) (44.36 citations per year), Guido Makransky et al. (2019) (77.00 citations per year) and Eric Klopfer and Kurt Squire (23.19 citations per year). Wu et al. (2013) discussed the subject of AR, and an overview of the definitions, taxonomies and technologies of AR was presented. In the research conducted by Hanus and Jesse (2015), the subject of VR was discussed, and the effects of a gamified course program on students' motivation, academic achievement, effort, and satisfaction were examined. On the other hand, Merchant et al. (2014) carried out a meta-analysis. In the research, the effect of selected instructional design principles in the context of virtual reality technology-based instruction in K-12 or higher education settings was examined. Similarly, Dunleavy et al. (2009) examined how teachers and students define/understand the positive and negative aspects of their participation in AR simulation. Di Serio et al. (2013), on the other hand, is to show that AR technology has a positive effect on the motivation of secondary school students. These articles receive much attention in the related field regarding their content and constitute a source for studies on these subjects. Figure 8 shows the distribution of the corresponding authors by country.

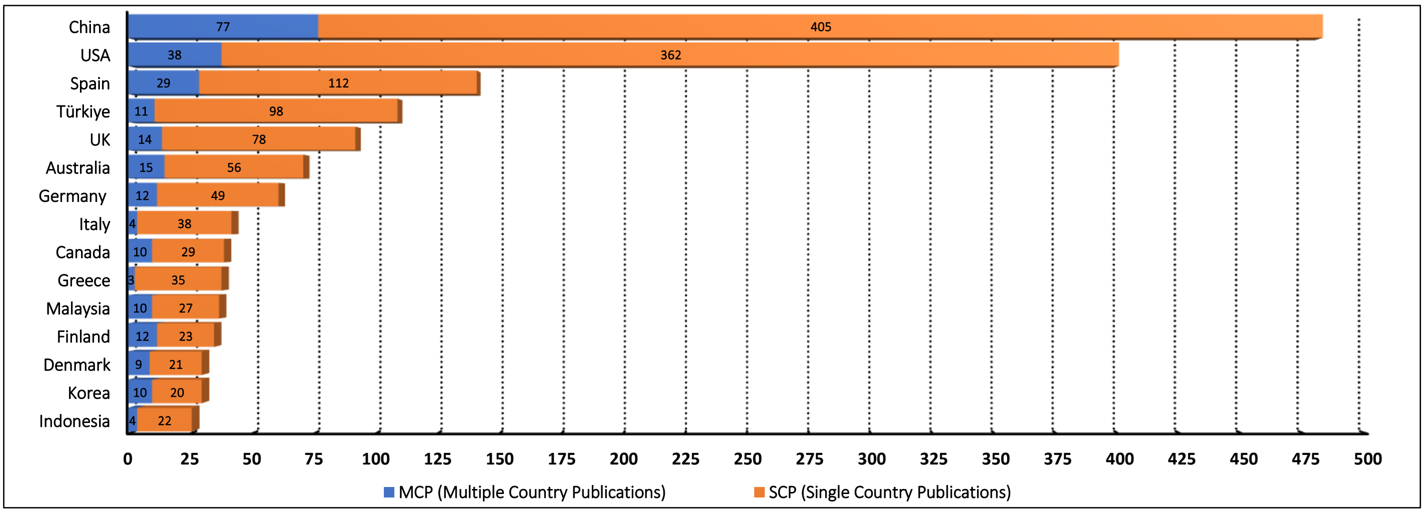

Figure 8. Corresponding author's country on AR, metaverse and VR

When Figure 8 is examined, it is seen that the authors publishing on AR, metaverse and VR are mostly related to the countries of China (n=482), USA (n=400), Spain (n=141), Türkiye (n=109), United Kingdom (n=92), Australia (n=71) and Germany (n=61). According to the figure, it is noteworthy that the number of single-country authors is higher. Therefore, the cooperation of the country's authors with the authors of other countries is limited. Figure 9 gives the distribution of dominant authors in a specific period.

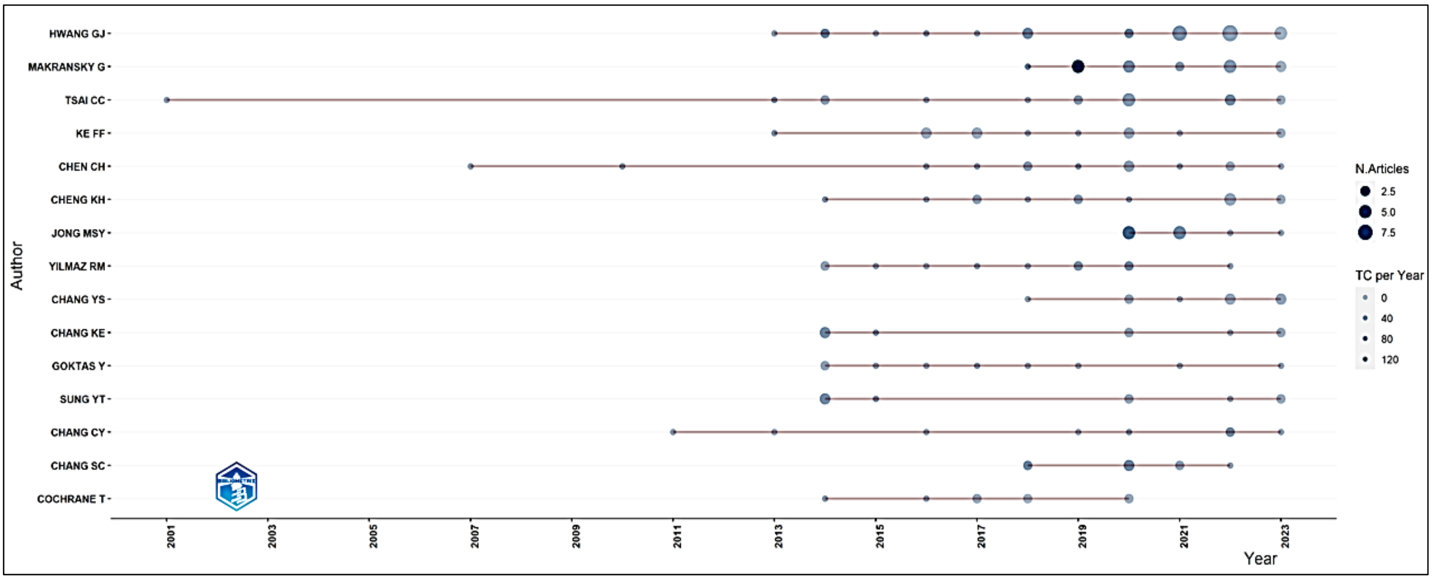

Figure 9. Authors' production over time on AR, metaverse and VR

Figure 9 shows the distribution of dominant authors by year. In bibliometric analysis, the dominance factor is determined by the number of articles with multiple authors. Accordingly, it is calculated by dividing the number of multi-authored articles to be the first author by their total number (Kumar & Kumar, 2008). When Figure 9 is examined, Hwang between 2013 and 2023, Makransky between 2018 and 2023, Tsai between 2001 and 2023, Ke between 2013 and 2023, and Chen between 2007 and 2023 come to the fore. The remarkable situation is that most of the authors in the dominant role have shown their effects until today. The quality articles published due to the increasing interest in new technical topics such as AR, metaverse and VR, especially in the last ten years, have made their impact felt for many years. This metric can also be measured using Lotka's law. Lotka's law states that "the number of authors producing a certain number of articles is a fixed ratio to single article authors, 2" (Mostafa, 2022, p. 6). The study's findings show that Lotka's law is valid in scientific articles published on AR, metaverse and VR (K-S two simple test p>.05). Figure 10 includes information about productive organizations in AR, metaverse and VR.

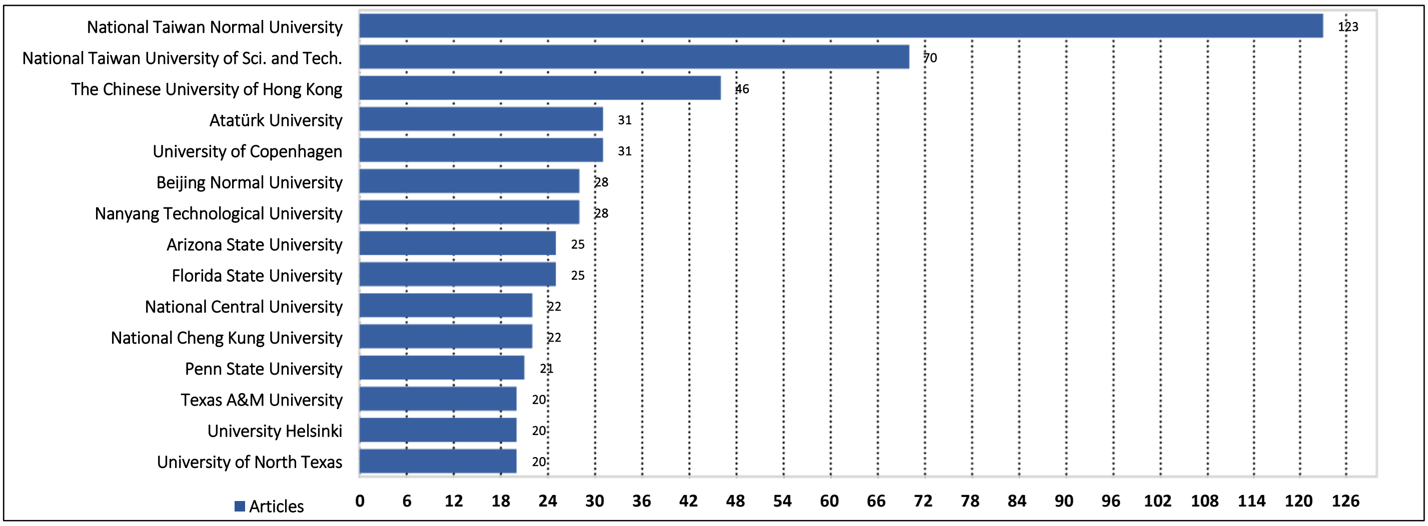

Figure 10. Most relevant affiliations over time on AR, metaverse and VR

Figure 10 shows the most productive institutions related to the research topic. National Taiwan Normal University ranks first with 123 articles. This is followed by the National Taiwan University of Science and Technology with 70 articles, The Chinese University of Hong Kong with 46 articles, and Atatürk University and the University of Copenhagen with 31 articles, respectively. According to these results, it is seen that far Eastern countries are quite productive in the context of AR, metaverse and VR. The dominance of these countries in the field of study is relatively high compared to other countries. Figure 11 shows a geographic atlas of publications covering AR, metaverse and VR.

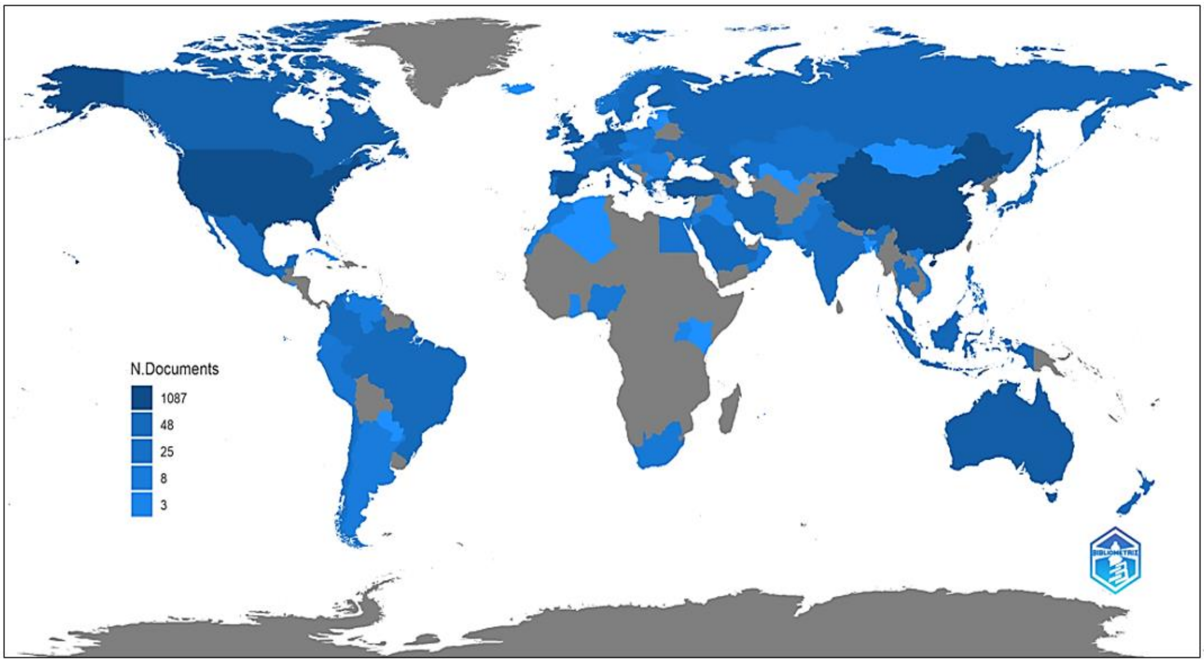

Figure 11. Country scientific production

When Figure 11 is examined, it is seen that the research topic determined is represented in many continents. According to the geographical atlas, China (*n*=1087) and USA (*n*=974) top the scientific production list of countries. These countries are Spain (*n*=283), Türkiye (*n*=204), United Kingdom (*n*=194), Australia (*n*=182), Germany (*n*=132), Canada (*n*=112), Italy (*n*= 102) and Finland (*n*=81) countries follow. Research on AR, metaverse and VR, which are of interest to many countries, has spread widely worldwide. There is a greater interest in such issues, particularly in developed and developing countries. Therefore, research on AR, metaverse and VR topics includes a general area of influence.

3.2. Network Analysis on Augmented Reality, Metaverse and Virtual Reality

3.2.1. Co-citation networks

Network analysis has an important place in bibliometric methodology. The basic structure of these analyzes is based on the visualization of the situations that occur together, such as authors, countries, institutions, and references. Co-citation network analysis, the most widely used network analysis, cites two scientific publications. When two authors are cited in a third reference in the joint citation network, in other words, the citation image/network of two scientific publications creates a co-citation (Bağış, 2021). It focuses on studies in the centre and around a research area and serves as a bridge. Therefore, this part of the research examined the relationship networks between authors and sources. Network visualizations related to co-citation analysis in the context of the determined criteria are presented respectively.

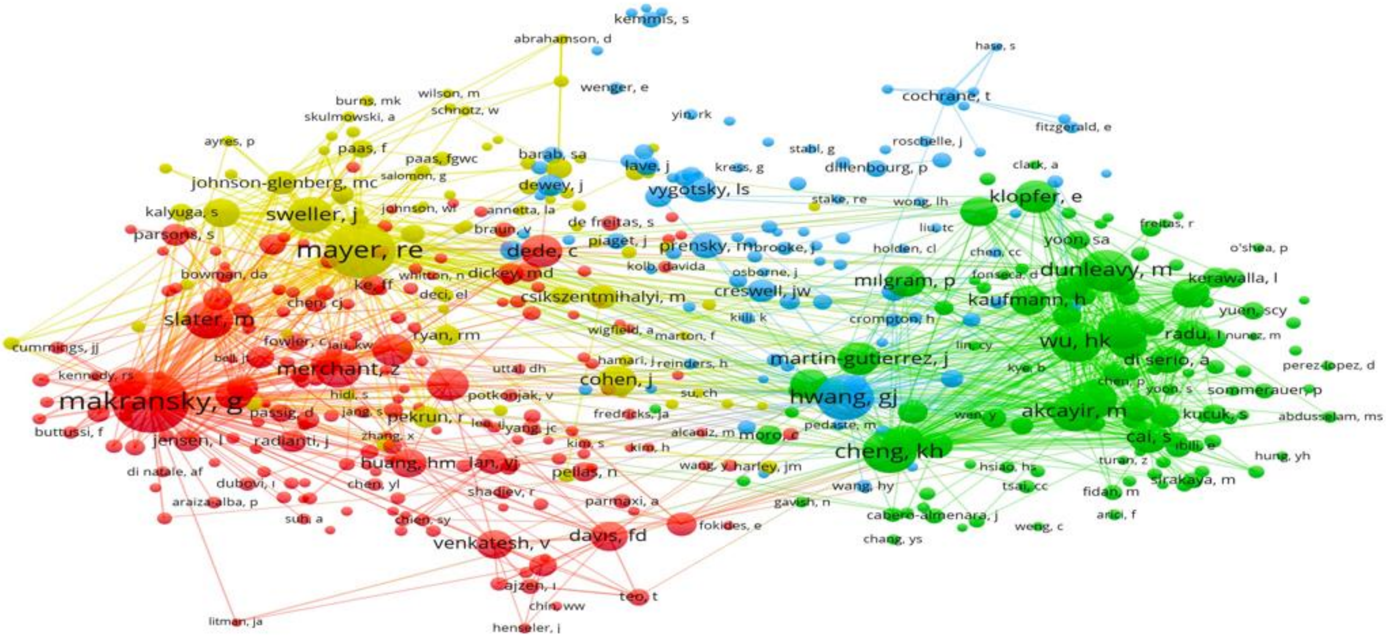

Figure 12. Co-cited network analysis in the context of cited authors (≥20 articles)

Figure 12 shows the network of co-cited authors on AR, metaverse and VR. Four different clusters emerge in the analysis of co-cited authors. The red-coloured cluster includes authors such as Makransky, G., Slater, M., Merchant, Z., Huang, H. M., and Lan, Y. J. The green-coloured cluster includes authors such as Cheng, K. H., Wu, H. K., Dunleavy, M., Akcayir, M., Martin-Gutierrez, J., Kaufmann, H., Klopfer, E. The blue-coloured cluster includes authors such as Hwang, G. J., Prensky, M., Creswell, J. W., Chu, C. H., and Hou, H. T. The yellow cluster includes authors such as Mayer, R. E., Sweller, J., Moreno, R., Johnson-Glenberg, M. C., Cohen, J., and Ryan, R. M. The size of the node indicates that the authors gain a central position in their cluster and influence the authors around them. These authors increase knowledge dissemination in the network and are known as influential writers. Some nodes are close, while others are far from each other. If the nodes are close to each other, this indicates a homophilic effect in the bibliometric methodology. Jiang, Ritchie and Benckendorff (2019) characterize homophilic influence as an indicator of "disciplinary or thematic similarity" (p. 1940). For example, nodes representing Makransky, G. and Parong, J. authors are very close to each other, indicating the presence of a homophilic effect. On the other hand, writers at the centre of the four different clusters significantly impact other communities as they control the spread of knowledge in the network and encourage other writers. Authors who are centrally located and tend to anchor other communities are known as influential writers (Mostafa, 2020). In Figure 13, a visual of the network structure formed according to the criteria of references within the scope of co-citation is given.

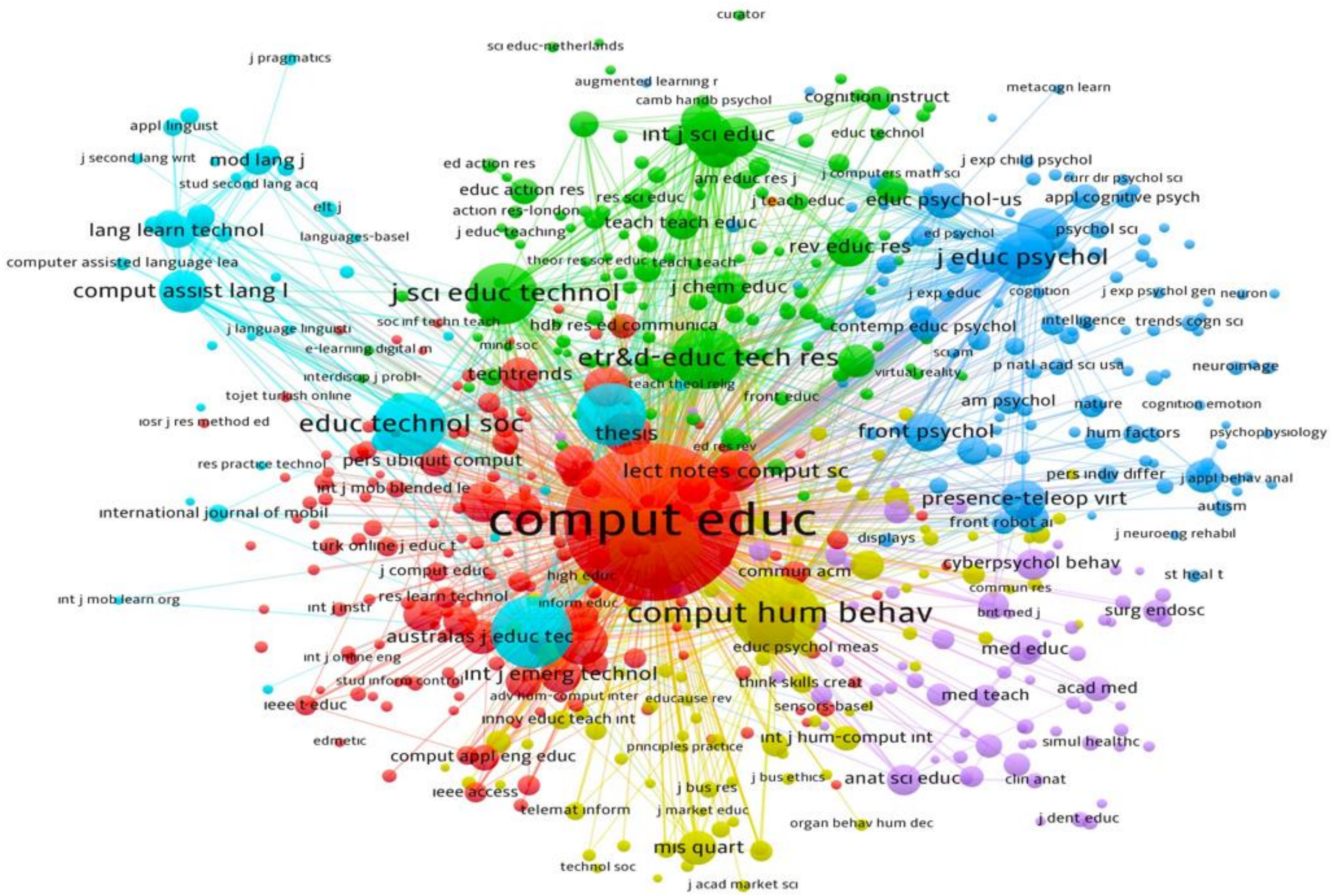

Figure 13. Co-cited network analysis in the context of cited sources (≥20 journals)

Figure 13 shows the network of co-cited sources on AR, metaverse, and VR. In the analysis of commonly cited sources, seven different clusters emerge. The red cluster includes co-citation in journals such as Computer & Education, Presence Virtual and Augmented Reality, Procedia-Social and Behavioral Sciences, Lecture Notes in Computer Science, IEEE Transactions on Learning Technologies, and the International Journal of Emerging Technologies in Learning. The turquoise cluster includes trim, commonly cited journals such as Interactive Learning Environments, Educational Technology & Society, Journal of Computer Assisted Learning, Computer Assisted Language Learning, and Language Learning and Technology. The blue cluster consists of several journal groups such as Contemporary Educational Psychology, Presence Teleoperators and Virtual Environments, Educational Psychology Review and Journal of Educational Psychology. Although there is little interaction between them, co-citation networks are formed between them according to the high number of journals. On the other hand, Computers in Human Behavior journal is in the center of the yellow cluster. In contrast, Educational Technology Research and Development, Journal of Science Education and Technology and International Journal of Science Education journals stand out in the green cluster. Journals that are the core of the cluster they are in are the sources that tend to be cited extensively (Mostafa, 2022). These journals give important ideas and guide studies on similar research topics.

3.2.2. Collaboration networks

This part of the research includes collaborations on AR, metaverse and VR and the interactions that emerged from these collaborations. Co-author analysis focuses on cooperation between authors, institutions, and countries. Thanks to this analysis, the image of the emerging social networks is determined. In co-author collaboration, it is the participation of more than one author in that article to produce a scientific article and determining how the collaborations form a structural network on the scientific article (Acedo, Barroso, Casanueva & Galan, 2006). This type of analysis examines social networks created by scientists collaborating on scientific articles (Bağış, 2021). In this section, the results of co-author analysis by authors, countries and institutions are given in order.

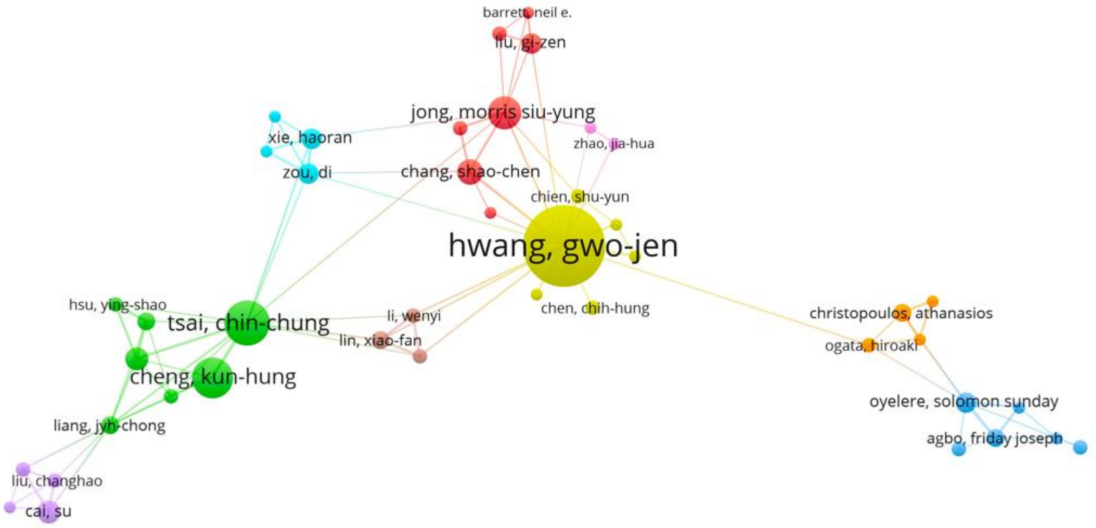

Figure 14. Co-authorship network analysis in the context of authors (≥3 articles)

Figure 14 shows the network of collaboration among authors. Nine different clusters emerge in the analysis of collaboration between authors. According to the figure, the thickness of the links increases in proportion to the articles written together. However, the number of nodes in the cluster groups formed due to the analysis is limited to certain connections. Gwo Jen Hwang dominates the yellow cluster in the centre of the mesh image. Writers such as Shao Chen Chang, Jong Siu-Yung Morris, Zou Di Daisy, Hiroaki Ogata, Chin Chung Tsai, Kun Hung Chen, Su Cai, Solomon S. Oyelere, Zhong Mei Liang act as bridges between other large clusters of the network. These authors have done quality studies on AR, metaverse and VR and are highly influential writers. The fact that the authors work in the same universities/institutions or geographical proximity effectively develops the cooperation network between the authors who stand out with technology-based studies. Authors who act as bridges are called "information brokers" and mediate information sources for other authors (Park, Lim & Park, 2015). On the other hand, some authors seem to be isolated. The closer one gets to the clusters at the centre of the network analysis, the greater the interaction and the farther away from the centre of the network becomes, the more isolated authors emerge. Figure 15 shows the emerging network of collaborations by institution.

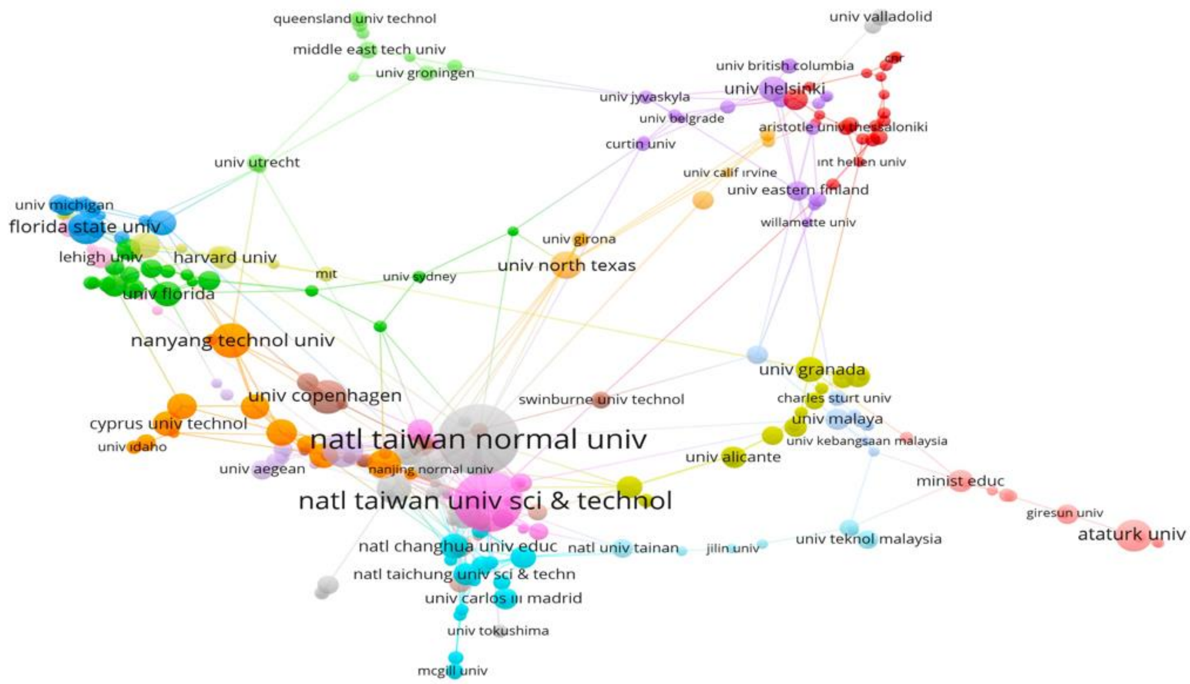

Figure 15. Co-authorship network analysis in the context of institutions (≥3 articles)

Figure 15 shows the cooperation network between institutions. In the analysis of cooperation between institutions, 23 different clusters emerge. According to the network visualization, the National Taiwan Normal University, National Taiwan University of Science and Technology, Nanyang Technological University, Helsinki University, Florida State University, Florida University and the University of Córdoba constitute the most collaborative initiatives in their cluster. It is seen that geographical proximity has a significant effect on inter-institutional cooperation. However, there are also limited and isolated collaborations, such as the Queensland University of Technology, Atatürk University, the University of Valladolid, and the University of Technology Malaysia. The sparse collaborative network indicates a lack of open cooperation in research. While there is more intense cooperation between institutions in the same country on AR, metaverse and VR, there is less cooperation between institutions of different countries. Figure 16 shows the emerging network of cooperation by country.

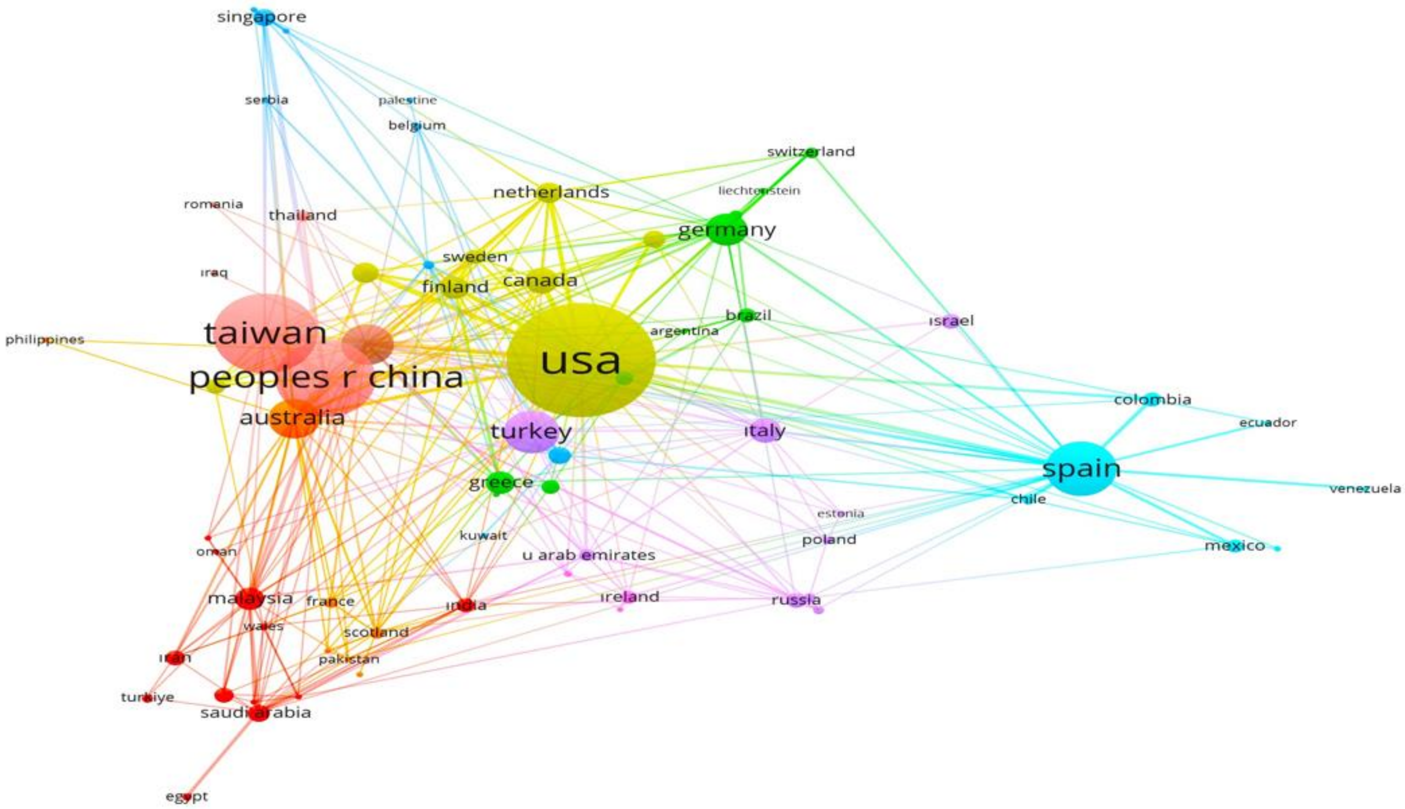

Figure 16. Co-authorship network analysis in the context of countries (≥2 articles)

Figure 16 contains the visual of the cooperation network between countries. In the analysis of cooperation between countries, ten different clusters emerge. Among the countries that cooperate in the scientific production of published articles, USA, China, and Taiwan stand out as the most productive countries in the network. In addition to practical cooperation, these countries encourage and direct developed/developing countries to scientific production. Geographical proximity is effective in collaboration between countries. For example, the brown-coloured cluster includes far Eastern countries such as China, Taiwan and Thailand, which are geographical close. The purple cluster contains countries more relative to each other regarding geographical location, such as USA, Canada, Sweden, Denmark and Finland. Similarly, the orange-coloured cluster includes countries close to each other such as Spain, Peru, Mexico, Chile and Colombia. According to the clusters in the network, it is seen that collaborative initiatives between countries stand out, especially in terms of geographical or linguistic proximity. For example, the immediacy and geographical similarities of the countries in the orange-purple-brown-green- and yellow-coloured clusters increase cooperation interactions. In addition, there are many cooperative structures between developed and developing countries and the redundancy of network connections. Figure 17 shows the design showing the world cooperation network.

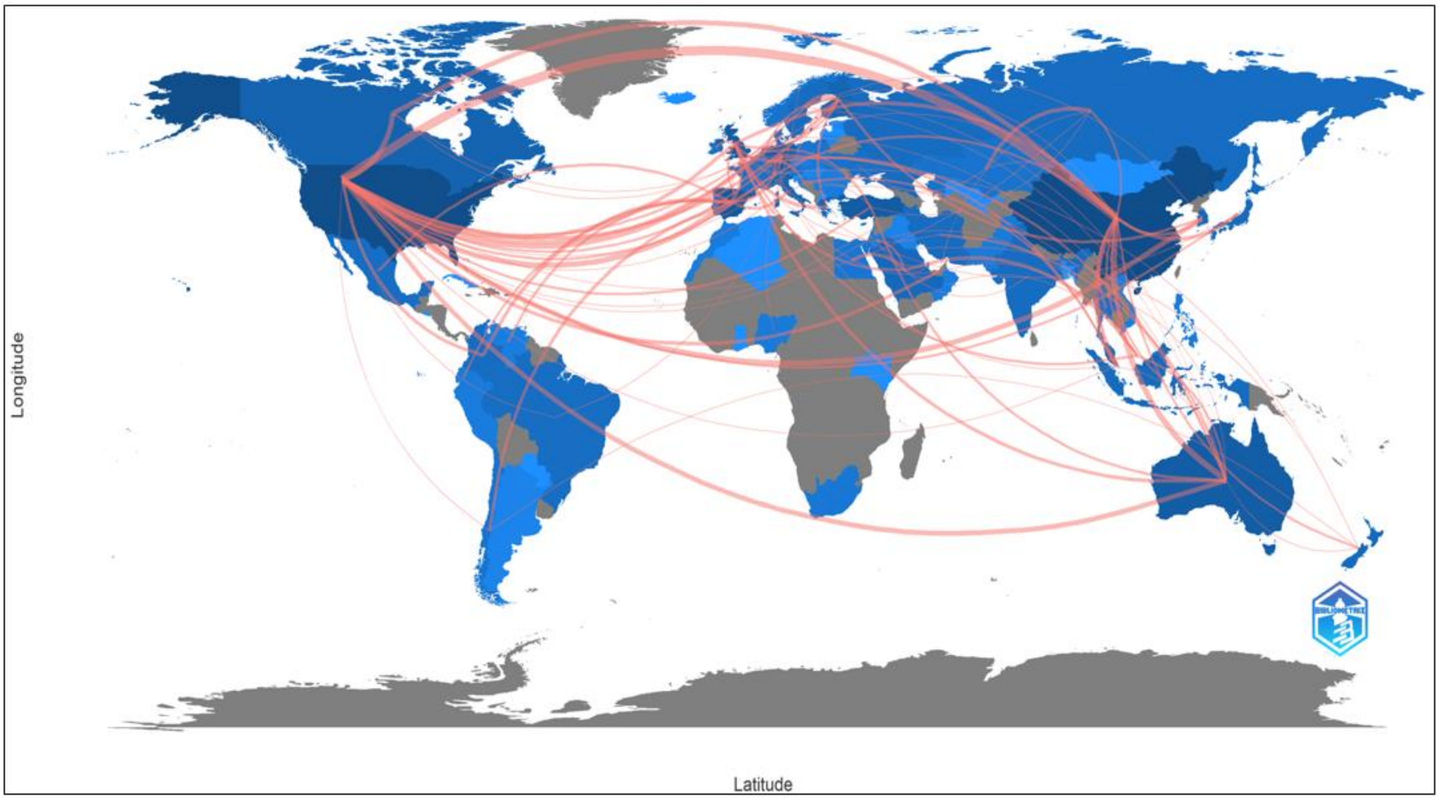

Figure 17. The AR, metaverse, VR authors' world collaboration network

In Figure 17, the intensity of the cooperation network between countries draws attention. There are significant collaborations between China and USA (*n*=26), between China and Australia (*n*=12), between China and Singapore (*n*=12), between USA and Canada (*n*=11), between USA and Korea (*n*=9), between USA and Spain (*n*=9), between China and Canada (*n*=8), between USA and Australia (*n*=8), between USA and Netherlands (*n*=8), between Finland and Sweden (*n*=7). There is intense partnership traffic between North American countries and countries in Europe and Asia. Similarly, partnerships between the continent of Australia and Asia, Europe and North America are striking.

3.2.3. *Keywords and co-occurrence network analysis*

Keywords are an essential element that helps to get an idea about the content of a study. Keywords are frequently preferred in bibliometric analyzes to reveal the content of documents due to their abstract structure (Chen et al., 2023). The structure containing a simple word cloud based on the keywords created by the author(s) of scientific articles is given in Figure 18. The word cloud is used as an attractive visual tool for summarizing the content of textual data. The proximity or distance of the word to the cloud formation reveals the value of the keyword in the study subject(s) (Liao, Tang, Li & Lev, 2019). The size of the word indicates the frequency of use of the words in the documents related to the research topic. The higher the number of similar words in the papers, the larger the cloud formation. Therefore, these terms occupy more space in the word cloud regarding volume.

Figure 18. Word cloud for AR, metaverse, VR (≤70)

The number of keywords is crucial in revealing the research topic's orientation and general structure. When Figure 18 is examined, the most relevant/frequently used keywords for AR, metaverse, and VR topics are "virtual reality" (*n*=693), "augmented reality" (*n*=505), "interactive learning environments" (*n*=112), "education" (*n*=90), "mobile learning" (*n*=82), "simulation" (*n*=66), "higher education" (*n*=62), "simulations" (*n*=50), and "action research" (*n*=46). The words "author's keywords" were used to reach more keywords in the articles. On the other hand, the authors also examined the formation networks of the preferred keywords for AR, metaverse and VR. Figure 19 shows the general structure that emerged at the end of the co-word network analysis.

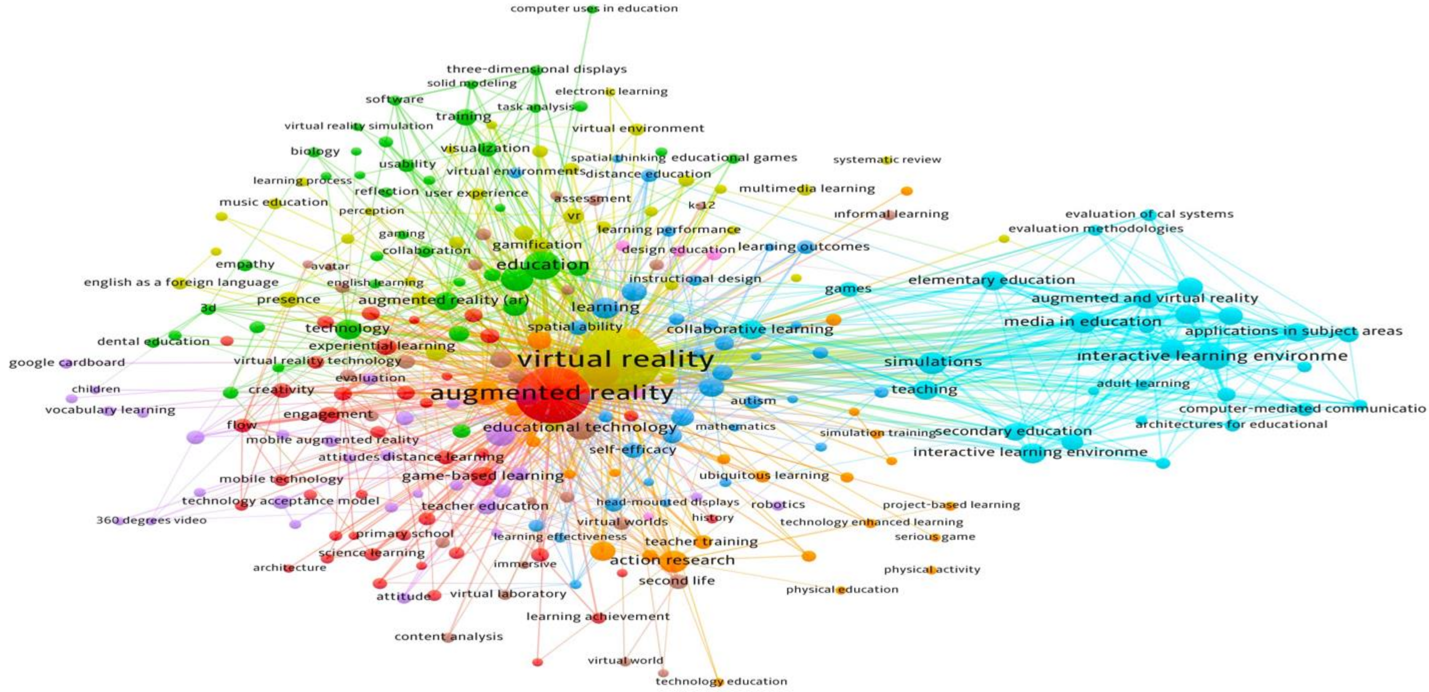

Figure 19. Co-occurrence network analysis in the context of author's keywords (≥5)

Figure 19 shows the co-occurrence network in the context of the keywords created by the authors. According to the keyword analysis, nine different main clusters emerge. For example, the red cluster consists of words such as "augmented reality", "blended learning", "game-based learning", "multimedia", "active learning", and "learning environment". The yellow cluster contains words such as "virtual reality", "virtual learning", "3D modelling", "immersive learning", "learning process", and "virtual learning environment". The green cluster includes words like "education", "simulation", "serious game", and "technology". At the centre of the turquoise-coloured cluster is the word "interactive learning environment". In addition, "augmented and virtual reality", "teaching", "applications in subject areas", and "media in education" are other words that are frequently used. The term "action" in the purple cluster and "actions research" in the orange cluster stand out. In Figure 20, according to the Sankey diagram (a three-field plot), to reveal the flow developments in AR, metaverse and VR, the emerging connections are given with keywords in the left block, authors in the middle block and institutions in the right block.

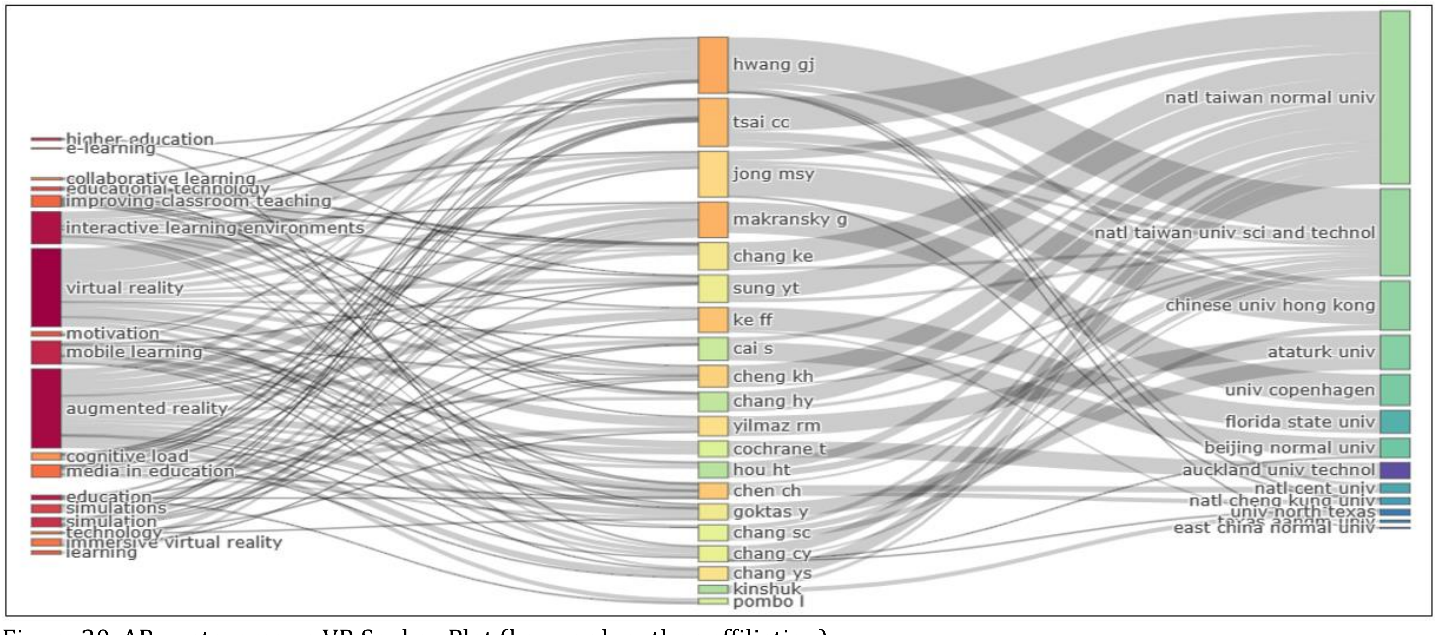

Figure 20. AR, metaverse ve VR Sankey Plot (keyword- author-affiliation)

According to Figure 20, the dimensions of the side boxes vary in proportion to the number of determined parameters (keyword-author-institution). For example, the margin widths of the words "augmented learning", "virtual learning", "interactive learning environments", and "mobile learning" are more extensive than other keywords. The size of the border width in the diagram shows that many authors prefer the keywords used in AR, metaverse and VR topics in their works. While some authors (Hwang, G. J, Chang, C. Y., Tsai, C. C., Makransky, G. *etc.*) use rich keywords to reflect better the content of the subjects they are working on, it is seen that some authors (Pombo, I., Kinshuk, Hou, H. T. *etc.*) do not prefer to use a rich word when reflecting the content of the subjects they are working on. In institutional margins, the National Taiwan Normal University and the National Taiwan University of Science and Technology stand out by far. Together with the authors these institutions have, the dominance of the field is quite evident and rich in content.

3.2.4. *Trending topics and thematic evolution*

This section covers trending topics and thematic in AR, metaverse and VR changes. Trending topics include changes in researchers' work. According to the trending topics, the evolution from the past to the present and the differences in the content of the topics are determined. In this context, the trending topic and thematic evolution represent research hotspots or emerging themes on a particular topic, providing invaluable insights into new research (Chen et al., 2023). Trending topics are accepted as hot spots in scientific documents (related to research topic) (Mostafa, 2022). In this respect, the trends of the topics that are trending over the years act as a bridge between the past and the future, opening the door to new perspectives. In Figure 21, emerging AR, metaverse and VR trends are given gradually.

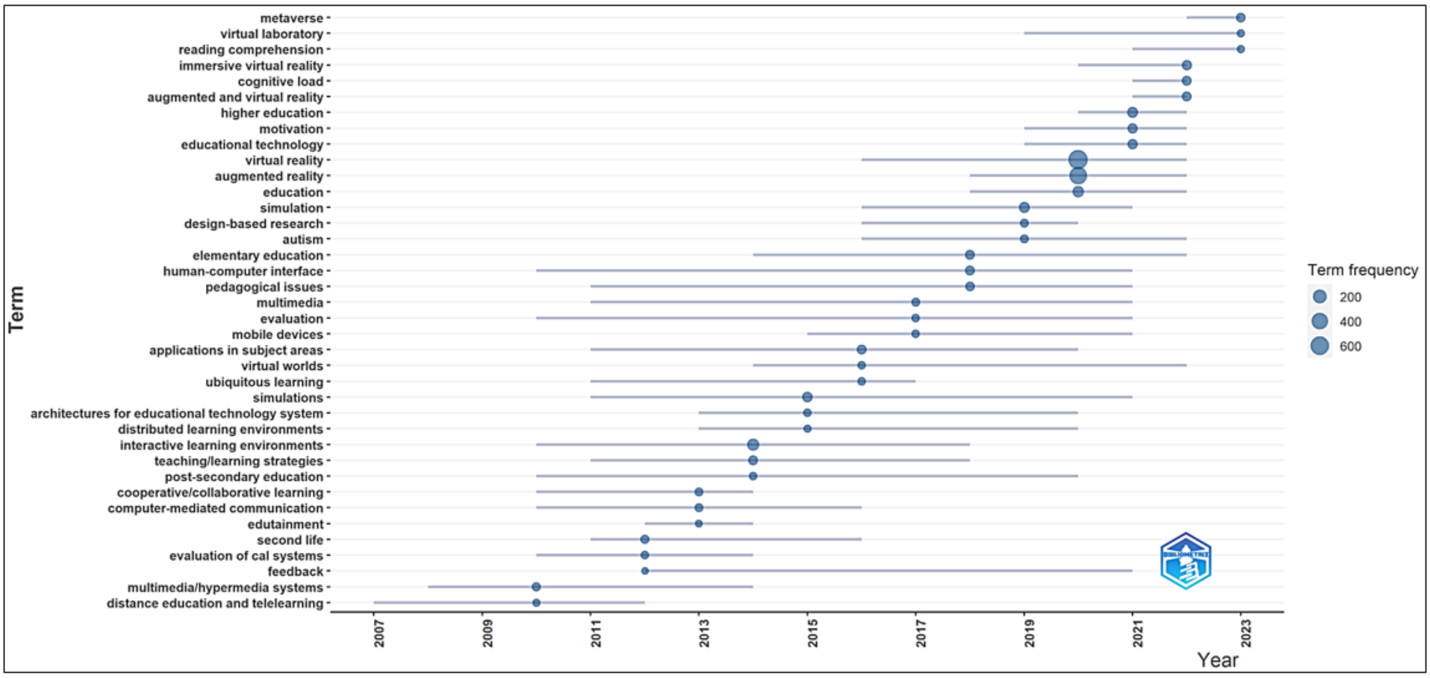

Figure 21. AR, metaverse and VR trending topics map (Author's keywords: 2000-2023)

Figure 21 shows trending topics in AR, metaverse and VR content studies. When the visual is examined, it is seen that there is a transition from basic subjects such as "distance education and telelearning" (2007-2010), "multimedia systems" (2008-2014), "computer-mediated communication" (2010-2016) and "teaching/learning strategies" (2011-2018) to learning environments where technological tool interactions such as "design-based research" (2017-2020), "simulation" (2017-2021), "augmented-virtual reality" (2021-2022), "immersive virtual reality" (2020-2022) and "metaverse" (2022-2023) occur intensively. The structures that emerged over the years represent evolving themes and highlight the hot spots in the field (Chen, Hu, Liu & Tseng, 2012). As we get closer to today, the knowledge of AR, metaverse and VR is more focused on technological applications and more on virtual reality applications. Sudden changes in subject headings indicate knowledge in a particular discipline. In the change of AR, metaverse and VR topics over the years, more focus has been placed on technological infrastructure, and more space has been given to topics in this content.

3.3. Conceptual Structure and Thematic Maps

It tried to determine the general lines of the conceptual structure by applying a Multiple Correspondence Analysis (MCA) on the keywords specified by the author(s) for AR, metaverse and VR. This way, conceptual mapping is performed on scientific articles with AR, metaverse and VR topics. The resulting map reveals the conceptual structure of the documents published on AR, metaverse and VR since 2000. Figure 22 shows the MCA findings for AR, metaverse and VR studies.

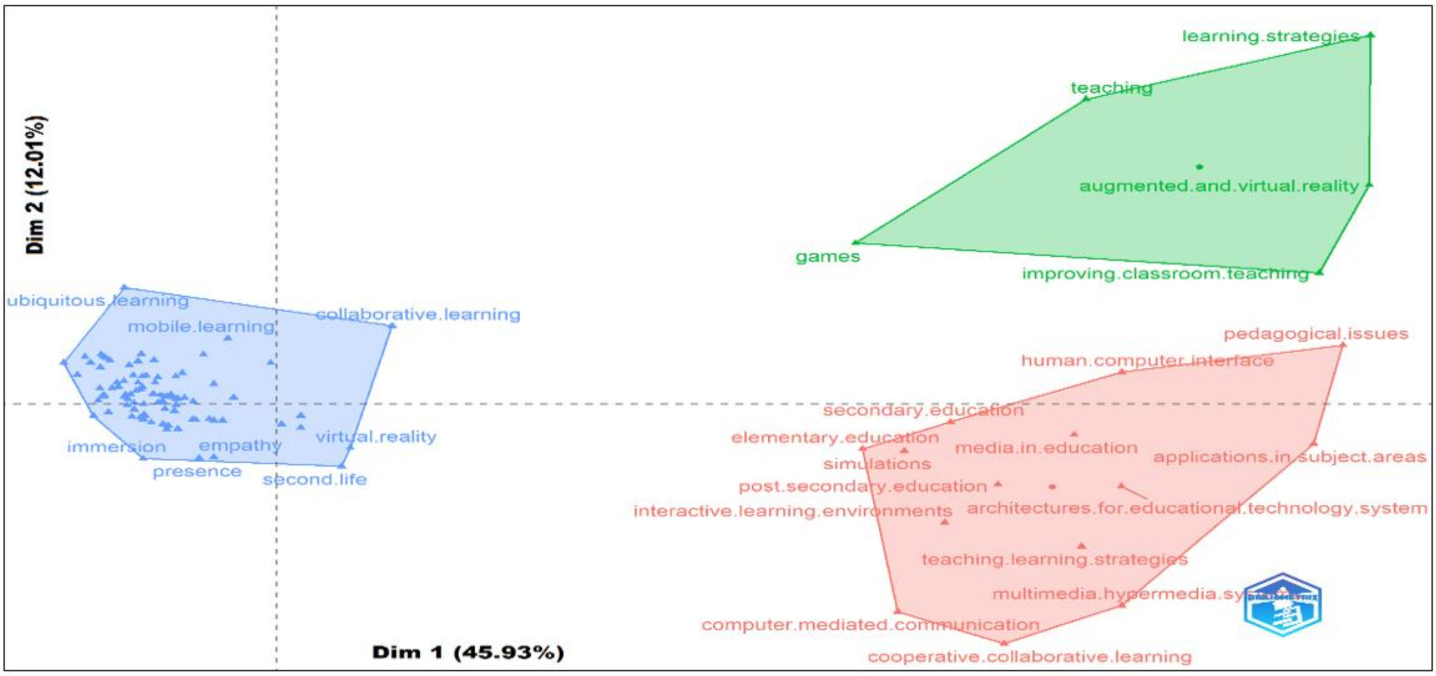

Figure 22. AR, metaverse and VR conceptual structure map (MCA method)

Figure 22 shows the basic structure when MCA is run on the author(s) provided keywords. This map reveals the conceptual structure in scientific articles covering AR, metaverse and VR. The best size reduction when running MCA accounts for about 58% of the total variability, revealing three different clusters. As the distance between the points decreases, the similarity and common feature increase in the represented profile (Wong, Mittas, Arvanitou & Li, 2021). The figure reflecting the factor analysis application reveals the depth and width of AR, metaverse and VR studies. MCA was run on the author's keywords to determine the conceptual structure. Each set of points on the map represents distinctive profiles. The represented profiles are in the blue, red and green coloured clusters. According to the keywords created by the authors, the red area contains words that emphasize technological learning environments such as "teaching learning strategies", "media in education", "human-computer interface", "interactive learning environments", "secondary education", "post-secondary education", and "simulations". The green area contains words emphasizing the strategy of using learning tools such as "augmented and virtual reality", "improving classroom teaching", "learning strategies", "games", and "teaching". The blue area contains words emphasizing the transformation of technological tools such as "second life", "immersion", "mobile learning", "collaborative learning", and "empathy". Figure 23 includes the thematic/strategic map representing AR, metaverse and VR.

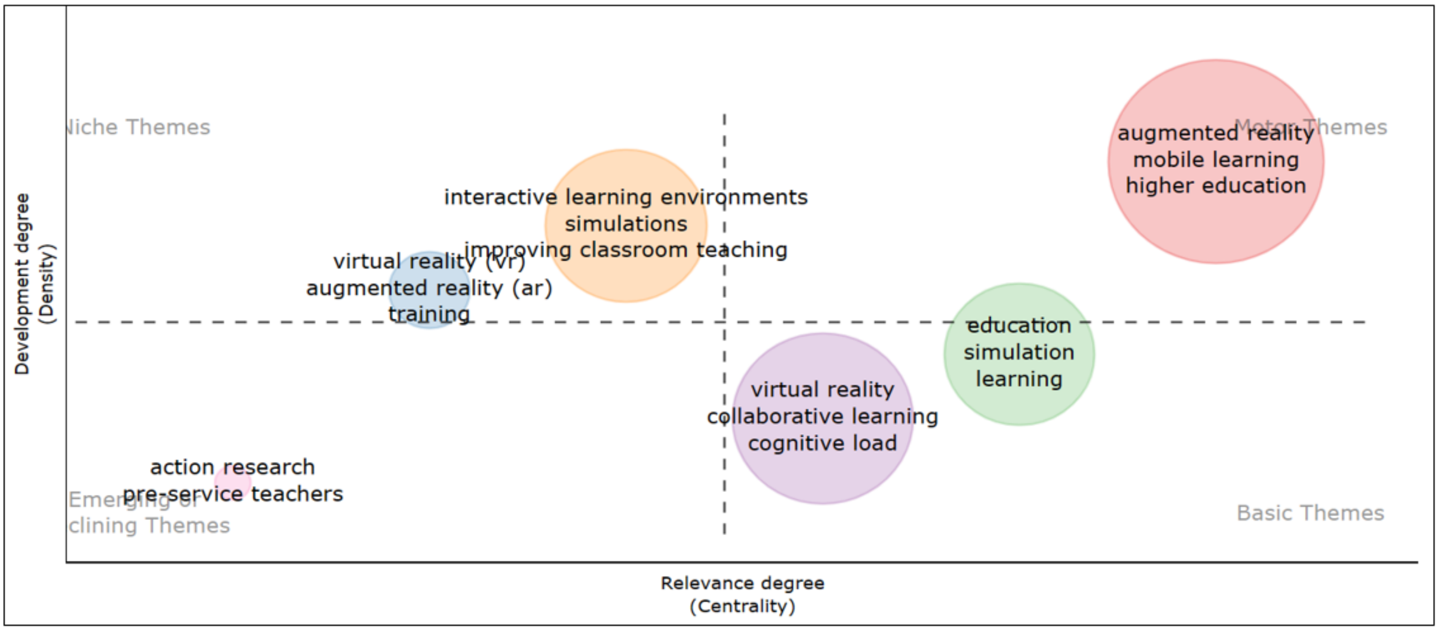

Figure 23. AR, metaverse and VR thematic map

Figure 23 shows the visualized structure of thematic/strategic changes in AR, metaverse and VR. In creating this mapping, Walktrap was preferred as the clustering algorithm. The resulting map consists of four quadrants according to the average value of both axes. The minimum cluster frequency (per thousand docs) value of five was chosen to reduce the contiguity in the clusters formed on the map. Each quadrant represents a different theme, and the bubble size is drawn in proportion to the number of keywords preferred by the authors (Mostafa, 2022). The first quartile, "motor themes", indicates high density and is characterized by centrality (Cobo et al., 2011). This theme shows internal and external development. AR, metaverse, and VR topics include "augmented reality", "mobile learning", and "higher education" as such themes. "Niche themes", the second quarter, is evaluated under the highly developed but isolated theme title. This theme is internally well-developed but externally important. AR, metaverse and VR topics include "interactive learning environments", "simulations", "improving classroom teaching", "virtual reality", "augmented reality", and "training". In another quarter, there are "emerging or declining themes", that is, the theme pointing to low density and centrality. The themes in this quadrant indicate low importance at both the internal and external levels. AR, metaverse, and VR topics include "action research" and "pre-service teachers" as themes. In the last quarter, "basic themes" are the ones with low density and high centrality. In addition, this theme is characterized by critical external links and indicates the prevalence of the study area (Mostafa, 2022). This theme includes "collaborative learning", "cognitive load", "virtual reality", "education", "simulation", and "learning".

4. RESULTS, DISCUSSION AND RECOMMENDATIONS

This study examines the scientific articles published on AR, metaverse and VR in the 21st century based on the WoS database. For this purpose, 2203 articles, including authors from 87 different countries, were analyzed with the help of bibliometric analysis. According to the research findings reached within the scope of scientific productivity, there has been a significant increase in the annual number of articles and citations since 2000. It has been determined that the number of articles and citations of AR, metaverse and VR content exhibits an upward trend, especially starting from 2015. These findings show that researchers' interest in ICT-based applications has increased with technological innovations. The increasing importance of innovative technologies such as cloud computing, AI, and the IoT with the digitalization trend in the new world order has led researchers to be more productive in these areas (Hwang & Chein, 2022). These findings of the study also support the results of similar studies with AR, metaverse and VR content. For example, the findings of the research, which deals with the change of AR and VR technologies from the past to the present, indicate that there are significant changes in the volume of studies with digital content (Akçayır & Akçayır, 2017; Cipresso et al., 2018; Li et al., 2022; Roda-Segarra et al., 2022; Rojas-Sánchez et al., 2023; Soto et al., 2020; Tas & Bolat, 2022). It has been determined that the names of Hwang, Makransky, Tsai, Ke, Chen, Cheng, Jong and Yılmaz stand out as the core authors on AR, metaverse and VR. In particular, it was determined that the author, Hwang, G. J., was well ahead in both citation and article. The author, an expert in digital learning and education, works at the National Taiwan University of Science and Technology. According to Hwang (2022), multimedia and internet technology in education will soon be replaced by innovative technologies such as AR, metaverse, VR, IoT, and AI. Thus, it will be inevitable that today's information and content related to information will differ in the future depending on technological diversity.

When the total and annual citation rate of articles containing one or more AR, metaverse and VR technologies in the 21st century are examined, Wu et al. (2013), the article named "current status, opportunities and challenges of augmented reality in education" was determined to be in the first place. The researchers discussed AR technology in their published article and explained its definition and components. In second place is the article "assessing the effects of gamification in the classroom: A longitudinal study on intrinsic motivation, social comparison, satisfaction, effort, and academic performance", published by Hanus and Fox (2015). In their study, the researchers examined the effect of a gamified course program with VR technology content on students with the help of various variables. One of the study's findings was obtained from the distribution of responsible authors by country. Although digitization has become a global force, responsible writers often include a single country. Multi-country broadcasts remained limited. Accordingly, cooperation between countries needs to be sufficiently developed. However, technology-based applications such as AR, metaverse and VR should be spread over a wider area, and information exchange between researchers should be felt more intensely.

A large number of studies/researches have been conducted on AR, metaverse and VR content studies since 2000, and in the meantime, the studies of some authors have received more attention from other researchers. These writers were dominant during their time and came to the fore more in specific periods as the first author. In particular, the authors of Makransky, G., Tsai, C. C., Chen, C. H., Hwang, G. J., Chang, C. Y., and Ke, F. F. have made dominance factors more felt in recent years. Considering productivity based on institutions, the National Taiwan Normal University, the National Taiwan University of Science and Technology, and the Chinese University of Hong Kong come to the fore. These institutions are very productive in AR, metaverse and VR content studies compared to other institutions included in the research. An essential feature of these institutions is that they are productive in studies with metaverse content (Tas & Bolat, 2022). At the same time, the most prominent feature of these institutions is that they attach great importance to technology, make severe investments in this regard, and support their teaching content with digital-based departments. In addition, some of the researchers have an important place in the fieldwork in these institutions. These institutions, located in the countries of the Asian continent, are also entirely developed in the transfer of digital transformation to educational environments. When the geographical atlas of the publications containing AR, metaverse and VR is examined, it is determined that China in the Asian continent stands out more. On the other hand, USA, Spain, Türkiye, United Kingdom, Australia, Germany, and Canada also made valuable contributions to AR, metaverse and VR. These findings are also similar to those of studies conducted in a similar direction in the literature. For example, in the study in which VR and AR contents were investigated, it was determined that USA, China, UK, Spain and Germany came to the fore (Cipresso et al., 2018; López-Belmonte et al., 2020; Menjivar Valencia et al., 2021; Roda-Segarra et al., 2022; Rojas-Sánchez et al., 2023). The study by Tas and Bolat (2022), in which metaverse content was investigated, determined that USA and China were the leading countries in productivity.

When the findings obtained from the co-citation network analysis of the research were evaluated in general terms, it was determined that the authors named Makransky, G., Mayer, R. E., Hwang, G. J. and Cheng, K. H. were in the centre of their cluster. These writers are knowledge-spreading writers who also influence the writers around them. The work of these authors leads to the dissemination of AR, metaverse and VR content to wider audiences. These authors frequently include the effect of transformed technologies on learning environments in their studies and develop up-to-date content on educational technology. This encouraging feature of the authors also influences other researchers and directs their studies. In this respect, these authors are considered pioneer authors and offer ideas that will inspire the content of studies in the field. It has been determined that Computer & Education journal interacts intensely with common references in the context of resources. This journal, which has been accepted globally, is at a perfect level both in impact factor and citation score. In particular, having qualified publications on AR and VR content and prioritizing studies on the reflections of technology on learning environments also expands the journal's scope. This journal is frequently emphasized in the findings of studies conducted in a similar direction. Especially in VR content studies (Roda-Segarra et al., 2022; Rojas-Sánchez et al., 2023), as well as in AR content studies (Arici et al., 2019; López-Belmonte et al., 2020). On the other hand, the prevalence of far Eastern countries stands out in the cooperation network based on institutions. Especially the National Taiwan Normal University, National Taiwan University of Science and Technology, and Nanyang Technological University institutions are very effective in the cooperation network. The study's findings in a similar direction indicate that these institutions significantly impact the field (López-Belmonte et al., 2020; Tas & Bolat, 2022). In the 21st century, China, USA, Taiwan, Spain, Germany, Türkiye, and Australia stand out as highly productive countries in AR, metaverse and VR and make a significant difference in cooperation with other countries. In particular, there are significant collaborations between China and USA, China and Australia, China and Singapore, USA and Canada, USA and Korea, USA and Spain, China and Canada, USA and Australia, USA and Netherlands and Finland and Sweden. In studies evaluated under separate headings, the dominance of these countries in the field is frequently emphasized, and it is stated that they make a significant difference in technology-based applications (Cipresso et al., 2018; Li et al., 2022; Rojas-Sánchez et al., 2023; Soto et al., 2020).

Keywords that stand out prominently in AR, metaverse and MR technology content; AR, VR, interactive learning environments, mobile learning, simulation, education, simulations and action research. Accordingly, the effects of technology are strongly felt in the keywords, which provide an important clue in having an idea about the content of the studies. As a matter of fact, in the co-occurrence network between the keywords determined by the authors, technology-based word groups such as blended learning, game-based learning, multimedia, active learning, learning environment, 3D modelling, immersive learning, virtual learning environment, applications in subject areas and media in education are frequently encountered. Therefore, the keywords that make up the reflection of technology in learning environments are more frequently preferred by the authors. When the trending topics and thematic changes in AR, metaverse and VR since 2000 are examined, there has been a trend towards metaverse, especially in recent years, in addition to the dominant roles of AR and VR topics. There is an evolution toward innovative approaches in learning environments depending on the changes in educational technologies. It is stated that technological changes take place more in learning environments today and make significant contributions to learning (Trilling & Fadel, 2009). In the future, learning environments will be shaped by technology and the technology ecosystem will be felt more (ISTE, 2016). It is known that in the 21st century, while AR, metaverse and VR technologies come to the fore more, there is an increasing interest in their transfer to the educational environment (Chang & Hwang, 2018; Dwivedi et al., 2022). In this respect, there is a shift towards teaching materials with more than one technological content rather than a single teaching approach. However, it is worth noting that such studies find more responses in higher education. The fact that applications take place more in higher education may be related to the fact that such studies require expertise and the supply of technological equipment. Therefore, it is very important to train more experts and increase their awareness on these issues.

The researcher's final finding was obtained from the conceptual structure and thematic mapping of AR, metaverse and VR studies. The research findings show that the MCA dimensions represent approximately 58% of the total variation. This indicates the depth and width of AR, metaverse and VR topics. According to the keywords created by the authors, words that emphasize technological learning environments such as teaching-learning strategies, human-computer interface, interactive learning environments, media in education, secondary education, post-secondary education and simulations come to the fore. Similarly, words that emphasize using learning tools such as augmented and VR, improving classroom teaching, learning strategies, games and teaching are prominently featured. On the other hand, AR, mobile learning, and higher education are the prominent themes as an indicator of internal and external development. In this respect, the rapid evolution of the social model, which has been experienced in learning environments with the acceleration of digital transformation and the emergence of the idea of the IoT, accelerates the researchers' orientation to current technological content. Within the scope of the study, the themes emerging in AR, metaverse and VR indicate this situation.

4.1. Limitations and Agenda and Implications for Future Research

The research carried out in the context of bibliometric methodology has some limitations as well as its contributions to future studies on AR, metaverse and VR. One of the important limitations of the research is that only the WoS™ database was preferred in creating the data set. Although the WoS™ database is the world's leading respected information platform, other academic databases such as Scopus, ProQuest, EBSCO, PubMed, DOAJ, Australian Education Index, British Education Index, Education Full Text (H. W. Wilson) and ERIC may be alternatives for future research. According to these databases, the position in the field and the direction of the research can be evaluated more clearly by conducting systematic research on low-importance topics such as interactive learning environments, simulations and improving classroom teaching. Also, according to the findings obtained from the motor themes section, which shows both internal and external development, the general trends of studies on AR, metaverse and VR can be determined by making content and descriptive analyzes on AR, mobile learning and higher education. In the research, only "article" was chosen as the document type, but document types such as book chapters, proceeding paper, and review article can also be used in similar studies. Therefore, changes in file types may cause differences in the results of the study subjects. Research on a single discipline, such as mathematics, science, social sciences, and information technology education, can be conducted by narrowing the scope of AR, metaverse and VR studies. One of the strengths of bibliometric analysis is that determining the changes in the field of study creates an essential resource for studies to be carried out in the same direction and shows the researchers the gaps in the field. In this respect, studies on AR, metaverse and VR should be examined at specific intervals with the help of analysis types such as meta-analysis, meta-synthesis, systematic, content or bibliometric. The examination of scientific studies on these subjects can be carried out to cover the period after 2023. Performance, network analysis, conceptual structure, thematic changes and popular topics were taken into account in the creation of the study. However, studies on similar subjects can include more review titles (index, document, *etc*.). AR, metaverse and VR were used as search terms in the research. In addition to these, studies on topics such as AI, machine learning, nanotechnology, quantum, robotic coding, virtual universe, motion-based computing, wearable digital tools, 3D printers, IoT, re-engineering and hologram, which will have an important place in education in the coming years, The contents of the studies can be examined. Therefore, similar studies can be conducted to know the effects of the tools that make a technological education world possible on societies and how they find a response in the field.

Research and Publication Ethics Statement

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

Contribution Rates of Authors to the Article

The authors equally contributed (e.g., conceptualization, literature review, setting research questions, designing the research, methodology, implementation, data analysis, writing the paper in English, auditing, and editing processes) for the article.

Statement of Interest

There is no conflict of interest between the authors.

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