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Research Trends and Gaps in the Adoption of Immersive Reality Technologies in African Education Systems

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Abstract. Immersive reality technologies (IMRT) hold transformative potential for educational practices. While there have been studies on the application of immersive technologies in education, fewer studies have attempted to map research trends and gaps in Africa with the continent's peculiarities. This mixed-methods bibliometric study analyses scholarly publications by African researchers and institutions to identify trends, research hotspots, and collaboration networks in the application of IMRT in education and training. Utilizing the SCOPUS database to generate the dataset, descriptive analysis and vosViewer were used to make sense of the data on publication output trends, publication by country and affiliations, funding, citation metrics, and co-authorship patterns from 2014 to 2023. Findings reveal a steady increase in immersive reality technology research around education. Academics affiliated with African institutions mostly cite academics from the western world than they cite fellow African academics. Results suggest limited local funding for research with significant funding contributions coming from external organisations. This may suggest that research directions on IMRT in African is heavily influenced by outside academics. Keyword analysis suggests that research in IMRT related to education is more biased towards higher education than secondary and primary education. Data analysis on author citations suggest significant recent research focus on how IMRT could impact curriculum reform and implementation. Research gaps exist in the application of IMRT in primary and secondary education. Policy makers could increase local funding in research directed towards coupling the application of immersive technologies with generative artificial intelligence tools in primary and secondary education.

Keywords: Immersive Learning; Immersive Technologies; Augmented Reality; Mixed Reality; Virtual Reality; Education technology

1. Introduction

Immersive technologies (IMT) such as augmented reality (AR), virtual reality (VR), and mixed reality (MR), have disrupted various sectors globally, including education (Dinet & Kitajima, 2018; Berglund, 2023; Tanaka et al., 2021; Dede, 2009; Lim & Ismail, 2015; Ladykova, 2024). These technologies offer transformative potential by providing interactive and engaging learning experiences that transcend traditional educational methods (Lim & Ismail, 2015). Despite such promises in enhancing learning, the state of research around the use of immersive technology in education remains unexplored on the African continent.

The integration of immersive technologies in education brings a myriad of benefits that enhance the learning experience (Berglund, 2023; Smutny, 2023; Tanaka et al., 2021). These technologies have been shown to improve student engagement, facilitate experiential learning, and enhance conceptual understanding (Dede, 2009). Augmented reality (AR) and virtual reality (VR) enable students to interact with digital content in three-dimensional spaces, making abstract concepts more concrete and easier to understand (Berglund, 2023; Tanaka et al., 2021). For example, in science education, AR can overlay digital information onto physical objects, allowing students to visualize molecular structures or explore the anatomy of organisms in a more intuitive manner (Dede, 2009). This hands-on approach to learning not only boosts comprehension but also increases student motivation and interest in the subject matter.

Additionally, immersive technologies offer unparalleled opportunities for experiential learning. VR simulations can recreate historical events, scientific phenomena, or complex systems, providing students with immersive experiences that would be impossible or impractical to replicate in a traditional classroom setting (Smith & Jones, 2020). This type of experiential learning can deepen understanding by allowing students to explore scenarios in a safe, controlled environment where they can experiment, make mistakes, and learn from them without real-world consequences. Moreover, these technologies can facilitate personalized learning experiences, catering to different learning styles and paces. Adaptive VR environments can provide instant feedback and adjust the difficulty level based on the learner's performance, ensuring that each student receives a tailored educational experience (Brown et al., 2019).

Furthermore, immersive technologies can bridge the gap between theory and practice, particularly in fields that require practical skills and hands-on training (Sakpere et al., 2023). For instance, in medical education, VR simulations enable students to practice surgical procedures and patient interactions in a virtual environment, honing their skills before working with actual patients (Green & Williams, 2022). This not only enhances skill acquisition but also builds confidence and reduces the risk of errors in real-life situations. Overall, the application of immersive technologies in education holds the promise of transforming traditional teaching methods, making learning more engaging, effective, and accessible to students around the world.

Africa has its unique challenges and potential for growth in terms of the application of technology in education (Sakpere et al., 2023). In past industrial revolutions Africa has lag other parts of the world in adopting to technological changes. Yet IMRT could play a pivotal role in addressing challenges of resources such as laboratory equipment in science classrooms (Jantjies et al, 2018). Furthermore, focusing on Africa may uncover new approaches IMRT can be adapted for indigenous knowledge preservation, multilingual education, and addressing diverse learning needs.

While the potential of IMRT have been positively lauded, Chng et al. (2023) admit that even in developed countries, the eventual implementation of these technologies has not reached its potential. The cost of setting up a learning environment using immersive technologies has been cited as one of the most prohibitive factors in the implementation of the technologies (Jantjies et al., 2018). Despite their potential, research around the adoption and integration of immersive technologies in African educational contexts remain underexplored. While existing literature highlights the benefits of these technologies, there is a paucity of comprehensive studies that systematically analyse the research trends and identify the gaps in the application of immersive technologies within African education systems.

This bibliometric study analyses scholarly publications from African researchers and institutions to identify trends, research hotspots, and collaboration networks in the application of immersive technologies in education and training. This bibliometric study aims to fill this gap by providing a detailed analysis of the research landscape surrounding immersive technologies in education within Africa. By examining publication patterns, research collaborations, thematic trends, and identifying underexplored areas, this study seeks to offer valuable insights for researchers, policymakers, and educators. Understanding these trends and gaps is crucial for informing future research directions, guiding policy decisions, and ultimately, harnessing the full potential of immersive technologies to address educational challenges in Africa.

By understanding these trends and gaps, we can inform future research directions, guide policy decisions, and ultimately harness the full potential of immersive technologies to address educational challenges in Africa. This study will examine publication patterns, key research themes, and prominent authors and institutions. Additionally, it will explore the extent to which immersive technologies have been integrated into African education systems and identify areas where further research and development are needed.

Research Questions

To guide this bibliometric study, we propose the following research questions:

1. What are the publication trends in research on immersive reality technologies in education within African contexts over the past two decades?

2. Which countries, institutions, and authors are leading the research on immersive technologies in African education?
3. What are patterns of South-South and South-North collaborations in Immersive technology education research in Africa?
4. What are the predominant themes and areas of focus in the existing literature on immersive technologies in African education?
5. What gaps exist in the current research on immersive technologies in education in Africa, and what are the implications for future research?

2. Background

Immersive technologies are advanced systems that create or enhance a user's perception of reality by immersing them in a simulated or augmented environment (Dinet & Kitajima, 2018; Dede, 2009; Turan & Karabey, 2023). These technologies often include elements of visual, auditory, and sometimes tactile stimuli, making the user feel as if they are part of the virtual or augmented world. These technologies create or extend reality by leveraging digital and physical spaces (Dede, 2009). Immersive technologies are being used in various fields, including education, entertainment, healthcare, and industrial training, to create more engaging, interactive, and realistic experiences. There are about five technologies that can be classified as immersive: Augmented reality (AR), Virtual reality (VR), mixed reality MR), 360-Degree Video and extended reality (XR).

Augmented Reality overlays digital information onto the real world (Duta et al., 2011; Turan & Karabey, 2023). Unlike VR, AR enhances the user's perception of their actual surroundings by adding digital elements, such as images, sounds, or other data, through devices like smartphones, tablets, or AR glasses (Jantjies et al., 2018). AR overlays digital information onto the real world, enhancing the user's perception of their environment (Duta et al., 2011; Jantjies et al., 2018). VR, on the other hand, provides a completely digital environment, immersing users in a simulated world. Users typically wear VR headsets, which block out the physical world and replace it with a 3D virtual space where they can interact with digital objects and scenarios. MR combines elements of both AR and VR, allowing digital and physical objects to coexist and interact in real-time (Milgram & Kishino, 1994). The 360-Degree Video technology allows users to explore a scene in every direction (Adnan, 2023). While it does not allow interaction like VR or AR, it provides a comprehensive view of an environment, often experienced through VR headsets or on platforms that support panoramic views (Adnan, 2023). Extended Reality (XR) is an umbrella term that encompasses VR, AR, and MR, as well as any other immersive experiences that blend the physical and virtual worlds (Guo et al., 2021). It represents the broad spectrum of immersive technologies (Guo et al., 2021).

The emergence of immersive technologies has fundamentally transformed the landscape of education (Chen & Liu, 2020). This section reviews the global application of immersive technologies in education, highlighting their potential and current usage. It then narrows down to the African context, discussing the

unique challenges and gaps in the literature concerning the adoption of these technologies.

The application of Immersive Reality in Education

For Dede (2009, p. 66) immersive technologies may enhance learning by allowing multiple perspectives, situated learning, and transfer. Several studies have demonstrated the effectiveness of immersive technologies in various educational contexts (Makransky et al., 2019). For instance, VR has been used to create virtual laboratories for science education, enabling students to conduct experiments in a safe and controlled environment (Makransky et al., 2019). AR has been applied in medical education to provide interactive anatomy lessons, significantly improving students' understanding of complex anatomical structures (Johnston, 2022). Moreover, MR has been utilized to facilitate collaborative learning, allowing students to interact with both digital and physical objects simultaneously (Liu et al., 2020).

In the United States, immersive technologies have been extensively utilized to create engaging learning environments (Dede, 2009). For instance, the University of Illinois implemented VR in medical training, allowing students to practice surgical procedures in a risk-free setting (Johnston, 2022). Similarly, in Japan, AR has been incorporated into classrooms to teach complex subjects like chemistry, where students can visualize molecular structures in 3D (Tanaka et al., 2021). Europe is also at the forefront, with institutions like the University of Copenhagen using MR to teach history by recreating ancient civilizations, providing students with a tangible connection to the past (Berglund, 2023).

The appeal for immersive technologies appears to be very urgent in tertiary fields where experiential learning is key for developing specific skills (Jantjies et al., 2018; LeBlanc, 2004). In medically related fields such as dentistry where pre-clinical training is required, immersive technology has become very useful substitutes for real life scenarios with real human beings (Jantjies et al., 2018; LeBlanc, 2004). Jantjies and others (2018) cite immersive technologies applications such as DentSim, virtual dental patient and Virtual Reality Dental Training System are some of the myriad applications that have been useful in supporting dentistry education. Immersive technologies provide much-needed access to practice sessions, provide prompt feedback and offer quick assessment of the skills acquired by students (Duta et al., 2011; Jantjies et al., 2018).

Studies on the application of immersive technologies in education and training have not been evenly balanced among the different types of technologies. Virtual reality and augmented reality appear to gain more attention from academics (Abad-Segura et al., 2020; López et al., 2019). Research on immersive technologies has focused on different levels of education, ranging from applications in higher education (Abad-Segura et al., 2020), with a few focusing on the application of these technologies in high school and elementary education (Billinghurst & Duenser, 2012). There is also a disproportionate number of studies that are

reviews, with only a few being empirical studies on the application of IMT in education and training (Liu et al., 2020; Mazzuco et al., 2022).

The application of immersive technologies appears to confirm the digital divide, with countries boasting high Gross National products (GDP) such as The United States, Japan, the United Kingdom and China, among others, leading the field of research and application (UNESCO, 2019). Despite the global advancements in immersive technologies, their adoption in African education systems remains limited. Several factors contribute to this lag, including inadequate infrastructure, limited funding, and a lack of trained personnel (Oke & Fernandes, 2020). Additionally, there is a scarcity of localized research addressing the specific needs and contexts of African education systems, leading to a significant knowledge gap.

While immersive reality technologies offer transformative potential for education, it is imperative to design learning environments that are both logical and interactive to maximize their benefits (Christopoulos et al., 2018; Meyer et al., 2019). Poorly conceived integration of these technologies can create confusion rather than clarity, leading to cognitive overload and diverting attention from the core learning objectives (Christopoulos et al., 2018; Meyer et al., 2019). Without careful planning and pedagogical alignment, the promise of immersive experiences may fall short, undermining the very educational outcomes they aim to enhance (Makransky et al., 2019b). Thus, the adoption of immersive reality should be guided by sound teaching practices and strategic decision-making to ensure that technology serves as a meaningful complement to the curriculum rather than a distraction from it. Rigorous instructional design and thoughtful alignment with learning goals remain essential to harnessing the full potential of immersive technologies in education (Christopoulos et al., 2018; Meyer et al., 2019).

Research on the application of Immersive Technology in Education in Africa

Research in African institutions lag the rest of the world on different parameters such as quality, funding, publication outputs among other factors (Asubiaro, 2019; Dao et al., 2022). Although there have been improvements in some parameters that measure development, Africa still lags in education technological research (Dao et al, 2022). It is plausible that such research may not be a top priority on a continent that is often plagued with other challenges. Government policy formulation and implementation, and lack of resources have been cited as some of the challenges (Arvanitis et al, 2022). According to Asubiaro (2019) only a few (4.43%) of all African studies are funded. Comparison with other regions is difficult because such data is not easy to verify. But it can easily be inferred that African countries lag countries such as the United States where government contributes about 22% of research expenditure while the business sector contributes about 70% of all research expenditure (Asubiaro (2019).

While limited fundings results in fewer opportunities to conduct research in Africa, high quality African journals are similarly limited. Asubiaro (2019) reports

that only 8.16% of African research outputs are published in Africa. African academics prefer publishing in Europe or in the Northern American in search for highly rated journals that may increase the visibility of their research products. Furthermore, collaborations among African academics were weak (Asubiaro, 2019). African academics prefer collaborating with European and north American researchers as this enhances their visibility. Asubiaro (2019) recommends the provision of funding for intra Africa collaborations targeted at research projects that solve African problems. Of greater concern is a conclusion reached by Glänzel (2001) that African research production is insignificant on the global stage.

On the other hand, in Africa, where educational systems face unique challenges such as limited resources, overcrowded classrooms, and a lack of access to quality teaching materials, immersive technologies present opportunities for enhancing teaching, learning and training outcomes (Calvet et al., 2019). The cost of setting up a learning environment using immersive technologies has been cited as one of the most prohibitive factors in the implementation of the technologies (Jantjies, Moodley & Maart, 2018). In the same study, Jantjies and others (2018) quoted the cost of one headgear at 3000 Unites States dollars. On a continent where education systems are grappling with the provision of even the most basic requirements, such costs may be beyond most institutions or schools.

Despite the above challenges, immersive technologies offer promising potential in African education systems (Calvet et al., 2019; Mbonye & Ebrahim, 2022; Sakpere et al., 2023). Kenya has seen the introduction of VR in vocational training, helping students gain hands-on experience in fields such as automotive repair and electrical installations (Mwangi & Wambugu, 2021). These technologies not only bridge the gap in resources but also offer interactive and engaging ways to learn. South Africa, with the highest GDP on the continent, seem to be leading in making inroads in the adoption of immersive technologies. Several universities have experimented with the use of immersive reality of in engineering education and medical education, allowing students to visualize and interact with complex machinery and systems in a virtual space (Kruger et al., 2022). Exploring students' perceptions on the use of VR in large South African classroom, Hill and du Preez (2021) concluded that students perceived the application of VR positively. They however cite challenges such as technological failures and exclusion issues as students with optical disabilities found it difficult to see the videos. In a continent where field trips may be too expensive for many students, immersive reality offers opportunities, possibilities and alternatives for better quality education.

Some studies have focused on the application of immersive technologies in elementary education and secondary education (Jantjies et al., 2018). In primary and secondary education, initiatives like the Virtual Reality Schools Project have been introduced, enabling students in rural areas to explore virtual field trips and simulations that would otherwise be inaccessible (Dlamini, 2023). Thus, in a country with one of the highest Gini coefficients of disparity index, IMRT have the potential to democratize education and provide equitable learning opportunities across diverse socioeconomic backgrounds. However, present

literature suggests that more research in this technology seem to be more concentrated in training and experiential learning in tertiary institutions than in secondary and primary schools.

The existing literature on immersive technologies in African education reveals several gaps. Firstly, there is a lack of large-scale, empirical studies that provide a comprehensive analysis of the effectiveness and impact of these technologies in African contexts. Secondly, there is limited research on the integration of immersive technologies into the broader educational ecosystem in Africa. While some studies have explored their use in specific subjects or educational levels, there is a need for research that examines their potential across different disciplines and educational stages (Chigona, 2021). Thirdly, there is a dearth of studies that shed light on important aspects of research around immersive technology education in Africa. For example, what topics are African academics mostly researching in IMRT? In an increasingly shrinking global space, collaborations among academics have become more indispensable. There is little research that has focused on unpacking collaboration patterns among African academics within Africa or their collaborations with other academics from other parts of the world. Understanding these factors is crucial for developing strategies that can effectively address the unique challenges faced by African education systems (UNESCO, 2019).

To address these gaps, a bibliometric analysis can provide valuable insights into the research landscape of immersive technologies in African education. Bibliometrics involves the statistical analysis of written publications, allowing researchers to quantitatively assess the impact of research outputs, identify trends, and uncover gaps in the existing literature (Ninkov et al., 2022). By analysing publication patterns, research collaborations, thematic trends, and identifying underexplored areas, bibliometric analysis can inform future research directions, guide policy decisions, and ultimately harness the full potential of immersive technologies to address educational challenges in Africa.

3. Methodology

This study uses bibliometrics as a technique. The bibliometric technique is a quantitative method used to analyse academic literature and research outputs (Phoobane et al., 2022). Bibliometrics is a robust quantitative method for comprehensively synthesizing and identifying patterns in a large corpus of academic publications and their associated metadata (Ninkov et al., 2022). It involves extracting and analysing data from scientific publications, including articles, books, and conference proceedings. In the age of "Big Data", where research outputs have increased almost exponentially, traditional methods of making sense of these large volumes of data have become limited, bibliometrics has become a very powerful research technique to understand research fields dynamics ((Marginson, 2022).

For this bibliometric analysis study, a Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) was used in the way it has been applied in

previous studies (Zabidin, Belayutham, & Ibrahim, 2019). PRISMA is designed to assist researchers improve the transparency and quality of their systematic reviews by providing a structured approach to presenting their methods and findings. The approach involves four stages: identification, screening, eligibility and inclusion. Table 1, below, summarises these four stages.

Table 1: The four stages of PRISMA (extracted from Phoobane, Masinde & Mabhaudhi, 2022).

Stage	What the stage entails
Identification	This stage involves identifying and retrieving relevant studies from various sources, like databases, journals, and conferences. In bibliometrics, it often includes keyword searches, citation tracking, and database-specific filters to gather studies that fit the scope of the review.
Screening	During screening, duplicate records are removed, and a preliminary assessment of each study is done based on its title and abstract to filter out those that do not meet the inclusion criteria. This stage refines the dataset by discarding studies outside the scope of the research question.
Eligibility	This stage requires a more in-depth evaluation of the remaining studies by reviewing the full text to confirm they meet all criteria set out in the review protocol. Studies are assessed on relevance, quality, and alignment with the bibliometric objectives.
Inclusion	In the final stage, eligible studies are included in the systematic review. Data are extracted and analysed, using vosViewer, to assess trends, co-authorship networks, citation analysis, and other relevant metrics.

With the research questions in mind, the following search string run by Title, abstract and author Key words was conducted in the Scopus database. Scopus is one of the most widely used and reputable databases for bibliometric analysis due to its extensive features and advantages (Phoobane et al., 2022).

TITLE-ABS-KEY (("immersive reality" OR "immersive technolog*" OR "augmented reality" OR "Virtual reality" OR "mixed reality" OR “360-Degree Video technology” OR “extended reality”) AND (education OR teach* OR learn* OR curricul* OR school OR training OR university OR College OR class*))

This generated a global list of 19 634 publications. Using country affiliations, publications that did not include any African academics were removed. This

resulted in 5886 documents by academics from African affiliations and their collaborators. For example, an article that was co-authored by a researcher from an African Affiliation and an academic from an institution outside Africa was included in the final dataset. These documents were further screened for relevance. Duplicates were also removed. The result was a dataset of 305 documents. The dataset was exported and saved as a comma separated values excel file.

vosViewer Analysis

The dataset was further analysed using VosViewer, a software for constructing and visualizing bibliometric networks, mapping relationships in publication data like citation, co-authorship, and keyword co-occurrence. It displays items (e.g., authors, keywords) as nodes, where node size reflects item prominence, and lines (or edges) show connections, with thicker lines indicating stronger relationships. Clustering techniques in vosViewer group related nodes into colour-coded clusters, making it easy to identify major themes, trends, and networks in a field. The vosViewer used the main analytical tools in the software such as cooccurrence, citations against units of analysis such as author, sources, and country to generate visualization maps of analysis.

4. Research Findings and Discussions

Below the results are presented and discussed. Firstly, the descriptive analysis focusing on Annual publication trends, publication by field, research outputs by affiliations, outputs by country are discussed. The results from vosViewer analysis on focusing on author keywords cooccurrence, co-author collaborations between countries, most cited authors and most cited sources are then discussed.

Annual publication Trends

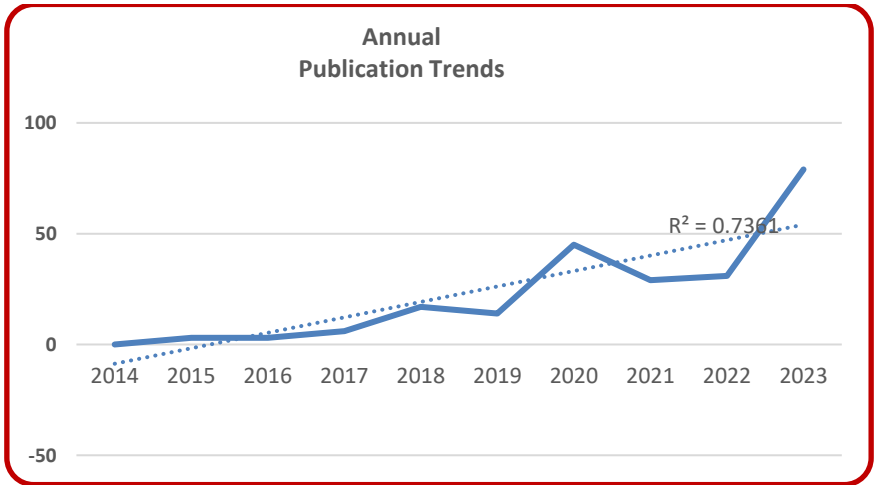


Figure 1: Annual publication trends

Annual publication trends show the change quantities of publication over time. Figure 1 below shows the annual publication trends from 2014 to 2023.

A total of 305 relevant publications were identified between 2014 and 2023. The results show a steady increase in the number of relevant publications, with the linear trendline $R^2 = 0.7361$. These findings concur with findings by Zamorano et al. (2023) in a bibliometrics study that focused on virtual and augmented reality and physical activity. In the present study publications rose from zero (0) in 2014 to eighty publications in 2023. Using a SCOPUS data in a bibliometric study to investigate the use of IMRT in health professional education, Li (2024) discovered a similarly significant surge in research outputs between 2015 and 2023. Furthermore, these results show similar trends to those obtained by Talan (2021) who used bibliometrics analysis on a Web of Science dataset to investigate trends in STEM publications. This general trend is expected to continue. The general increase in publications could be explained by two factors. Firstly, there has been a general increase in academic outputs as part of the "big data" phenomenon. Secondly, the emergence of more affordable gadgets on the market may have enhanced access to immersive technologies in education related fields.

Publications by type

This study also investigated the platforms through which the academic research on immersive reality applications in education and training was being disseminated. Figure 2 below, shows the publication types.

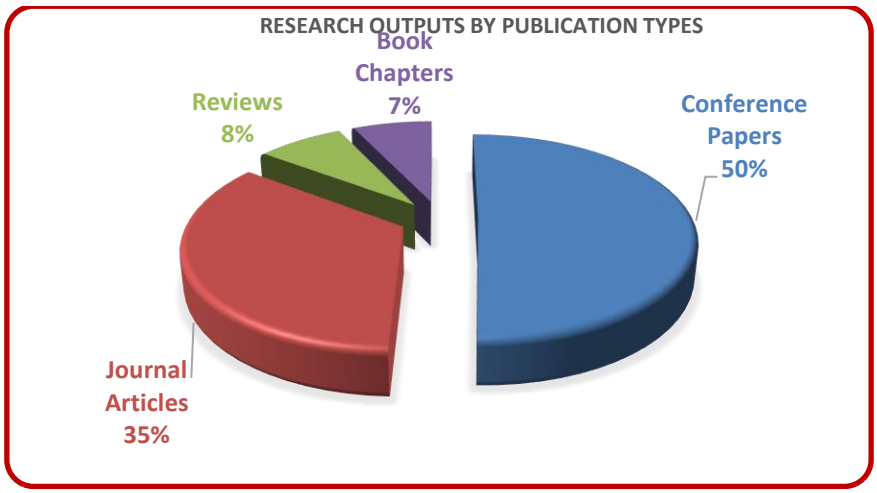


Figure 2: Publication by Type

Almost half of the publication outputs (50%) were published as conference proceedings. Research articles constituted more than a third (35%) of the publications. Reviews and Book chapters constituted significant portions of the types of publications (8% and 7% respectively). A study by Phoobane et al. (2022) mirrors similar distribution of publication outputs by types. The relatively high number of conference proceedings could hint at a trend of African academics engaging in discourse on research around the application of immersive reality technologies in education and training.

Research Products by Affiliations

Part of the the descriptive analysis focused on how the research products were distributed amoung African affiliations. Figure 3 below, shows the distribution amoung the top ten Affiliations with the most outputs.

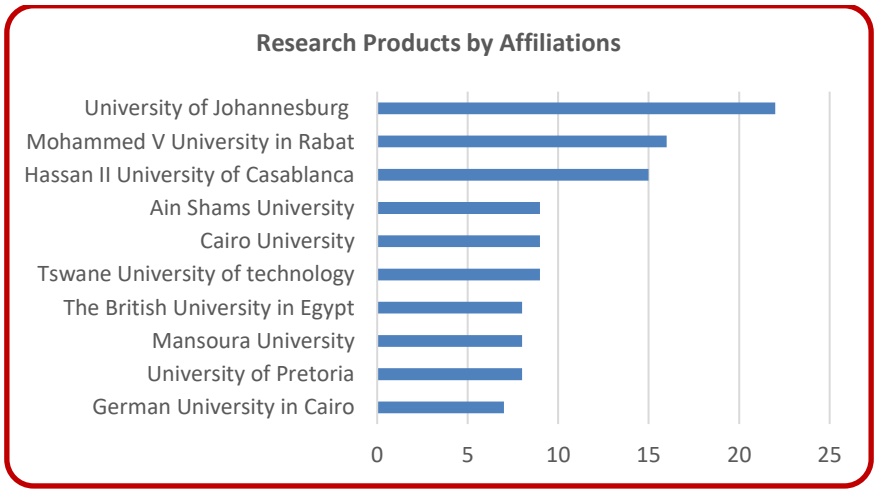


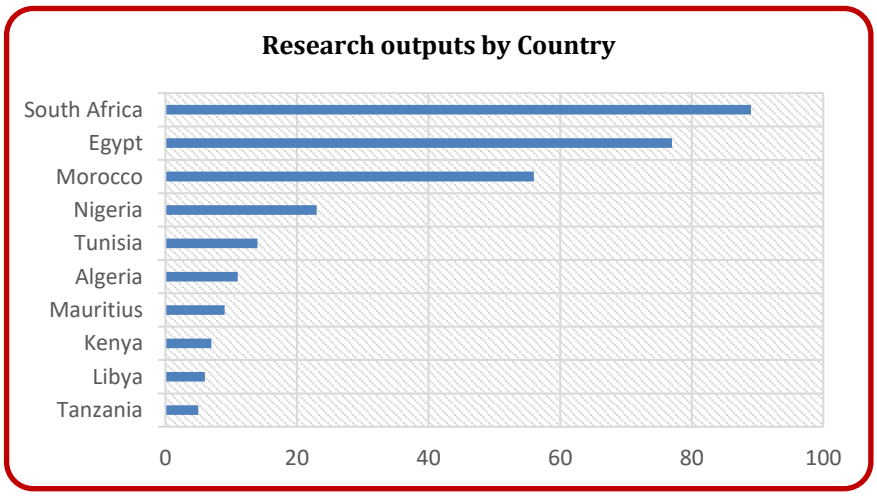
Figure 3: Research outputs by affiliations

The list of the ten most productive affiliations consisted of affiliations from 3 countries only: Egypt (4), South Africa (3) and Morocco (3). With 22 publications between 2014 and 2023, the University of Johannesburg had the most research products on immersive reality applications in education. Tshwane University of Technology ranked sixth, and the University of Pretoria (ranked ninth) were two other South African universities in the top ten. Egyptian affiliations dominated the top ten list of the affiliations with most research products. As similarly observed in distribution by country, the distribution by Affiliations also revealed disparities among African affiliations. For example, although South Africa contributed a significant portion of the outputs as a country, these contributions are only from a few of its universities, with the majority registering no publications. The results in this study differ from those obtained by Sivankalai and Yemane (2017). In their study on African research outputs on management their findings placed five South African institutions in the top ten, with no Egyptian or Moroccan institutions in the top ten most productive institutions. The South Africa system is known for incentivising research production in its universities and that may be one reason outputs in its institutions are high.

Research Products by country

Part of the descriptive analysis focused on how research products were distributed amoung African countries. Figure 4 below, shows the distribution amoung the top ten countries.

Figure 2: Research outputs by country



South Africa, Egypt and Morocco lead among countries with most outputs. These results are almost similar to findings obtained by Mouton and Blanckenberg ((2018) in a study on African publications in science. Together, these three countries countributed almost three quarters of all publications on the subject in Africa. Mouton & Blanckenberg (2018) concluded that countries that published the highest numbers of research outputs were South Africa, Egypt, Tunisia and Nigeria. With 53 three countries on the continent, only half of these (26) had at least one publication. Thus, half the countries in Africa did not contribute any research outputs on immersive technologies in education between 2014 to 2023. These disparities have been linked to Gross National products, with some countries like Chad, South Sudan and Djiboti with no research outputs and having the some of the lowest GDP on the planet. This emphases persistent disparities on the African continent. Besides their high GDP, countries with high research outputs seem to support research through adequate policy formulation and implementation (Phoobane et al., 2022). For example, South african through the Department of Higher Education and Technology (DHET) provides incentives to its institutions and academics for each research article published in reommended journals (Harley, 2016). Further research may be conducted to determine what policy formulation and implimentenation work best for Africa.

Author Keywords

Author keywords are a vital component in bibliometrics, enabling the analysis and mapping of research landscapes, trends, and patterns. Figure 5 below shows the Vosviewer visualization map of author keywords.

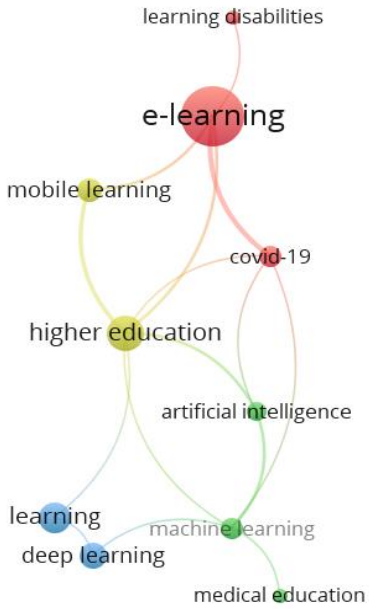


Figure 5: vosViewer Author Keyword Map Visualisation

After removing and disregarding words such as "education", "virtual reality", "mixed reality", "augmented reality", and "immersive reality", the generated map showed "higher education" and "e-learning" appearing more frequently than other words**.** Appearance of terms such as "learning disabilities" were unexpected, hence interesting. A closer look at publications that had these terms as keywords revealed that immersive technologies were being used to address issues of inclusivity on the content. The appearance of "medical education" suggests that the medical field has been one of the fields that has led innovations in the applications of immersive technologies. Further scrutiny of publications revealed disparities in the application of technology in teaching and learning. The appearance of "higher education" (and the absence of keywords such as "high school") suggests that there are more applications of immersive technologies in African tertiary institutions such as universities than in elementary schools. This is of concern because the powers of IMRT could benefit African students in high schools and primary schools especially in the sciences, where safety issues and lack of science apparatus have been reported. "E-learning" and "Covid" were some of the most often appearing words, pointing to the impact that the pandemic had in terms of the application of technological tools, as institutions used online and blended platforms to reach students during lockdowns (Turan & Karabey, 2023). The appearance of "artificial intelligence" among the most common words seems to have increased in outputs published after 2022. This may be linked to the emergence of generative artificial intelligence tools such a ChatGPT. Future research may focus on how generative artificial intelligence tools may be coupled

with immersive technologies to create more engaging environments in education.

Co-author collaborations in Immersive technology education and research

Collaborations are critical in advancing research in a field (Phoobane, Masinde & Mabhaudhi, 2022). Collaboration patterns may reveal important partnerships and may unpack levels of visibility of research outputs. This analysis sought to identify collaboration patterns of African academics amongst themselves, and their collaborations with other academics outside Africa. Figure 6 below shows the co-author collaboration VosViewer visualization map between counties.

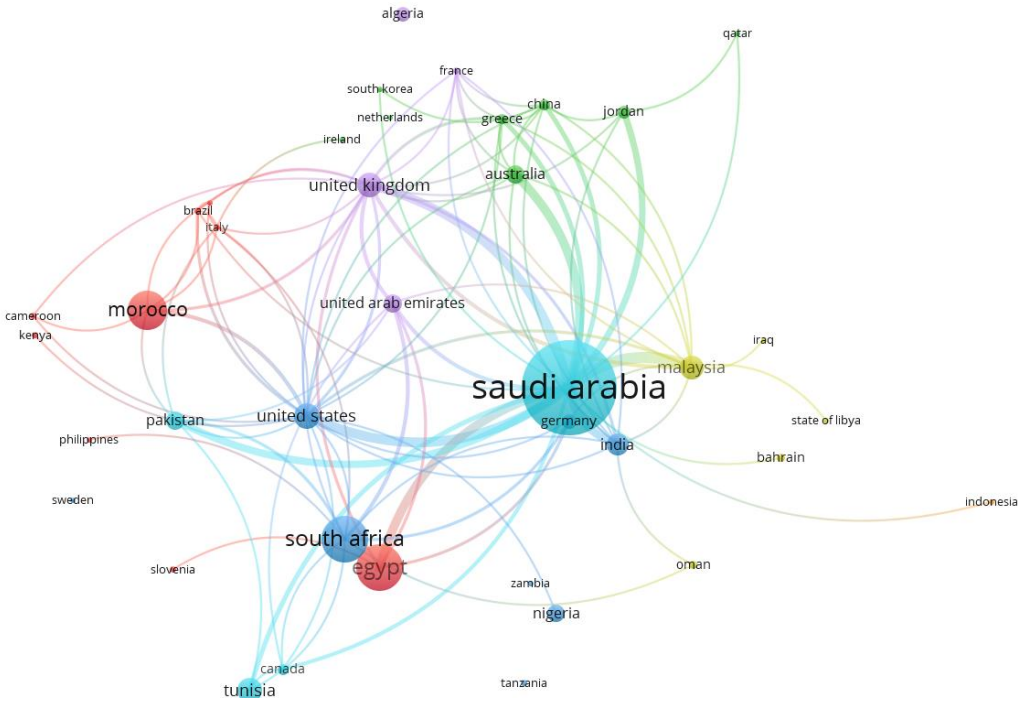


Figure 6: Co-author collaborations

The VosViewer visualization map revealed four major collaboration hubs on the application of immersive reality publications in African institutions. The largest collaboration hub was around institutions in Saudi Arabia. Thus, many academics were collaborating with researchers in Saudi Arabia. This was surprising because African academics have been reported to prefer collaborations with North American and European academics (Asubiaro, (2019). Collaboration hubs around Egypt and South Africa indicated collaboration of these countries with the United States, Asian and other African countries. Overall, the visualization maps suggest more collaboration South-North collaborations than South–South collaborations. Previous research has suggested that many African academics prefer collaborations with western or Asian academics because these collaborations enhance their visibility. Furthermore, for African academics such South-North collaborations enhance the publication of their research outputs in high impact journals (Asubiaro, 2019). These results slightly study differ from those of a study by Confraria and Godinho (2015) who linked collaboration patterns to colonial legacies by observing that former French colonies such as Morrocco and Tunisia

collaborated more with France while former British colonies collaborated more with the United States and the United Kingdom.

Most cited sources

Analysing most cited authors in a dataset on a subject may reveal influential works, research trends, interdisciplinary connections, research gaps and opportunities around the subject. Table 2 below shows a list of the most cited sources from this dataset.

Table 2: Most cited sources on Immersive technologies and education in Africa

	Source	Number of documents	Number of citation	Link strength	Q
1	ACM international conference proceeding series	12	64	1	Na
2	advances in intelligent systems and computing	3	7	0	Na
3	applied sciences (Switzerland)	3	136	4	Q2
4	education and information technologies	8	82	3	Q1
5	electronics (Switzerland)	3	55	0	Q2
6	IEEE access	3	790	0	Q1
7	information sciences letters	6	1	3	Na
8	interactive learning environments	4	78	5	Q1
9	international journal of emerging technologies in learning	3	375	8	N/a
10	international journal of information and education technology	3	2	1	Q3
11	lecture notes in computer science (including subseries lecture notes in artificial intelligence and lecture notes in bioinformatics)	4	14	0	Q2
12	lecture notes in networks and systems	9	18	2	Q4
13	studies in computational intelligence	3	5	0	Q4
14	sustainability (Switzerland)	5	88	1	Q1
15	world neurosurgery	3	2	0	Q2

Of the top 15 sources only four (4) had no quartile status with the rest having quartile status. This suggests that African affiliations publishing on immersive reality and education research were conducting high quality research and publishing in high journals. The Association for Computing Machinery (ACM) international conference proceeding series had twelve documents, which had been cited for a total of 64 times in the data set. The United States based ACM is one of the world's largest computing societies and brings together researchers in computer related fields. The ACM conference series has not been assigned Quartile status. However, the participation and publication through ACM proceedings suggests that academics from African institutions are participating in the discourse of the application of immersive technology in education.

Most cited authors

Co-author citation analysis reveal interesting aspects such as the most influential academics in a field and may suggest "hotspots" in a field. In this analysis, the author also sought to shed light on which academics were most cited by African researchers on IMT application in education, and hence unpack which authors were most influential in Africa in the research field. The table 3 below shows the most cited authors on immersive reality and education from Africa.

Table 3: Authors most cited by African academics

Author	Number of citations	Link strength	Country
Billinghurst, M.	**68**	**149**	New Zealand
Dede, C.	**47**	**187**	United States
Wang, X.	**39**	**132**	China
Dunleavy, M.	**35**	**150**	United States
Yilmaz, R.M.	**34**	**105**	Turkey
Baldiris, S.	**31**	**90**	Colombia
Wang, J.	**31**	**79**	China
Azuma, R.	**30**	**82**	United States
Wang, Y.	**30**	**82**	China
Hwang, G.-J.	**29**	**76**	Taiwan
Radu, I.	**29**	**80**	United States
Mitchell R	**28**	**150**	United States

From a total of 19138 authors who were cited, 12 met the set criteria of having at least 28 citations. The most cited author analysis provides hints on who could be the most influential researchers in a field. Furthermore, by analysing the most cited academic works, a bibliometric study may also provide "hotspots" or areas of interest in a field.

The most cited author with 68 citations is Billinghurst, M. who is affiliated with the University of South Australia in Auckland, New Zealand (at the time of writing), and has published more than 30 articles on immersive reality, mostly augmented reality. Billinghurst's academic research has been instrumental in shaping the development and application of immersive reality technologies, impacting both academic research and practical implementations across various industries, including education. Billinghurst's research in immersive reality application in education has focused on making complex concepts easier to learn through visualisation and has contributed to making learning more effective and more inclusive (Billinghurst, 2002). Furthermore, Billinghurst has also conducted research focusing on making learning more interactive and more engaging.

With 47 citations, Chris Dede, a professor at Harvard University Graduate School of Education, was the second most cited and has published on immersive learning environments and the impact these immersive technologies have had on

curricula. Their research explores how immersive technologies can create rich, engaging learning experiences that cater to diverse learners. None of the most cited authors are affiliated with African institutions.

Of the top 12 most cited authors, almost half (5) are from the United States, and two are from China. While citing mostly academics from the more development world may be regarded as something positive because it points that African academics are drawing from world renowned academics, it also raises concerns. Academics from African institutions seem to cite these renowned academics more than they cite their peers from other affiliated African institutions. This bias in citation through regions may not be surprising considering the discrepancy in development between African and other regions such as North America and Europe.

Research Funding on IMRT education research in Africa

Previous studies have identified the lack of research funding as a big challenge in African institutions (Asubiaro, 2019). Figure seven below summarises the top funding agencies for the dataset under study.

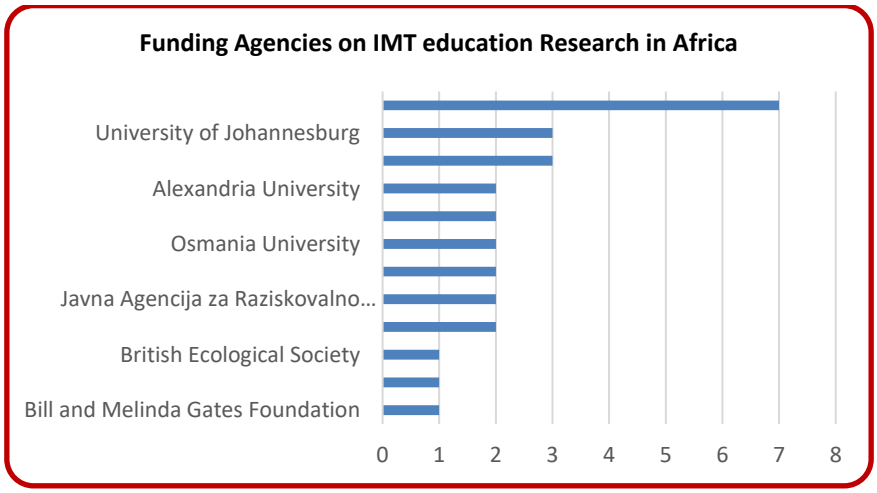


Figure 7: Top Research funding organisation on IMT education research in Africa

From the 305 publications that formed the dataset used for this study, the National Research Fund, a United States government agency, sponsored the highest number of publications, having funded seven (7) research outputs. The Wellcome Trust, the European Commission, the British Ecological Society, the Bill and Melinda Gates foundation and the British Council are all funding organisations from outside Africa. From this dataset it can be inferred that a relatively large portion of funding in African research is from outside Africa. These results seem to echo Arvanitis et al. (2022, p. 364) who concluded that "…African research relies heavily on foreign funding coming from a large variety of funders, each with their own agendas and objectives…".

5. Limitations of the Study

This bibliometrics study was conducted using a dataset extracted from Scopus which limits the findings as some research outputs on IMRT applications in education and may not be part of the Scopus database. The study could have been strengthened by merging the Scopus dataset with other data extracted from other databases such as Web of Science.

6. Conclusions

There was a steady linear increase in publications on education-related research on immersive technologies in African institutions between 2014 and 2023. However, these publications are not evenly distributed on the continent. Institutions in South Africa, Morrocco and Egypt dominate in these contributions. Some African countries such as Chad did not contribute any research publications on IMRT application in education. This implies a large digital divide even among African countries. Researchers from African institutions collaborated more with academics from outside African than amongst fellow academics from fellow African institutions. Furthermore, publications from African institutions seem to cite European, North American and Asian authors. The most cited academics were mostly from Europe, North America and China. Furthermore, the results revealed a significant amount of funding from external organisations. This may suggest that there is reduced discourse among African academics to resolve African challenges as opposed to engage to agendas generated from outside the content. It is not clear whether external funding agencies will advocate for research agendas that puts Africa's interest first. The appearance of keywords such as "artificial intelligence" and "learning disabilities" may suggest new "hotspots" in research around IMRT and education. The author key word analysis suggests that artificial intelligence tools may couple with IMRT to create more enhanced teaching and learning environments. Research may also be focusing on using IMRT to enhance learning in students with learning disabilities. Limited research in the Application of IMRT in secondary and primary education is of concern as it may imply that Africa continues to lag other parts of the globe in the implementation personalised education. IMRT are expected to play a vital role in Education 5.0 which mostly emphasises the use of technology to promote personalised learning.

7. Future Directions

Future research could merge Scopus data with other databases such as Web of Science to provide a more complete research landscape as using single databases may exclude important research outputs. Strong policy formulation around funding and research partnership among African institutions is required or African education systems will always be playing catch up with the rest of the world. Future research could be directed towards addressing geographical imbalances and promoting research on IMRT in underrepresented countries and institutions. Research could also focus on understanding why intra-African collaborations are weaker than extra-African collaborations and finding ways to bridge this gap.

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