REVIEW
ARTICLE

Mixed reality and children's motor skills: Bibliometric analysis of Scopus database one decade (2015-2025)

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ABSTRACT

The advancement of science and technology continues to develop and has a significant impact on human life, especially on motor skills. In this context, Mixed Reality provides understanding and improvement of skills. This study presents a bibliometric analysis of articles related to Mixed Reality and motor skills published from 2015-2025. A total of 259 articles match the keywords in the Scopus database. This study examines the growth rate of research year by year, with the use of commonly used keywords, articles that are widely cited, countries that have collaborations with other countries, and countries with the most documents and new research keywords. The results of this study convey that the number of publications in one decade (2015-2025) is the most in 2024 as many as 48 publications, and the most keywords are Mixed Reality, Argument Reality, and Virtual Reality, while (S. Gallagher and R. Lindgren), and (H. F. Al Janabi et al) are the most cited documents, the countries with the most documents are the United States, Germany and Japan, for the novelty of keywords seen from the yellow image, such as motor tasks, arthroplasty, haptic feedback, and virtual environments. Germany, United States, United Kingdom are countries that have high collaboration. With the presence of this research, it is expected to provide a meaningful contribution to researchers in the future related to Mixed Reality, especially in the field of motor skills.
Keywords: Mixed reality, Motor skills, Children, Bibliometrics.

INTRODUCTION

In today's era, science and technology continue to develop. One of them is mixed reality (MR) technology. MR is the process of combining the real world and the virtual world to create new representations and environments where digital and physical items can coexist and communicate in real-time (Rokhsaritalemi, Sadeghi-Niaraki, and Choi 2020). MR combines elements of virtual reality and augmented reality by using "*glasses*" that have transparent screens that allow viewing of 3D digital objects, such as holograms, and interaction with these digital objects is mostly done through hand gestures, voice commands, or simply fixing the gaze at a certain point. MR technology is usually paired with Head-Mounted Displays (HMD), usually in the form of a headset or glasses that make learning easy to access and interesting (Barteit et al. 2021). One of the top ten ICT innovations in 2020 is MR technology (Flavián, Ibáñez-Sánchez, and Orús 2019).

In addition, research on MR has shown that motivation can be increased and effective in learning. Specifically, MR in education allows the development of MR applications that help visualize abstract concepts more effectively. This device allows participants to interact by exploring materials and more interesting ways. This content can be displayed on devices used such as MR glasses, with the presence of information provided by MR devices, research that has been done says that Mixed Reality can improve children's motor skills and provide direct feedback.

Some technologies have begun to develop in education, one of which is immersive technology which includes (AR, VR, and MR) (Ryan et al. 2022), immersive technology provides a real experience (Tang et al. 2022). There are several previous studies that convey that the application of MR in increasing, provides insight into the growing trends in this field. Recently, research on this topic has grown significantly, MR training over a longer period of time or 6-8 weeks, with training sessions occurring 2-3 times per week can improve motor and cognitive skills (Heyn et al. 2014; Leung and Shi 2023), and When providing the main variables analysed, many studies have the same theme.

The purpose of this study is to explore, analyse the development and trends of global research published in 2015-2025 in the Scopus database. The specific objectives of this study are to determine which keywords are most frequently used in scientific publications and to utilize bibliometric mapping based on keyword co-occurrence to analyse relationships between topics, between countries and provide an overview of current research and major opportunities for future development.

METHODOLOGY

This study is a bibliometric analysis with quantitative evaluative and descriptive techniques, this is used to identify patterns and research from publications. By using bibliometric visualization, the arrangement of regions can be displayed (Garfield 2009). A total of 259 searches on the article search engine with the Scopus database, with the provisions of research between 2015-2025 as many as 221 articles, and with English being 217, articles that are included with the criteria that match the researcher's search are 175, this includes research articles. The search keywords in this study are mixed reality and motor skills. Using the VOSviewer application with three views with publications between 2015-2025. The indicators can be known by paying attention to the quantity of publications, the number of citations, and the overall link strength between the objects being displayed.

The years 2015-2025 are the initial and final years of researchers conducting searches and collecting meta data on literacy and learning outcomes using the Scopus database. VOSviewer is used to analyse author

bibliographies, keywords, countries, and years of publication. VOSviewer is a software that produces network visualizations of frequently used terms in a particular field (van Eck and Waltman 2017; Orduña-Malea and Costas 2021; Oyewola and Dada 2022; Sovacool, Daniels, and AbdulRafiu 2022). A very helpful and popular application for bibliometric analysis is VOSviewer (van Eck and Waltman 2010; Shah et al. 2020) In addition to creating network visualizations, VOSviewer is also used in analysing the evolution in a particular field based on commonly used terms (Guleria and Kaur 2021; Huang et al. 2022). The five stages of research in bibliometric analysis are outlined below by (Dewi et al. 2021).

The five stages of bibliometric analysis techniques are depicted in the figure above. Specifically, as follows: 1) Selection of research terms or keywords: Before starting data collection, researchers search for information on keywords related to Mixed reality and motor cycles; 2) Limiting the scope of the first search; in this case, researchers use the Scopus database to find articles based on the keyword list; 3) Researchers manually browse all search results using the VOSviewer tool, reducing the total initial search volume if necessary; 4) Creating an initial statistical image: combining information to describe the topic, such as collecting results from visualizations of countries, organizations, journals, publications, and author bibliography pairs, along with author keywords; 5) Analytical narrative interpretation of the data: VOSviewer is used to assess the data and explain the study's conclusions based on the selection results. VOSviewer visualization provides a representation of the data in the form of a variable map that is linked to keywords and has room for improvement.

A deductive approach is used for data analysis, which begins with broad conclusions and develops into more focused conclusions. Country Bibliography, Publication Bibliography, Author Bibliography, and Keyword Appearance are some examples. So that readers can follow the information provided from comprehensive information to more specific information (Ersozlu and Karakus 2019; Lee, Felps, and Baruch 2014)

Research questions
RQ1: What is the total number of publications on MR and motor skills in the period 2015-2025?

RQ2: What keywords appear most frequently in searches for MR and motor skills? And what research is most often cited by authors in the period 2015-2025?

RQ3: Which countries have collaborations with other countries? Which countries have the most publications? And what are the latest research in this decade?

RESULTS

Based on the search results on the Scopus database using the keyword Together visualized with VOSviewer, all present the results of bibliometric analysis (Ellili 2022; Donthu et al. 2021). From the search on the Scopus page, which initially obtained 259 articles that matched the keywords mixed reality and motor skills. However, the data was refined by several procedures until there were 175 publications left, as can be seen in Table 1.

Based on Figure 1, it can be said that the publication trend of the first era (2015-2017) was small and erratic. The year 2015 started with about three documents, increased to about five documents in 2016, and then dropped drastically to about two documents in 2017. Initial growth (2018-2019): About 8 documents were recorded in 2018 and increased to about 18 documents in 2019, indicating the beginning of productivity development. Temporary decline (2020-2021): a period of stagnation or decline in productivity is reflected by a small increase in 2021 (about 12 documents) and a subsequent decline in 2020 (about 11 documents).

Significant production growth (2022-2024). The peak occurred in 2024, which was around 48 documents, the highest value during the monitoring period. After the previous highest value, there was a significant decrease in the number of documents in 2025, reaching around 18 documents.
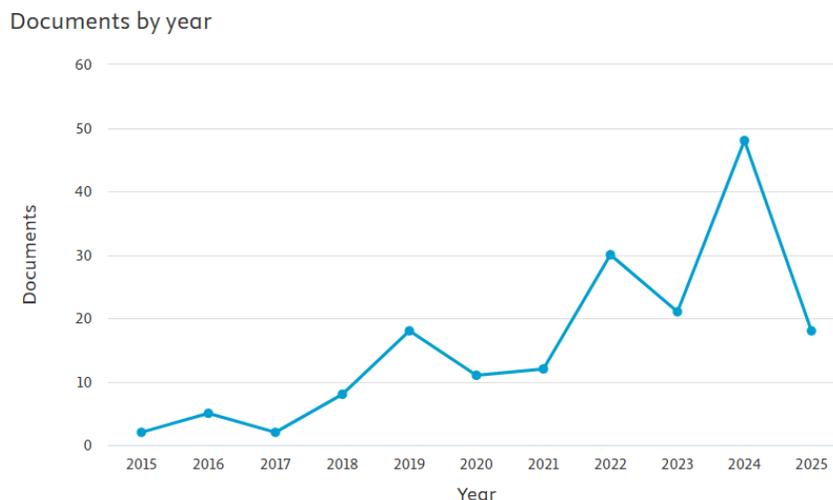

Figure 1. Year of publication.

Table 1. Number of publications and citation trends.

TAHUN	TP	NCP	TC	H	G	C/P
2025	18	0	0	0	0	0.0
2024	48	29	81	5	5	1.7
2023	21	20	117	8	9	5.6
2022	30	28	262	9	14	8.7
2021	12	12	173	5	12	14.4
2020	11	9	256	6	11	23.3
2019	18	17	174	7	12	9.7
2018	8	7	148	5	8	18.5
2017	2	2	102	2	2	51.0
2016	5	5	121	4	5	24.2
2015	2	2	167	2	2	83.5
Total	175	131	1601	53	80	

Based on Table 1. It can be seen that with a number of indicators, including the total number of publications (TP), Number of Citation Papers (NCP), Total Citations (TC), H-Index (H), G-Index (G), and citations per publication (C/P), the table displays publishing statistics from 2015 to 2025. Although 2024 has the most articles (48), the low C/P value (1.7) indicates that most papers have not been screened much. Although only 11 publications, 2020 is famous for the second highest C/P value (23.3) and the most locations (256). With the largest C/P value (83.5), 2015 shows excellent effectiveness and indicates that, although it only has two publications, the publications are very important. In general, early-stage publications have a higher impact (as seen from high C/P values), while new papers are often less screened. This illustrates that scientific impact takes time to develop and does not always correlate with publication volume.

Table 2. Publications with the most citations.

Year	Author	Title	Journal name	Quote	Quotes per year
2015	(Gallagher and Lindgren 2015)	Enactive Metaphors: Learning Through Full-Body Engagement	Educational Psychology Review	145	14.50
2020	(Al Janabi et al. 2020)	Effectiveness of the HoloLens mixed-reality headset in minimally invasive surgery: a simulation-based feasibility study	Surgical Endoscopy	120	24.00
2021	(Georgiev et al. 2021)	Virtual Reality for Neurorehabilitation and Cognitive Enhancement	Brain Sciences	90	22.50
2017	(Frank and Kapila 2017)	Mixed-reality learning environments: Integrating mobile interfaces with laboratory test-beds	Computers & Education	90	11.25
2018	(Pellencin et al. 2018)	Social perception of others shapes one's own multisensory peripersonal space	Cortex	87	12.43
2016	(Colomer et al. 2016)	Effect of a mixed reality-based intervention on arm, hand, and finger function on chronic stroke	Journal of Neuro Engineering and Rehabilitation	83	9.22
2019	(Aruanno and Garzotto 2019)	MemHolo: mixed reality experiences for subjects with Alzheimer's disease	Multimedia Tools and Applications	38	6.33
2020	(Jansen et al. 2020)	ShARe: Enabling Co-Located Asymmetric Multi-User Interaction for Augmented Reality Head-Mounted Displays	UIST 2020 - Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology (2020) 459-471	37	7.40
2020	(Riegler, Riener, and Holzmann 2020)	A Research Agenda for Mixed Reality in Automated Vehicles	ACM International Conference Proceeding Series (2020) 119-131	32	6.40
2019	(Sagheb et al. 2019)	SWISH: A Shifting-Weight Interface of Simulated Hydrodynamics for Haptic Perception of Virtual Fluid Vessels	UIST 2019 - Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (2019) 751-761	32	5.33

Data from publications on Mixed Reality (MR) show that this technology is increasingly being used in various industries, including autonomous driving, education, and healthcare. Although research on MR has been around for a long time, the application of the technology began to grow rapidly around 2020, as seen from the publications in 2015 that had the highest number of citations. The number of publications with high citations in 2020, such as in the fields of user interfaces and surgery, shows this. It is interesting to note that publications published in 2021 had the highest average annual number of citations (22.5), indicating that MR is highly valued in the field of cognitive rehabilitation. According to most publications, MR applications involving direct user experience, such as in learning or therapy, attract more attention and are often cited by

other researchers. This shows that MR has great potential as a leading technology in the real world, as it can be used to support human life in addition to providing pleasure.

Trends in research collaboration between countries
Figure 3 shows international research collaboration in the fields of mixed reality and motor skills. The circles in the figure represent countries that have produced scientific articles on the subject. Only countries with at least three publications are shown in the research figure meeting the three-document criterion.
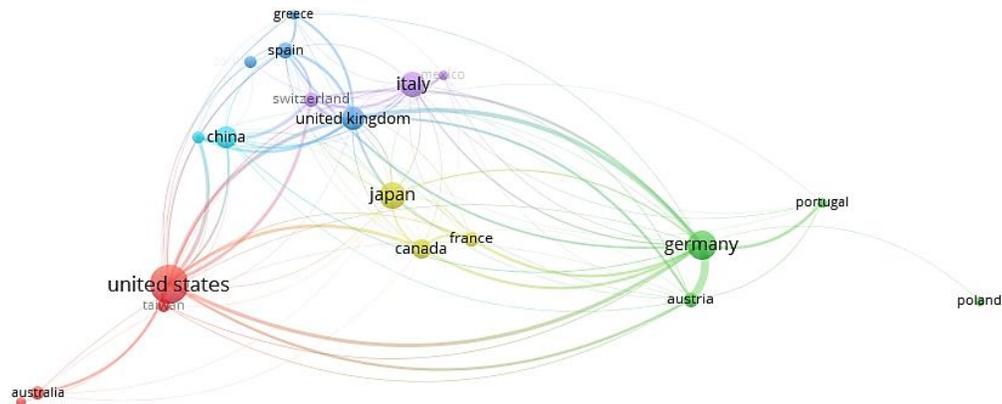
Figure 2. Relationships between countries.

This figure shows a map of the international scientific collaboration network based on the relationships between co-publishing. The large, thick circles and the many lines connecting them to other countries such as China, Japan, Germany, the United Kingdom, and Australia indicate that the United States is the largest hub of collaboration. This suggests that the main hub of global cooperation is the United States. With many connections to countries such as Austria, France, Portugal, and Poland, Germany is also an important node in Europe and plays a significant role in regional cooperation. In addition, there is an active collaborative network between Italy, Japan, and the United Kingdom involving other countries. Although they are still connected to the main node, the involvement of many countries including Greece, Mexico, and Taiwan in this network indicates a more limited level of cooperation. This network generally illustrates how international scientific collaboration works, with prosperous countries with strong research infrastructures at its core.

Figure 3. Documents by region.

With nearly 42 documents, the United States has more publications than any other country, according to the "*Documents by Country or Region*" chart. With 24 records, Germany is in second place, followed by the United Kingdom, Italy, and Japan, each with 17-20 documents. Significant contributions from China and Canada are next, with around 15 and 12 documents, respectively. With between six and nine documents, countries such as France, Austria, Spain, and Switzerland have the fewest documents. With fewer than six papers submitted, South Korea, Taiwan, Australia, and the Netherlands are in last place. According to these statistics, industrialized countries continue to produce the majority of scientific papers. The supremacy of the United States is a reflection of the strength of its infrastructure and research capabilities. The differences in the number of documents among countries are a reflection of the variations in funding, resources, and research priorities that support scientific endeavours.

Research focus

Figure 4 shows the emphasis of research on motor skills and mixed reality. Figure 5 illustrates the originality of the research. The VOSviewer program with a threshold of 5 was used to display the images. This indicates that there are at least five separate papers that use the keywords displayed.

Figure 4. Research emphasis.

Using Vosviewer, the figure above visualizes the term network map (Co-occurrence) in research on reality technologies including virtual reality, augmented reality, and mixed reality. According to several studies, the phrases "*mixed reality*," "*augmented reality*," and "*virtual reality*" emerge as the largest size centres, indicating their high frequency of presence. Green, red, and blue are the three primary colour clusters. With an emphasis on the elements of technology interaction and education, the green cluster covers subjects including motor transportation, e-learning, human-computer interface, and helmet-mounted displays. With terms such as rehabilitation, haptic feedback, and motor function, the red cluster emphasizes neurological and motor rehabilitation. Meanwhile, the blue cluster is mostly related to clinical features and human populations, including adults, stroke, physical, and humans. This map highlights the interdisciplinarity in

immersive technology research by depicting the close relationship between several sectors, ranging from education and transportation to rehabilitation.

Figure 5. Research novelty.

Figure 5 shows a bibliometric representation of terms used in mixed reality, augmented reality, and virtual reality research from 2021 to 2024. The node colours show the temporal distribution; purple indicates terms that were more prevalent at the beginning of the era (2021), while yellow indicates more recent trends (2023-2024). Keywords such as "*augmented reality*," "*mixed reality*," and "*virtual reality*" continue to be the focus of studies. The use of mixed reality in rehabilitation technology and haptic feedback is becoming more popular, as seen by the bright yellow terms "*haptic feedback*," "*rehabilitation systems*," and "*motor function*." On the other hand, the blue cluster is mostly related to clinical aspects and human populations, such as human, adult, stroke, and physiology. This map shows the close relationship between the fields, highlighting the interdisciplinarity in the study of immersive technologies, from rehabilitation to education and transportation.

DISCUSSION

The results of this study convey that publications on MR and motor skills, sourced from the Scopus database from 2015 to 2025 have been visualized with the help of VOSviewer, with keyword frequency bibliometric techniques, mapping of author collaborations between countries, and publication trends for a decade (2015-2025).

Bibliometric visualization findings show that research related to mixed reality, augmented reality, and virtual reality has experienced significant development during the period 2021 to 2024. This is reflected in the strength and connection of the keywords displayed on the map, where "*mixed reality*" is the main centre with a wide keyword network. This study shows that mixed reality is not only an important issue but also functions as a bridge connecting various disciplines, including technology, health, and human-computer interaction
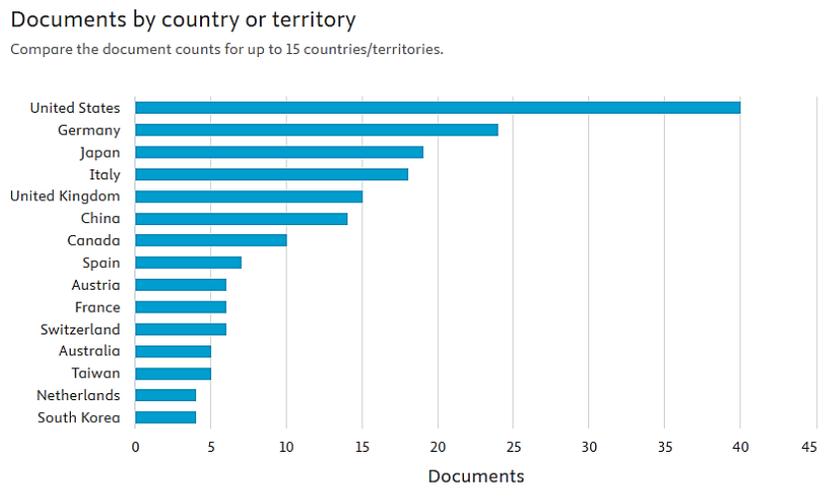
(Suryodiningrat et al. 2024). The shift in focus from the development of hardware technology to its application in the medical and rehabilitation disciplines is also reflected in the latest research trends, which are marked in yellow on phrases such as haptic feedback, rehabilitation systems, and motor function. This shift shows that mixed reality technology is starting to be widely used in real life, not just as a technological advancement, but has been used in patient rehabilitation and motor function recovery (Mandolini et al. 2025).

Information on the use of MR and motor skills from 2015 to 2025 is presented based on the findings and objectives of this study, which shows a significant increase in publications and academic interest in the field of MR and motor skills. This study highlights emerging trends, such as key contributions, and possible future integration paths between motor skills and MR are emphasized in this study. Overall, the results of the study indicate that MR has great potential to change the way skills are learned and taught. It is hoped that as technology advances, research and use of MR in skill improvement will expand and improve overall educational standards.

CONCLUSION

Based on the results of the study, it can be said that the bibliometric analysis describes the publication trend on MR and motor skills in the 2015-2025 period. The document selection process involves a search engine from the Scopus database and is filtered to get 259 of the keyword matches. Based on the data analysis, the most publications were in 2024 with 48 documents showing that the use of MR has increased in motor skills. A picture of a trend that will continue to increase in the coming year.

The findings of this analysis convey that the keywords that often appear in research related to the application of MR with motor skills. These keywords are "*mixed reality*" virtual reality, argument reality and motor skills. Among these keywords, MR is the central centre that most often appears in research discussions. The United States, Germany and Japan are the countries with the most documents and Germany, the United States, and the United Kingdom are countries with high collaboration. In this analysis, we found new keywords such as motor tasks, arthroplasty, haptic feedback, and virtual environments. This is expected to be a guideline and motivation in conducting future research.

AUTHOR CONTRIBUTIONS

This work was carried out as a team, but the division of responsibilities was as follows: Research concept and design: Yanuar Kiram, Wilda Welis, and Sri Gusti Handayani. Data compilation: Wilda Welis, Anton Komaini, and Sri Gusti Handayani. Data analysis and interpretation: Yanuar Kiram, Heru Andika, and Rully Effendi. Report review: Anton Komaini, Heru Andika, and Rully Effendi.

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DISCLOSURE STATEMENT

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