JOURNAL OF TECHNICAL EDUCATION AND TRAINING
ISSN: 2229-8932 e-ISSN: 2600-7932

JTET

Vol. 17 No. 3 (2025) 134-149
https://publisher.uthm.edu.my/ojs/index.php/jtet

Human-Metaverse Interaction in TVET: Research Trends and Future Directions

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DOI: https://doi.org/10.30880/jtet.2025.17.03.010

Article Info

Received: 25th March 2025
Accepted: 1st September 2025
Available online: 14th October 2025

Keywords

Human metaverse interaction, bibliometric analysis, virtual reality, augmented reality, emerging technologies, TVET

Abstract

Technical and Vocational Education and Training (TVET) is swiftly advancing to integrate digital and immersive technologies, equipping learners for prospective employment markets. The metaverse, a shared virtual environment facilitating real-time interactions between individuals and digital entities, is an emerging technology impacting TVET. As metaverse applications proliferate, they are anticipated to transform training techniques, skill acquisition, and workforce preparedness in Technical and Vocational Education and Training (TVET). A comprehensive analysis of prior studies on Human-Metaverse Interaction (HMI) is essential for grasping these implications. This study performs a bibliometric analysis of HMI, pinpointing essential topics, authors, publications, and trends within this domain. Primary bibliographic data is obtained from the Scopus database using keyword searches and quantitatively examined using bibliometric approaches in VOSviewer software. The analysis examines publication volume, thematic content, national connections, and keyword frequencies to delineate the intellectual framework of HMI research. Research findings reveal an increasing emphasis on virtual reality, augmented reality, and metaverse-related classifications, while highlighting deficiencies in domains like human-robot interaction and social virtual reality. This study offers significant insights for TVET educators and professionals, emphasizing how breakthroughs in HMI research might influence curriculum design, pedagogical approaches, and workforce readiness for a metaverse-oriented future.

1. Introduction

Technical and Vocational Education and Training (TVET) is experiencing a transition propelled by digitization, Industry 4.0, and upcoming technologies such as the metaverse. More than 67% of countries have synchronized their TVET policies with UNESCO's 2015 recommendations, highlighting equity, quality, and industry relevance. The integration of digital technologies, augmented reality (AR), virtual reality (VR), and metaverse environments is becoming vital for improving training experiences and workforce readiness (New UNESCO Report on TVET Recommendations to Improve Global Skills Development, n.d.).

Youth unemployment continues to be a substantial issue in Southeast Asia, mostly attributable to the disparity between the competencies of TVET graduates and the requirements of the business. Enhancing collaborations between TVET universities and industries is a crucial method to close this gap. Numerous institutions have formed cooperation, however their efficacy differs. Towip et al. (2021) performed research to assess these collaborations from the viewpoint of TVET institutions. The study examined 129 institutions, utilizing quantitative analysis through SPSS software and qualitative content analysis of open-ended responses. The results indicated that public-private partnerships have favorably impacted the development of workforce capabilities, especially in promoting demand-driven training, industry involvement in curriculum design, regulatory assistance, and a transition from short-term to long-term workforce planning. Nonetheless, obstacles remain in synchronizing training programs with the swiftly changing requirements of Industry 4.0.

With the swift progress of information and communication technologies (ICTs) in the 21st century, the significance of Technical and Vocational Education and Training (TVET) has become increasingly paramount. Siriwardene and Qureshi (2009) assert that TVET is a crucial catalyst for economic and social advancement, providing individuals with essential skills for employment and sustainable living. To maintain relevance, TVET must implement a paradigm shift, aligning with the evolving demands of the global workforce.

The emergence of Industry 4.0 has engendered transformative disruptions, especially in automation, artificial intelligence, and digitalization, reshaping the labor market and educational frameworks. Nonetheless, numerous ASEAN students continue to be ill-equipped for these transitions. Adnan et al. (2021) executed a qualitative study with ASEAN student leaders from polytechnics in Brunei, Indonesia, and Malaysia, employing online interviews and focus group discussions. The findings revealed a deficiency in students' knowledge of the competencies necessary for Industry 4.0, highlighting the pressing requirement for retraining and upskilling programs to prepare them for the post-Industry 4.0 landscape.

The progression of TVET research demonstrates its increasing amalgamation with technology and workforce development. Majid et al. (2022) performed a bibliometric analysis of 7,512 articles spanning from 1999 to 2021, delineating three distinct research phases: human capital development (1999–2006), technological transition in education (2007–2014), and vocational studies in higher education aimed at productivity enhancement (2015–2021). These developments underscore TVET's growing dependence on digital technology and the necessity for ongoing adaptation to evolving skill requirements.

With the emergence of the metaverse as a transformative entity, redefining education, workforce training, and digital engagement, the incorporation of Human-Metaverse engagement (HMI) into Technical and Vocational Education and Training (TVET) is essential. Comprehending the influence of HMI on skills training, identity, and privacy will facilitate the formulation of immersive, inclusive, and industry-relevant TVET regulations. Future research should concentrate on synchronizing metaverse-based learning environments with workforce requirements, guaranteeing that TVET continues to be a pivotal element in equipping students for the digital economy.

This study performs a bibliometric analysis of Human-Metaverse Interaction (HMI) to evaluate its significance in Technical and Vocational Education and Training (TVET). As the metaverse transforms education and workforce training, comprehending its effects on human interaction, cultural norms, and digital learning is essential. This research assists TVET institutions, enterprises, and policymakers in the responsible integration of immersive technologies by identifying essential ideas, trends, and deficiencies. By addressing issues such as identification, privacy, and digital engagement, it guarantees that metaverse adoption improves workforce training while upholding ethical standards. This study establishes a theoretical framework that integrates HMI with future-oriented vocational education, facilitating TVET's adaptation to the changing digital environment.

2. Theoretical Background

The metaverse, a term combining “meta,” meaning “beyond,” and “universe,” is a potential future interaction of the internet that allows users to enjoy immersive experiences through augmented reality, extended reality, and virtual realities. The metaverse project aims to develop a domain ontology (MetaOntology) that specifies the infrastructure and cutting-edge technologies relevant to the metaverse. This project adopts a four-step methodical approach to develop the ontology, but does not aim to provide a comprehensive overview of the domain.

As illustrated in Fig. 1, the phrase "virtual reality" refers to a method called "virtual reality," which uses a computer to simulate a virtual setting. A virtual reality experience is mostly made up of imagery, which may be seen on a computer screen or a 3D display device. Through the use of customary imported devices, users may interact with the virtual world (Phakamach et al., 2022).

Fig. 1 *Virtual reality. Source: Phakamach et al. (2022)*

Augmented reality, which brings digital elements and virtual characteristics into the actual world to make it better, takes a new approach to physical locations. As illustrated in Fig. 2, the real world and the virtual world are integrated geographically. The end product is a layer of spatially projected digital artefacts that are mediated by transparent surfaces such as smart phones, tablets, glasses, and contact lenses. AR can also be utilised in VR headsets that support pass-through mode by displaying data from integrated camera sensors (Mystakidis, 2022)

Fig. 2 *Augmented reality. Source: Phakamach et al. (2022)*

By building visuals that users can interact with in a setting that merges the real and virtual worlds, Mixed Reality (MR), as illustrated in Fig. 3 builds on the advantages of VR and AR technologies and advances them to the next level. By utilizing cutting-edge touch and image technology, MR enables hands-on interaction with a virtual environment while keeping the user's glasses on. This allows us to see and experience the world around us (Phakamach et al., 2022).

Fig. 3 *Mixed reality. Source: Phakamach et al. (2022)*

A collection of realistic technologies, including electronics, communications, and digital environments where information is presented and projected, is together referred to as extended reality (XR) or cross reality (XR). As illustrated in Fig. 4, VR, AR, and MR will all be combined to create XR technology. Humans view and participate in all or some of the synthetic digital world produced by these technologies in each of the XR's following components (Phakamach et al., 2022). The relevance of human-computer interaction (HCI) research in the creation of software, user interface toolkits, and the Internet was explored by Myers (1998). The research focuses on how advancements in interface technology have spurred the development of technology as a whole, and how universities and business research laboratories are working on creating user interfaces for the next generation of computers. In recent decades, the attention of researchers has shifted to the emotional aspect of user experience in mobile learning (Taharim et al., 2013; Taharim et al., 2015), website (Noor et al., 2008; Bidin and Lokman, 2018; Ismail and Lokman 2020), e-learning (Redzuan et al., 2011; Isa et al., 2015), video (Abd Kadir et al., 2021) and avatar (Lokman et al. 2014).

Fig. 4 *Extended reality or cross reality. Source: Phakamach et al. (2022)*

Society is becoming more digitally, cybernetically, and informationally connected, leading to the growth of the metaverse idea. Wang et al. (2021) discuss plans for the metaverse's development and propose a common system architecture and foundation for it. Feng et al. (2022) examined the metaverse's effects on social and economic theories and how they affect scholarly investigation.

Bibliometric analysis, a quantitative approach used to examine the significance of scientific publications, is a vital tool for identifying research trends, assessing the impact of research, and determining the future course of research for academics, institutions, and funding organizations. Donthu et al. (2021) discussed the value of bibliometric analysis for examining and analyzing scientific data, particularly in business research.

Bibliometric analysis is conducted using bibliometric software such as Gephi, Leximancer, and VOSviewer, which examines the social and structural connections among various research elements, such as authors, nations, institutions, and themes. VOSviewer is not only user-friendly but also capable of visualizing larger networks (Ahmi, 2022).

Several studies have examined the metaverse from a bibliometric perspective. Feng et al. (2022) conducted a bibliometric study of 183 metaverse-related research articles in the WoS core database since 2000, summarizing the characteristics, main topics, and rules of metaverse development in each stage. Verma et al. (2022) summarized the most important metaverse research using bibliometric analysis, addressing how technology develops economies, notably the industrial interest in metaverse technology.

Undale et al. (2023) stated that there is still more to learn about the metaverse, and more academics are becoming interested in it. They used bibliometric analysis to identify the top contributing authors, top nations, and top journals that publish research in the metaverse by analyzing 504 papers from the Scopus database published between 1977 and 2022.

Shenetal (2023) presented the findings of a 2012–2021 bibliometric investigation of academic metaverse research, focusing on VR, AR, and other immersive technologies. The study sought to discover metaverse research hotspots and frontiers, the most prolific nations, and their topic grouping and hotspot evolution.

According to Feng et al. (2022), university research advances more slowly than business research. Tlili et al. (2023) emphasized the need for more international collaboration to promote metaverse adoption internationally. Lukava et al. (2022) emphasized the necessity of more inclusive design principles for neurodiverse individuals when using XR technology, which can also be applied to the creation of the metaverse.

As Liu & Lu (2023) described, the metaverse reshaped education, creating new possibilities for teachers, students, and businesses. Its impact became especially clear during the pandemic, demonstrating how immersive, interactive, and hands-on learning enhanced education. Driven by real-world and industry demands, the metaverse helped Technical and Vocational Education and Training (TVET) evolve, modernizing teaching methods and better preparing students for the workforce. To fully harness these benefits, TVET institutions needed to integrate metaverse technology while addressing challenges like privacy concerns and digital addiction. This study explored these opportunities and risks, offering practical strategies for using the metaverse effectively in vocational education.

Despite numerous studies on the metaverse, there hasn't been a thorough bibliometric analysis of the field examining human interaction in the metaverse. The majority of current metaverse research is focused on computer software and applications, automation, and other scientific and technological fields.

3. The Methods

This section describes the methods used in the research implementation.

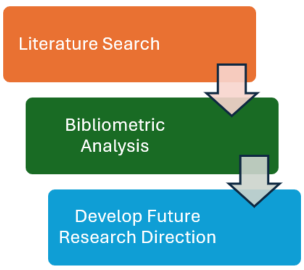


Fig. 5 *The research process*

The research process (refer Fig.5) began with an extensive search for relevant literature on January 10, 2024, resulting in 2,451 records that were included in the subsequent bibliometric study. Sample sizes were determined based on Rogers et al. (2020), who suggested that a sample size of less than 200 publications is considered a baseline for analytical robustness. Samples of 1,000 publications or more could give a reliable indication of relative citation performance at an institutional level, particularly when the research is led by high-performing individuals. The search strategy is as shown in Fig. 6.

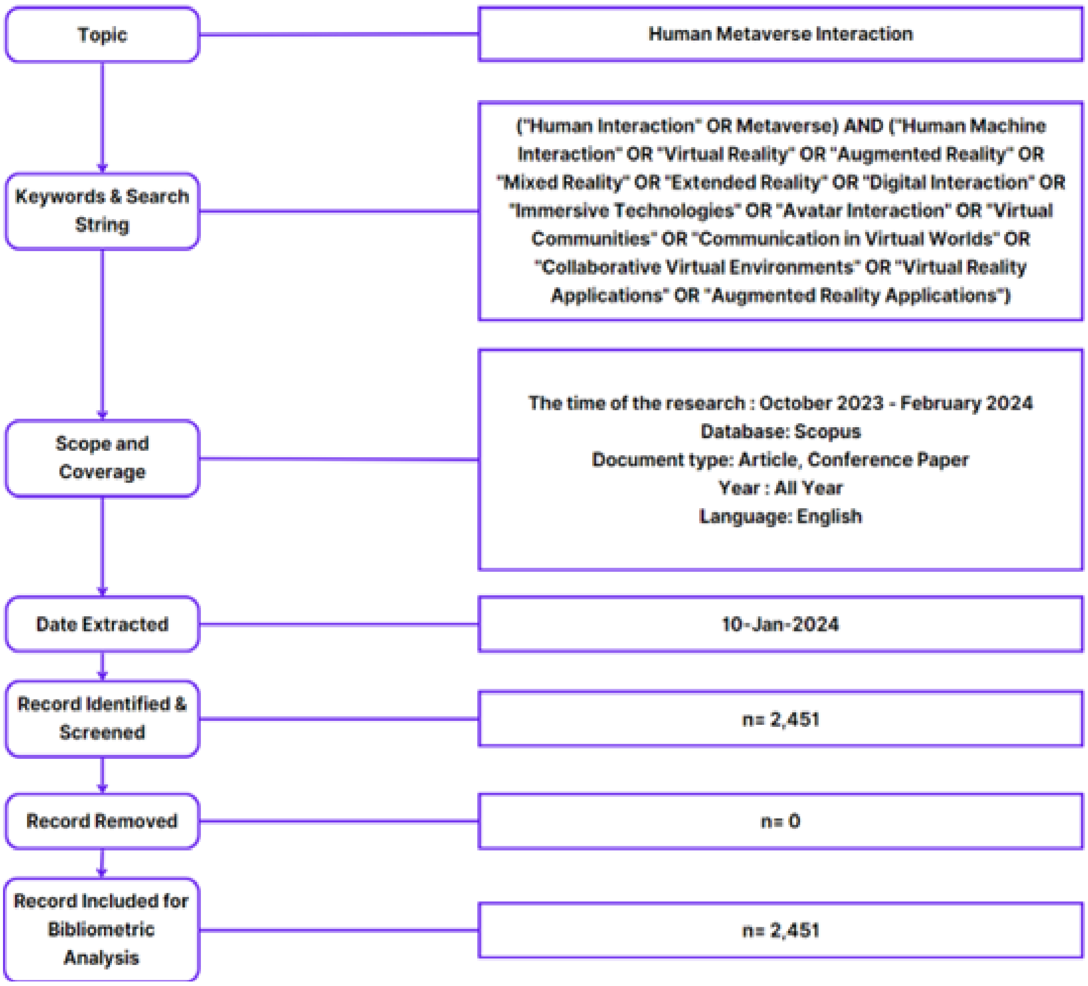


Fig. 6 *Search strategy on past literature*

The primary data was sourced from Scopus, a comprehensive search engine that covers approximately 84% of all journal titles. The secondary data was collected through a meticulous literature review and obtained from the university Online Database. Scopus was chosen as the primary data source due to its wide coverage and the availability of relevant research publications. The data collection method for this research involved keyword extraction, which was based on a prior literature review. Keywords related to human interaction and the metaverse were chosen to identify literature on this less studied aspect and to find literature on how the metaverse is being applied in industries like education and healthcare.

The bibliometric analysis procedure proposed by Donthu et al. (2021) was used to analyze the data, Step 2 shown in Fig 7. The VOS viewer software was used to conduct bibliometric analysis, which examines the social and structural connections among various elements of research, such as authors, nations, institutions, and themes. This method provides a concise summary of the bibliometric and intellectual structure of a field of study. This research focused on several variables: the number of publications, subject area, countries of origin, and frequency of keywords. The number of publications indicates the amount of scholarly output and research in this area, while the subject area covers the areas of study interest. Countries of origin indicate the countries represented in the papers, while keyword frequency indicates the emphasis and prevalence of specific themes within the field.

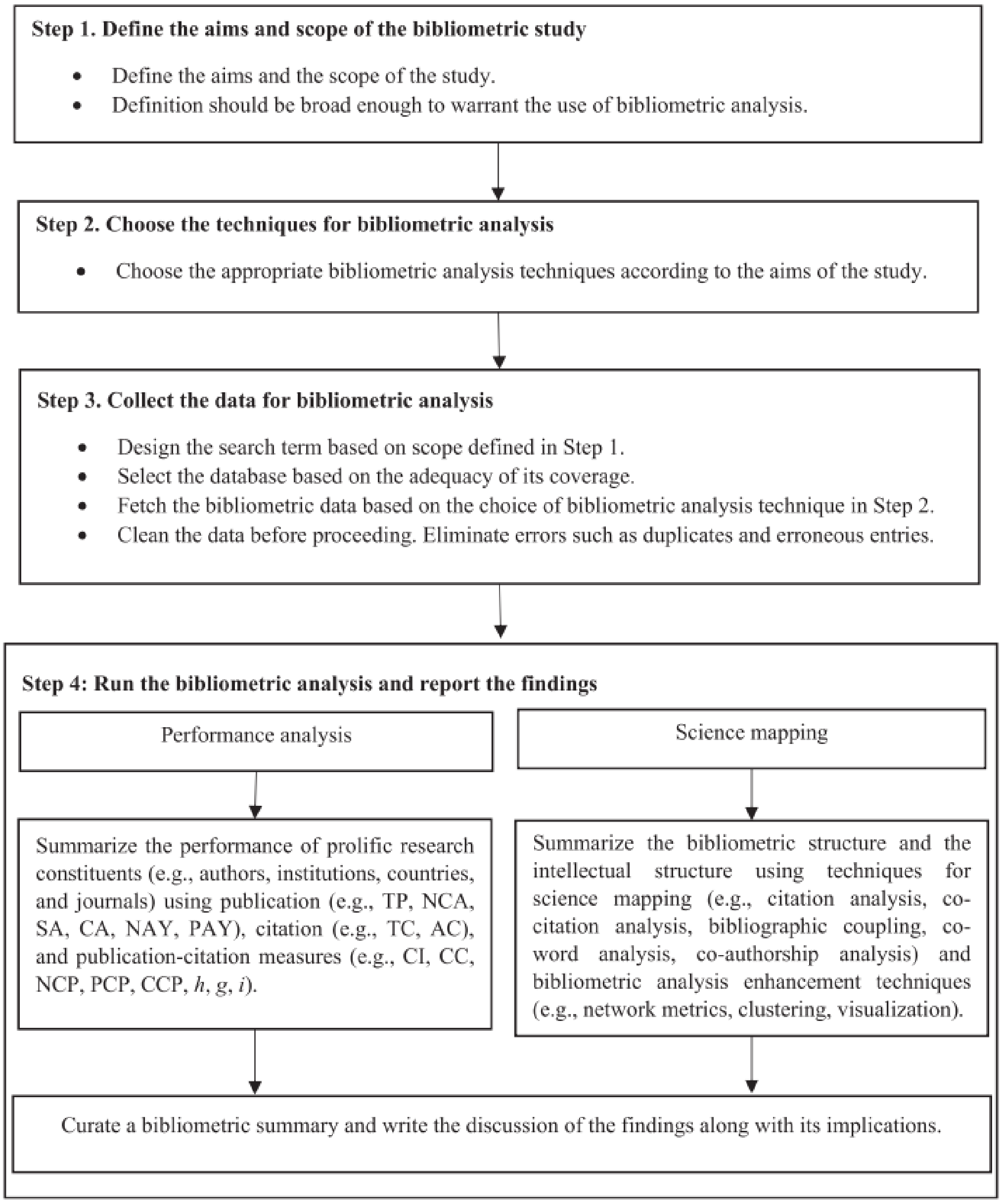


Fig. 7 *The bibliometric analysis procedure. Source: Donthu et al. (2021)*

4. Results and Discussion

This section describes the research results and discuss the findings.

4.1 Number of Publications

Table 1 shows the dataset under consideration spans from 1985 to 2024, encompassing a total of 2451 scholarly papers. These papers have collectively garnered 23996 citations over a period of 39 years, resulting in an average of 615.28 citations per year. On a per-paper basis, the average number of citations stands at 9.79. The dataset exhibits an average of 8712.32 citations per author and 963.26 papers per author. Additionally, each paper, on average, has 3.65 authors. The h-index, a measure of productivity and impact, is recorded at 68, signifying that at least 68 papers in the dataset have received a minimum of 68 citations each. The g-index, another productivity measure, is 108, indicating that the top 108 papers collectively received 11664 citations. The hI,norm, a normalized h-index per year, is 36, offering a per-year measure of impact.

Table 1 *Citation metrics*

Publication Year	1985–2024
Papers	2,451
Citations	23,996
Citations Years	39
Cites/Year	615.28
Cites/Paper	9.79
Cites/Author	8,712.32
Papers/Author	963.26
Authors/Paper	3.65
h-index	68
g-index	108
hI,norm	36
hI,annual	0.92
hA-index	35

The hI,annual, representing the annual increment of the h-index, is 0.92. Furthermore, the hA-index, an author-level h-index, is 35, suggesting that at least 35 papers by an author have each received a minimum of 35 citations.

The citation metrics show a reasonably high research impact and productivity over the 39-year period, with strong citation rates per paper and per author. The g-index and h-index values indicate that the top papers have had a particularly high citation impact. Overall, these metrics provide a quantitative overview of the influence and citation patterns of the scholarly output in the dataset.

Fig. 8 shows the total number of publications as well as the cumulative number of publications in a particular study topic from 1985 to 2024. The first few years (1985– 1999) see a slow rise in publications. But starting in 2000, there is a noticeable increase that peaks in 2004. Publications see a significant uptick between 2008 and 2011, with a peak in 2011. The number of publications is still comparatively high and consistent (although with some swings) from 2012 to 2019. There is a notable upsurge from 2020 to 2024, particularly in 2022 and 2023, when there are 551 and 972 publications, respectively. Interestingly, there is a notable spike in research production in 2023. Data for 2024 shows that there will be 41 more publications, for a total of 2451. The data indicates the research area has gone through distinct growth phases, with recent years showing accelerated expansion in scholarly publications and overall output.

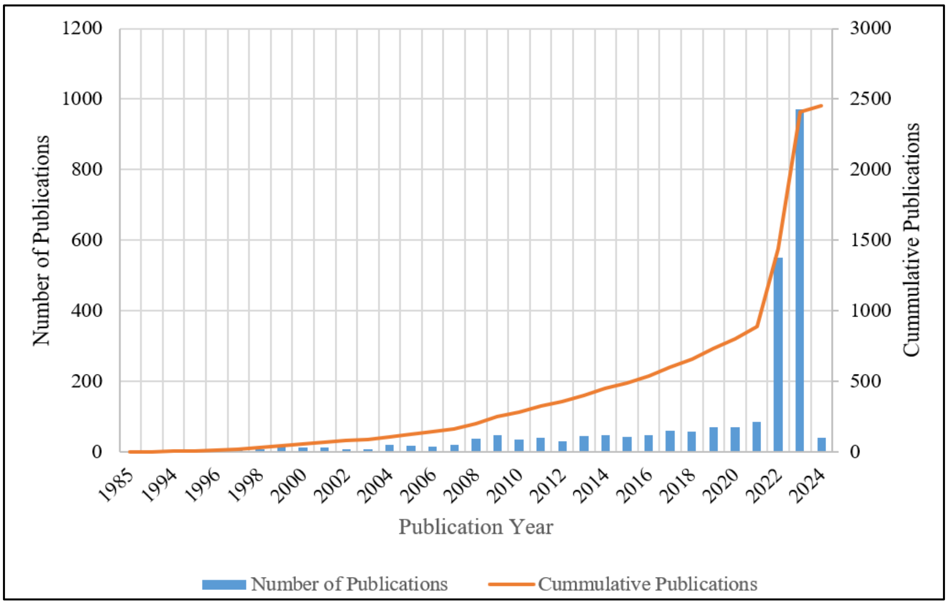


Fig. 8 *The number of publications on a year-on-year basis in the field of HMI*

4.2 Subject Area

As shown in Fig. 9, the dynamic landscape of human metaverse interaction reveals distinct roles played by various academic disciplines, with Computer Science taking the lead at 34.8%, followed by Engineering at 19.3%, emphasizing the technical foundations of this field. Social Sciences (9.2%) and Decision Sciences (5.3%) contribute significantly to understanding user behavior and decision-making processes within the metaverse. Mathematics (4.5%) and Medicine (3.7%) bring quantitative and health care perspectives, respectively.

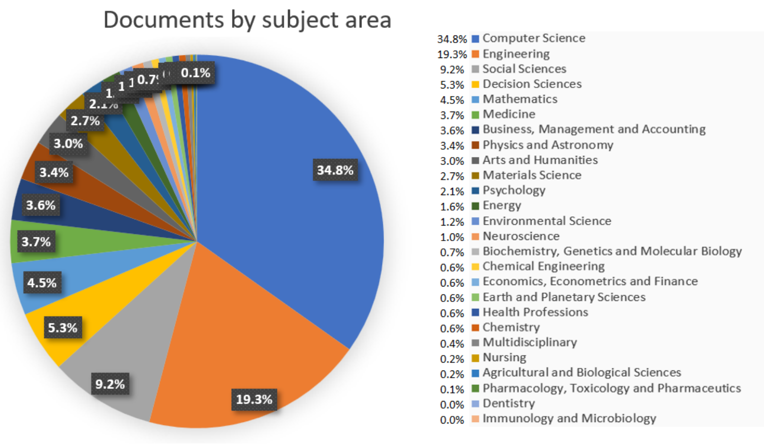


Fig. 9 *Document by subject area in the field of HMI*

4.3 Countries of Origin

Table 2 *Top 5 countries that published more than three documents in the field of HMI*

No	Country	Quantity	%	Citation	Average Citation per Document	Total Link Strength
1	United States	481	14.32	8334	17.33	805
2	China	368	10.95	3195	8.68	619
3	South Korea	183	5.45	2626	14.35	636
4	United Kingdom	175	5.21	3377	19.30	616
5	Germany	173	5.15	3074	17.77	204

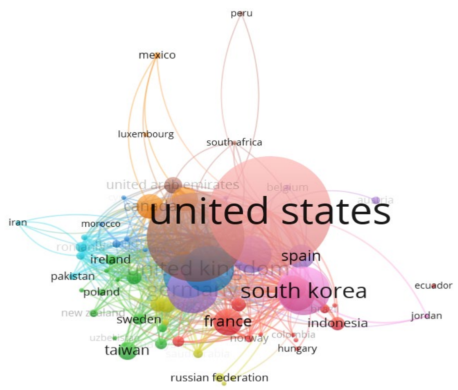


Table 2 presents a comprehensive overview of the top 5 countries that have made significant contributions to research on human metaverse interaction, each having published more than three documents. Topping the list is the United States, which has published 481 documents, constituting 14.32% of the total publications in the top 10. The research from the United States is notably impactful, receiving a substantial number of citations (8334) with an average of 17.33 citations per document. Collaborative efforts are evident, as indicated by a strong total link strength of 805. Following closely is China, with 368 publications (10.95% of the total) and a considerable number of citations (3195), averaging 8.68 citations per document. China also demonstrates collaborative strength with a total link strength of 619. South Korea, ranking third, has published 183 documents (5.45%), received 2626 citations, and exhibited a notable average citation per document of 14.35. The total link strength of 636 suggests a well-connected network of South Korean-authored documents. The table thus provides valuable insights into the research output, impact, and collaboration strengths of these leading countries in the specified field. The figure shows network visualization of the countries with the bubble size indicating publication size from highest to lowest.

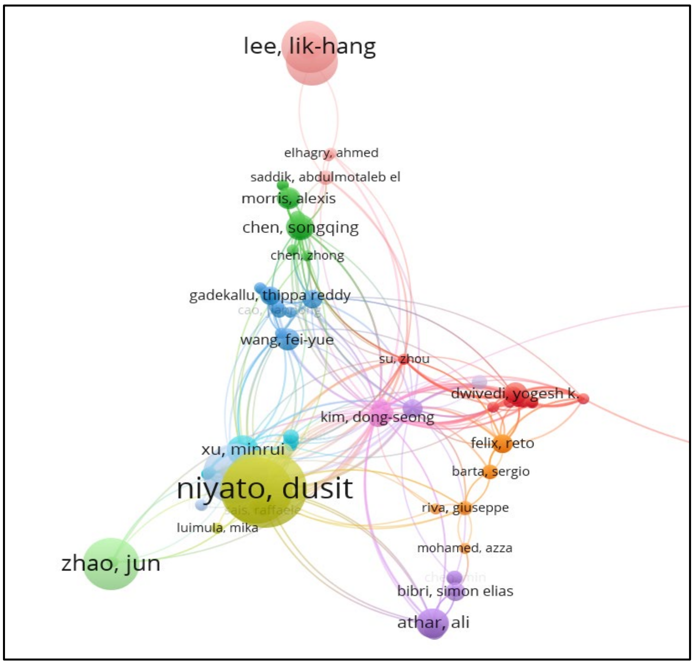
4.4 Analysis by Author Affiliations and Collaboration

In the realm of human metaverse interaction, certain authors stand out for their prolific contributions, as evident in Table 3. Dusit Niyato leads with 21 publications, garnering 219 citations and an impressive average of 10.43

citations per document, establishing a significant link strength of 65. Zehui Xiong closely follows with 18 documents, amassing 359 citations at an outstanding average of 19.94 per document, contributing to a total link strength of 60. Jiawen Kang, with 16 documents, demonstrates a strong impact with 274 citations and an average of 17.13 per document, resulting in a total link strength of 57. The diverse landscape of contributors includes Lik-Hang Lee, Jun Zhao, Pan Hui, Tomio Watanabe, Jonathan Gratch, Ali Athar, and Hee-Cheol Kim, each leaving their mark in this dynamic field, combining to create a rich tapestry of research and insights in human metaverse interaction. The network visualization can be show on the figure.

Table 3 *Top authors that published more than three documents in the field of HMI*

No	Author	Documents	Citations	Average Citations per Documents	Total Link Strength
1	Niyato, Dusit	21	219	10.43	65
2	Xiong, Zehui	18	359	19.94	60
3	Kang, Jiawen	16	274	17.13	57
4	Lee, Lik-Hang	14	44	3.14	19
5	Zhao, Jun	14	31	2.21	16
6	Hui, Pan	13	92	7.08	24
7	Watanabe, Tomio	12	84	7.00	8
8	Gratch, Jonathan	10	277	27.70	4
9	Athar, Ali	8	167	20.88	20
10	Kim, Hee-Cheol	8	167	20.88	20

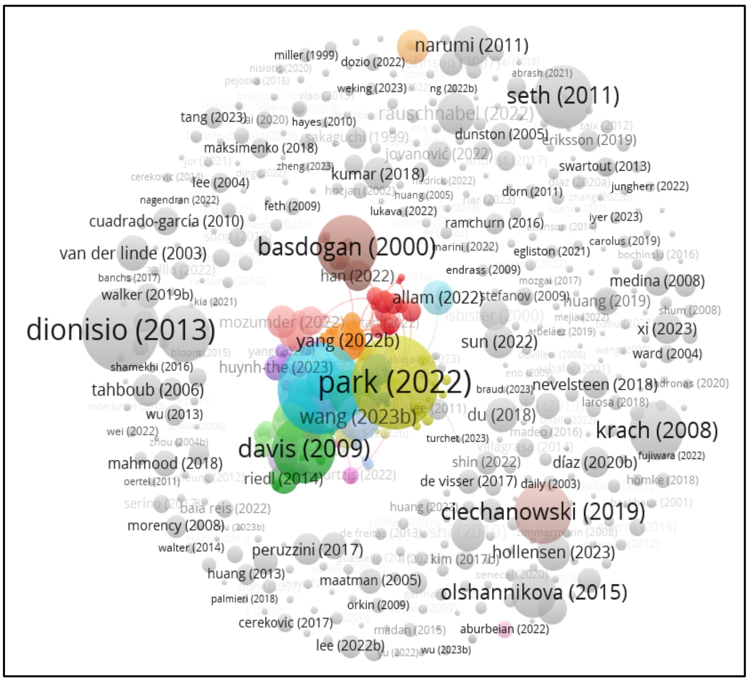


4.5 Analysis by Document Title

Table 4 presents the top-cited references in the field of human metaverse interaction, detailing the author, publication year, citation count, link strength, and title of each reference. Notably, Park's 2022 paper, "A Metaverse: Taxonomy, Components, Applications, and Open Challenges," claims the top spot with 524 citations and 51 link strengths. Dwivedi's 2022 work, "Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice, and policy," follows closely with 505 citations and 7 link strengths. Dionisio's 2013 paper, "3D Virtual worlds and the metaverse: Current status and future possibilities," holds the third position with 440 citations. These references cover a broad range of topics within human metaverse interaction, including taxonomy, challenges, virtual reality, touch in shared virtual environments, assembly methods prototyping, human-chatbot interaction, machines' perspective-taking abilities, copresence taxonomy, and visualizing big data with augmented and virtual reality. The high citation counts suggest their influential role in shaping the discourse and research directions in this evolving field. The network visualization shows some of the clusters in grey, indicating they are not connected to each other.

Table 4 *Top-cited references in the field of HMI*

No	Author	Year	Citations	Link	Title
1	Park	2022	524	51	*"A Metaverse: Taxonomy, Components, Applications, and Open Challenges"*
2	Dwivedi	2022	505	7	*"Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy"*
3	Dionisio	2013	440	0	*"3D Virtual worlds and the metaverse: Current status and future possibilities"*
4	Davis	2009	330	10	*"Avatars, People, and Virtual Worlds: Foundations for Research in Metaverses"*
5	Basdogan	2000	310	2	*"An experimental study on the role of touch in shared virtual environments"*
6	Seth	2011	296	1	*"Virtual reality for assembly methods prototyping: a review"*
7	Ciechanowski	2019	285	1	*"In the shades of the uncanny valley: An experimental study of human–chatbot interaction"*
8	Krach	2008	263	0	*"Can Machines Think? Interaction and Perspective Taking with Robots Investigated via fMRI"*
9	Zhao	2003	254	0	*"Toward a Taxonomy of Copresence"*
10	Olshannikova	2015	207	0	*"Visualizing Big Data with augmented and virtual reality: challenges and research agenda"*

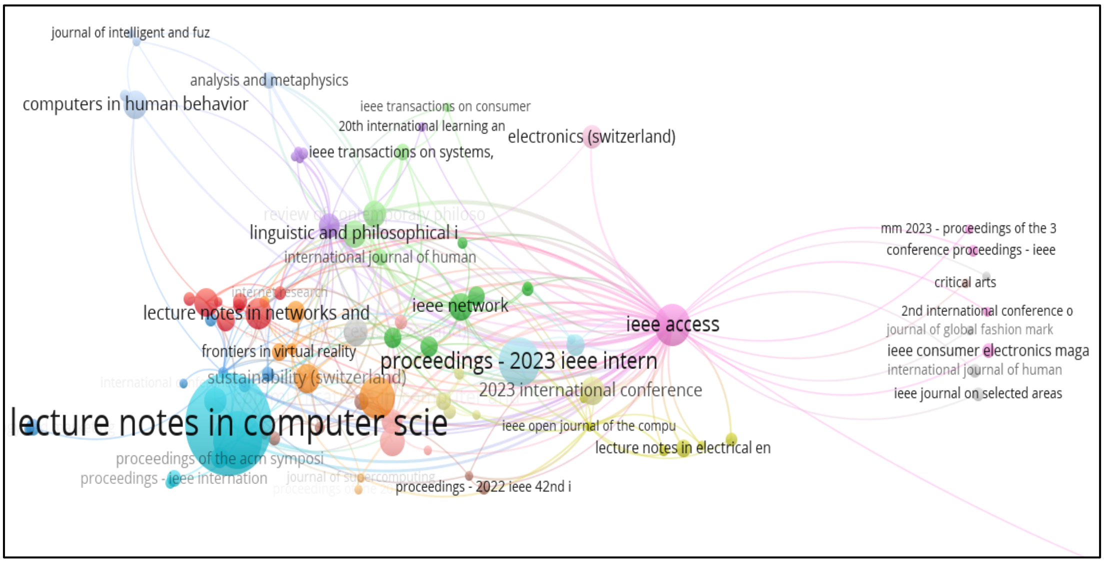


4.6 Analysis by Journal Sources

Table 5 summarizes the prominent sources in the domain of human metaverse interaction research, shedding light on their impact through the number of documents, citations, and average citations per document. Notably, "Lecture Notes in Computer Science," comprising subseries in Artificial Intelligence and Bioinformatics, emerges as a prolific source with 141 documents, 752 citations, and an average of 5.33 citations per document. "IEEE Access" stands out for its substantial impact, presenting 32 documents with an impressive 943 citations, resulting in an average of 29.47 citations per document. Meanwhile, "Proceedings - 2023 IEEE International Conference on Metaverse Computing, Networking, and Applications, Metacom 2023" is a notable contributor with 41 documents, although it has not yet received citations. These insights provide a nuanced understanding of the scholarly landscape, emphasizing the significance and influence of specific sources in advancing research within the realm of human metaverse interaction. The network visualization shows the bubble size indicating the size of occurrences from largest to smallest.

Table 5 *Top 10 sources about HMI research*

No	Source	Documents	Citations	Average Citations
1	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	141	752	5.33
2	ACM International Conference Proceeding Series	54	194	3.59
3	Proceedings - 2023 IEEE International Conference on Metaverse Computing, Networking, and Applications, Metacom 2023	41	0	0.00
4	IEEE Access	32	943	29.47
5	Communications in Computer and Information Science	32	117	3.66
6	Conference on Human Factors in Computing Systems - Proceedings	29	621	21.41
7	Proceedings of SPIE - The International Society for Optical Engineering	26	75	2.88
8	Lecture Notes in Networks and Systems	20	13	0.65
9	CEUR Workshop Proceedings	19	30	1.58
10	Sustainability (Switzerland)	18	216	12.00



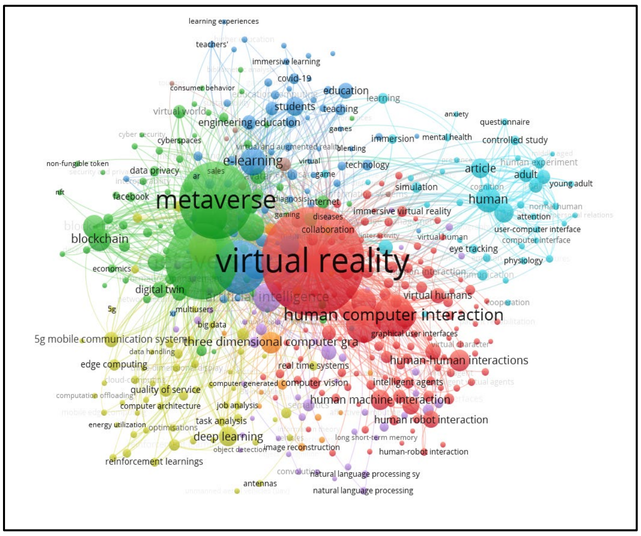
4.7 Frequency of Keywords

Table 6 outlines the top five key words associated with research on human metaverse interaction, presenting their respective occurrences and total link strength. Notably, "virtual reality" stands out as the most prevalent keyword, occurring 1673 times with a substantial total link strength of 10505. Following closely are "metaverse" and "metaverses" with 930 and 901 occurrences, respectively. Other significant keywords include "augmented reality," "human computer interaction," and "virtual worlds." The "Total Link Strength" column further illuminates the interconnectedness and significance of each keyword within the context of human metaverse interaction research. This comprehensive overview of keyword frequencies and link strengths provides valuable insights into the prevalent themes and focal points in the literature on this subject. The network visualization shows the bubble size indicating the size of occurrences from largest to smallest.

The analysis of gaps in the literature and emerging trends in Human Metaverse Interaction (HMI) reveals several directions for future research. The lack of common terms like "virtual humans," "social virtual reality," and "human-robot interaction" highlights the need for more research on understanding and improving social interactions in virtual environments. Nevertheless, little research has been found addressing robot interaction and how it affects people who interact with robots (Aziz et al., 2015a; Aziz et al., 2015b; Ismail et al., 2016; Ismail et al., 2018). Multidisciplinary research that unites social sciences and computer science is crucial to fully examine the sociocultural dynamics of the metaverse.

Table 6 *Top five keywords in the field of HMI*

No	Keyword	Occurrences	Total Link Strength
1	virtual reality	1673	10505
2	metaverse	930	5917
3	metaverses	901	6672
4	augmented reality	504	3452
5	human computer interaction	323	2221



Research areas that require more study include Psychology, Arts and Humanities, and Neuroscience. Investigating brain correlates immersive experiences, understanding psychological and cognitive components of people's interaction with the metaverse, and exploring artistic and creative expressions in virtual worlds can provide insights into HMI development.

The rising use of terms like "extended reality (XR)" and "digital twins" indicates a developing topic that needs further investigation. Future research may focus on the assimilation of digital twin technologies into the metaverse and the consequences of extended reality on immersive virtual environments.

Considering the metaverse's growing influence on interpersonal relationships, cross disciplinary comparisons, investigation of cultural contexts impacting virtual environment user experiences, and examination of moral issues related to digital identity, privacy, and security in the metaverse are essential.

4.8 Future Research Framework for HMI

Findings show that future research in HMI needs to explore how people connect and interact in virtual spaces. Areas like "virtual humans" and "social virtual reality" remain underdeveloped, leaving gaps in our understanding of the metaverse's social dynamics. Fields such as psychology, neuroscience, and the arts are also underrepresented, yet they offer valuable insights into human behavior, cognition, and creative expression in digital environments. A multidisciplinary approach can help uncover the cultural and emotional impact of the metaverse.

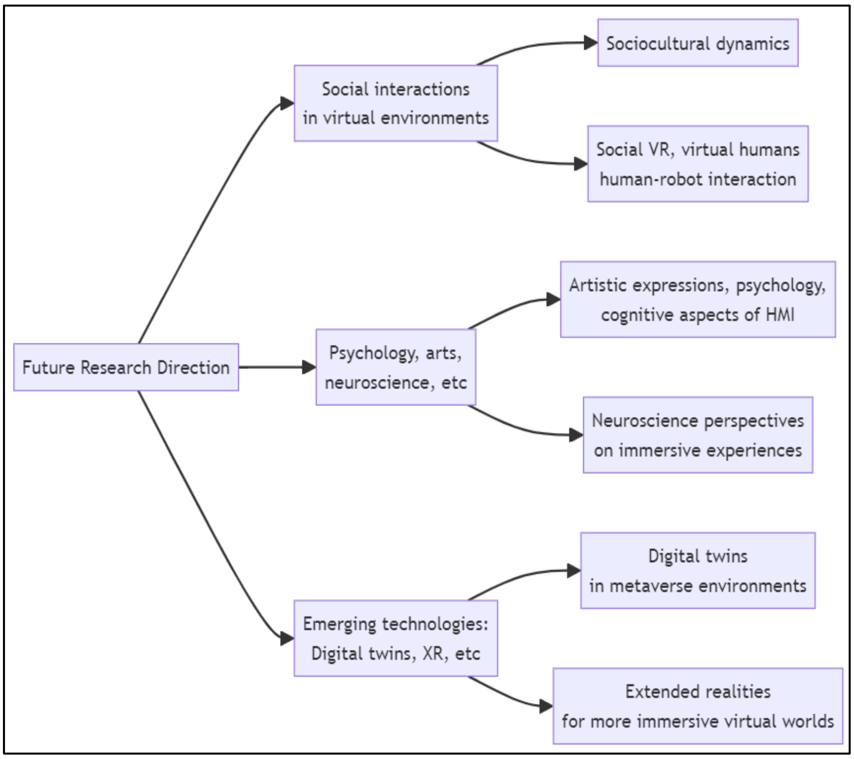


Fig. 10 *Future research agenda framework for HMI*

Meanwhile, emerging technologies like "extended reality" and "digital twins" are shaping the future of virtual spaces. Research should focus on enhancing these innovations to create more immersive and functional environments while also addressing challenges related to privacy, security, and digital identity. Hardware advancements, such as improved head-mounted displays, will be essential for refining user experiences. As the metaverse becomes more integrated into daily life, balancing technological development with human-centered considerations will be key. Fig. 10 summarizes these research priorities, highlighting the need to explore new technologies and fill critical gaps in HMI studies.

4.9 TVET and Human Metaverse Interaction

The important role that TVET plays in adapting to the digital age, particularly through the integration of the metaverse, has been highlighted in recent research. As noted by Adnan et al. (2021), Industry 4.0 demands critical skills from TVET students across ASEAN countries, making the integration of immersive technologies crucial. By bringing immersive and innovative learning experiences to the table, the metaverse is transforming how skills are taught and learned. This shift is especially impactful for TVET institutions, which are now able to update their teaching methods to better reflect the evolving needs of industries. The use of virtual and augmented reality allows students to practice technical skills in a simulated environment, removing the need for physical resources and expanding training opportunities (Jalil et al., 2024; Sazly et al., 2021).

At the same time, the study points out that TVET institutions must stay ahead of digital changes while also addressing potential challenges like privacy concerns, the risk of digital addiction, and ensuring all students have equal access to technology. This aligns with findings from Isa et al. (2015), who explored the adoption of blended learning and mobile technologies in education, emphasizing the importance of carefully considering implementation strategies. The bibliometric analysis of studies on the metaverse shows that interest in its educational uses is growing, but there are still many questions about its full potential in vocational training. As Liu and Lu (2023) discuss in their study on metaverse applications in vocational education, by looking at trends and important contributions, research helps set the stage for future exploration of how TVET institutions can better use the metaverse to develop skills, prepare workers, and promote lifelong learning. Ultimately, TVET's role in this research underscores its vital contribution to equipping learners with the skills they need for the future while taking a responsible approach to the role of technology in education.

5. Conclusion

This study presents an in-depth bibliometric analysis that significantly contributes to the growing body of research in Human Metaverse Interaction (HMI). The findings, recommendations, and future directions presented act as a guide for scholars, researchers, policymakers, and practitioners. This work identifies research gaps and highlights promising areas for additional examination, hence facilitating the ongoing advancement of HMI research to tackle the evolving issues presented by the metaverse (Feng et al., 2022).

The research underscores the necessity of cultivating a human-centric approach to HMI, guaranteeing responsible and inclusive progress in this swiftly evolving digital environment. As the metaverse transforms digital interactions and educational experiences, comprehending human engagement within this realm is essential (Undale et al., 2023). This study underscores the necessity for researchers to tackle critical challenges, close existing knowledge gaps, and establish a basis for a comprehensive, ethical, and industry-relevant metaverse (Williams and Bornmann, 2016).

Interdisciplinary collaboration is essential for attaining this objective. By synthesizing insights from other fields, academics can contribute to the development of a metaverse that adheres to ethical principles, emphasizes human experiences, and promotes diversity. These insights extend beyond academia, impacting business practices, government policies, and collaborative initiatives aimed at fostering a digital landscape that improves workforce preparedness and connectivity (Wang et al., 2021).

This study highlights the metaverse's transformative impact on learning approaches within Technical and Vocational Education and Training (TVET). The metaverse facilitates immersive and interactive educational experiences, allowing TVET institutions to transcend conventional barriers, especially amid disturbances like the COVID-19 epidemic. Although these technologies offer novel avenues for digital innovation, they simultaneously pose obstacles such as privacy issues, risks of digital addiction, and ethical dilemmas. By meticulously incorporating metaverse-based training into Technical and Vocational Education and Training (TVET), students can acquire skills pertinent to the future while maintaining the adaptability of educational systems to the changing digital environment.

This study's findings have substantial significance for TVET policies, especially in harmonizing educational frameworks with the requirements of Industry 4.0 and developing technologies. Numerous nations have modified their TVET policies in accordance with UNESCO's guidelines, emphasizing equity, quality, and industry relevance. This research offers data-driven insights that facilitate additional policy improvements, especially in utilizing HMI for workforce development, digital engagement, and skill enhancement. This study highlights the necessity for policy reforms that incorporate immersive technologies, including Virtual Reality (VR) and Augmented Reality (AR), into vocational training curricula. These advancements will empower TVET institutions to provide practical, industry-relevant education, thereby closing the divide between conventional learning paradigms and the changing employment landscape. Enhancing collaborations between TVET institutions and industries—a validated approach for workforce development—can be further improved through metaverse-based platforms that enable real-time, remote, and practical training experiences.

This study underscores the imperative of enacting data privacy protections, ethical digital engagement frameworks, and equitable access to metaverse education from a legislative standpoint. Policymakers must formulate regulations that encourage safe and responsible technology utilization while addressing issues pertaining to cybersecurity threats, digital addiction, and the digital divide. By utilizing the findings from this research, TVET institutions can implement more flexible, inclusive, and progressive educational frameworks that equip students for the digital economy. These policy advancements will enhance employability by equipping graduates with advanced skills and contribute to economic growth by cultivating a workforce adept at adapting to technological changes. Ultimately, these advancements underscore the vital importance of TVET in fostering sustainable and equitable skill development for the digital era.

Acknowledgement

The authors would like to acknowledge the Research Initiative Group for Emotion, Kansei and Design Engineering (RIG EKDE), Universiti Teknologi MARA (UiTM), as well as Malaysia Association of Kansei Engineering (MAKE), for all their assistance to the research paper.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *I Made Bambang Ariawan, Anitawati Mohd Lokman, Ana Hadiana;* ***data collection:*** *I Made Bambang Ariawan;* ***analysis and interpretation of results:*** *I Made Bambang Ariawan, Anitawati Mohd Lokman, Ana Hadiana, Shamsiah Abd Kadir;* ***draft manuscript preparation:*** *I Made Bambang Ariawan, Anitawati Mohd Lokman, Ana Hadiana, Shamsiah Abd Kadir. All authors reviewed the results and approved the final version of the manuscript.*

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