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The Metaverse and complex thinking: opportunities, experiences, and future lines of research

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Research trends about the Metaverse have increased in recent years due to its potential to create immersive realities, where complex thinking becomes relevant as an ability to promote emerging ways to understand and explain the different realities that comprise a digital society. Although some investigations allow us to know both topics' concepts and applications, scientific literature production about them is scarce. In this work, we conducted a systematic review of the literature (SLR), analyzing 234 publications from various databases, including Scopus and Web of Science, to understand how studies about the Metaverse overlap with the components of complex thought. The results showed that there has been extensive exploration of the Metaverse since 2022. The prevalence of the Metaverse aligns with the design of algorithms and retail sales, and it primarily correlates with virtual reality technology. Likewise, various reference frameworks and taxonomies have been designed to explain the operation of the Metaverse in different formative spaces. We concluded that examining the Metaverse from the perspective of critical, systemic, scientific, and innovative thinking can open lines of research that affect the knowledge of immersive technologies and the evolution of disruptive digital ecosystems.

KEYWORDS

higher education, Metaverse, complex thinking, educational innovation, education 4.0

1. Introduction

The use of digital technologies to strengthen the quality of education and provide innovative training experiences has been a continuous topic in educational systems (UNESCO, 2018; Cabero Almenara and Martínez Gimeno, 2019). In this sense, the Metaverse's potential to offer virtual environments that allow users to socialize, collaborate, and learn through developing high-quality immersive experiences has positioned it as an alternative content source for students (META, 2022).

The use of this technology gained importance in 2003 when the Second Life (SL) platform was released. SL can be considered the first virtual world in which teachers in different educational levels had the opportunity to build simulated work scenarios such as laboratories and classrooms without walls with avatar interactions in immersive realities (Carr, 2008; Brennen and Erika dela Cerna, 2010; Beaumont et al., 2014).

In the SL environment, disruptive learning strategies like problem-based learning, role-playing, gamification, and various training practices flourished (Ortiz et al., 2019). It made virtual reality an option to participate in alternate realities in which the virtually enhanced physical reality and the physically persistent virtual spaces converge, that is, digital mirrors in which interactions, communication, and information exchanges are generated in cyberspace (Collins, 2008).

Over the years, the Metaverse evolved into shared three-dimensional virtual spaces (Hackl, 2021), with a structure composed of seven layers that make its growth and implementation possible (Radoff, 2021), allowing teachers and students to access, use, and appropriate the immersive technologies on which virtual environments are based. Table 1 identifies and describes each of the seven layers.

Also, the Metaverse has been categorized into at least four models that coexist in the environment of a large Metaverse: (1) games and virtual realities, (2) mirror worlds, (3) augmented reality, and (4) digital recording systems that collect data from the environment (lifelogging; Márquez, 2011). These models have main characteristics of interactivity, corporeality through the design of an avatar, and persistence (meaning the ongoing functionality of the Metaverse, even when the avatars are not connected; Castronova, 2001).

In this regard, Kye et al. (2021) classify four types of Metaverses: (1) augmented reality, (2) lifelogging, (3) mirror world, and (4) virtual reality, also suggesting that the Metaverse has the potential to consolidate as a new educational environment since it generates a new space for social communication, a greater degree of freedom to create and share, the opportunity to create disruptive learning experiences, and a high immersion in alternative reality through virtualization. Table 2 shows the classification of the Metaverse and its possible contributions to education.

Therefore, in the educational context, the Metaverse concept is much broader than using virtual reality glasses and interacting with avatars because it involves training experiences with various tools. These include the HoloLens, with which anatomical models of diseases can be explored using augmented and virtual realities (Stromberga et al., 2021), virtual and augmented reality platforms to build molecular models (Cortés Rodríguez et al., 2022), and gamification experiences to motivate learning (Park and Kim, 2022).

In higher education, the Virtual Campus of Tecnologico de Monterrey is an environment specially designed for students to attend classes with their personalized avatars (TecReview, 2021). In this Metaverse space, both thematic sessions and an entire higher-level course (CONECTA, 2021) have been conducted, highlighting that in this simulated campus, not only interactive and dynamic learning experiences can be generated, but also skills such as digital transformation, the reasoning for complexity, social intelligence, and communication (Rocha et al., 2022).

Due to the above, the Metaverse and its strategic implementation to create disruptive learning scenarios are based on a paradigm shift that moves from training dynamics in face-to-face, hybrid, or digital modalities mediated by videoconferences and educational platforms to a fully immersive educational process requiring a change in content delivery formats. There are different approaches to analyzing the Metaverse structure and its impact on educational settings. Therefore, the objective of this document is to analyze the scientific production regarding the subject of the Metaverse in the field of education from the perspective of the sub-competences of complex thought, in order to elaborate a classification that allows identifying which lines of research can be emerge to continue with the study of the use of disruptive technologies.

1.1. Complex thought and the Metaverse

University education must respond to the challenges of emerging educational scenarios, which, as has been observed in the context of

TABLE 1 Layers of the Metaverse and their application in education.

Layer	Description
Infrastructure	Access to Metaverse technology, such as computers, digital tablets, and smartphones.
Human Interface	Access to hardware for an immersive experience in the Metaverse, such as virtual reality glasses and cardboard.
Decentralization	Democratize and offer freedom to interact in the Metaverse by designating spaces and avatars.
Spatial computation	Use virtual, augmented, and extended realities to design learning experiences.
Economy	Possible monetization of school services in the Metaverse.
Discovery	Virtual campuses tours and advisory service offerings from professors or experts.
Experience	Design accessible, diverse spaces for learning, such as classrooms, libraries, and conference rooms.

TABLE 2 Contributions of the Metaverse to education.

Metaverse types	Possible contributions to education
Augmented Reality	Learning with three-dimensional applications, access to virtual learning spaces that simulate high physical risk, and hologram teacher technology.
Lifelogging	Learning through data analytics, personalized learning, adaptive learning, and social intelligence. Strengthening of digital literacy skills.
Mirror World	Learning in multiple communication spaces such as videoconferences, learning management systems, social networks, real-time collaboration software, and video games.
Virtual Reality	Learning using virtual campuses, high-fidelity simulations, low-cost 3D devices such as cardboards, having a digital identity through an avatar, and acquiring knowledge through social interactions.

the pandemic, can be changing and not necessarily present in face-to-face formats (Sepulveda-Escobar and Morrison, 2020). It is imperative to seize the opportunities offered by technological trends to transform education through disruptive learning.

However, developing skills that allow the advancement of pedagogies based on the use of technologies such as the Metaverse should also be privileged. In addition, in university settings, improving complex thinking (CT) is a necessary enabler for more accurate academic decisions in many higher education disciplines (Vázquez et al., 2022).

Complex thinking is a mega-competency with four sub-competencies: scientific (ST), critical (CR), systemic (ST), and innovative (IT) thinking (Ramírez-Montoya et al., 2022) that allow students, through cognitive skills, to participate in the Knowledge Society, Industry 4.0, and Education 4.0. Figure 1 shows the components of complex thinking (Miranda et al., 2021; Ramírez-Montoya et al., 2022) and those of the Metaverse and their possibility of overlapping.

These sub-competencies can be intertwined with the essential Metaverse characteristics to offer added value to the training processes that use new digital-pedagogy experiences (Abdul et al., 2020) and knowledge dissemination in dynamic, hybrid learning ecologies (Vodovozov et al., 2021; Wasilah et al., 2021). The previous also contributes to recognizing complex skills that serve to develop classifications that answer the research question posed in this article: How can research on the Metaverse in the educational field be categorized within the framework of complex thinking, and what are the research lines they can promote?

There are different approaches to analyzing the structure of the Metaverse, as well as the impact it is having on educational settings. This article analyzes scientific production around Metaverse experiences in the educational field to contribute to a classification using the components of complex thinking to generate new lines of research. Thus, this article presents the results of a bibliometric investigation that focuses on identifying studies that consider the relationship between systemic, scientific, critical, and innovative thinking and the Metaverse. To this end, a systematic literature review (SRL) was prepared using various databases.

2. Method

To guide the development of this work, we formulated the following research question: How can research on the Metaverse be categorized within the framework of complex thinking, and what lines of knowledge generation can be promoted? Figure 2 shows the methodological approach implemented in this research.

The research aims to identify and categorize the scientific production of the Metaverse with the components of complex thought. The research is descriptive since it collects information to analyze the social phenomenon of the Metaverse and how it overlaps with complex thinking (Shields, 2020). The Systematic Literature Review (SLR) was selected as the method, applying the proposal of Kitchenham and Charters (2007), who proposed the identification, evaluation, and interpretation of all available and relevant research related to the subject.

Metaverse (MV) was a keyword used to search for scientific production, and Complex Thought (PC) was a contextual term. The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method (Page et al., 2021) consists of two stages, planning, and action (Vázquez et al., 2022), which were applied as a

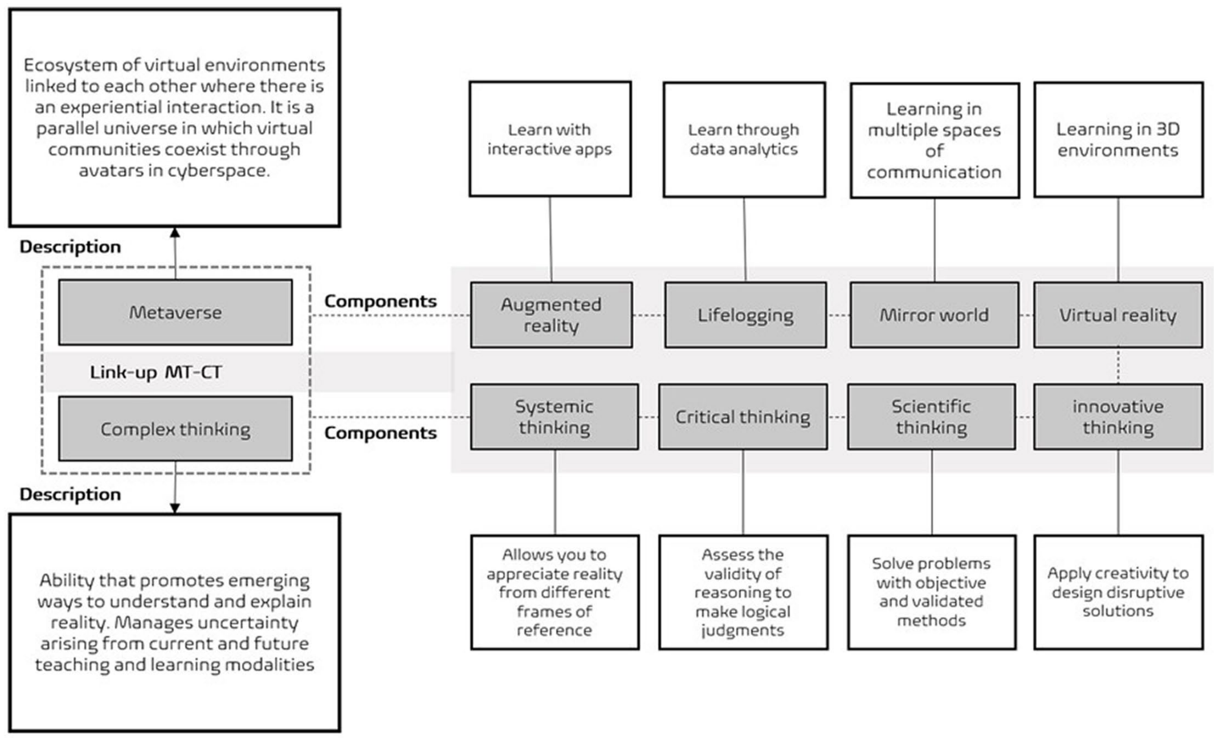

FIGURE 1
Approach to the components of the Metaverse and complex thought.

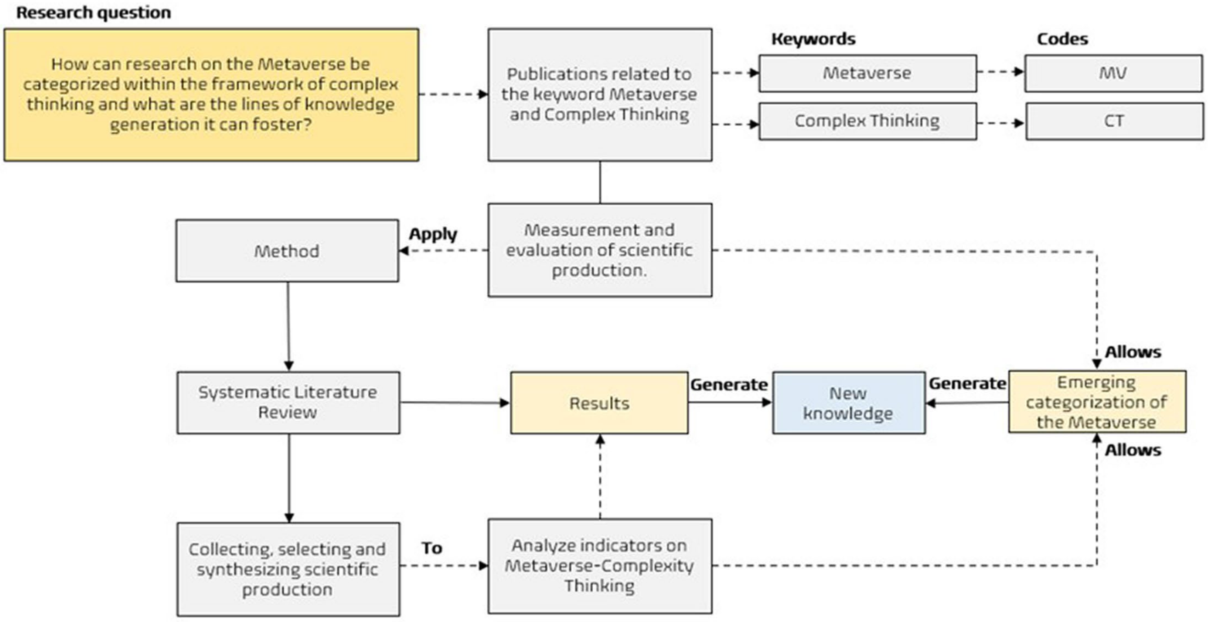

FIGURE 2
Systematic literature review methodology.

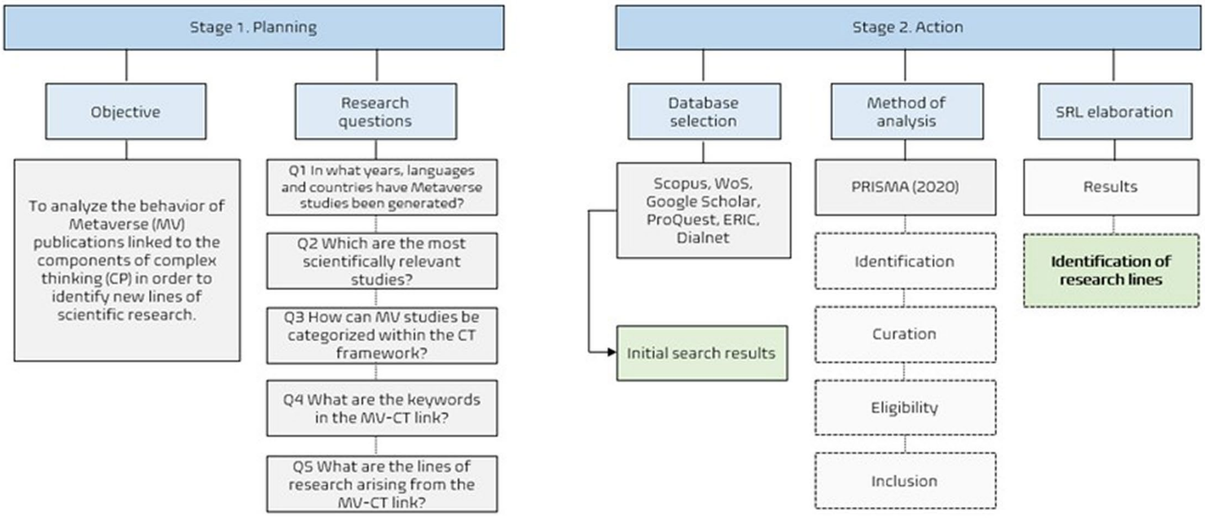

FIGURE 3
Systematic literature review process.

strategy to collect and select scientific production. Figure 3 shows the objective and the research questions, the selected databases, and other details of the applied strategy.

2.1. Search strategies and inclusion, exclusion, and quality criteria

Seven databases were used to identify and select the documents: Dialnet, ERIC, Google Scholar, ProQuest, Scielo, Scopus, and Web of Science (WoS). Emphasis was placed on using Scopus because it is considered one of the largest and most prestigious databases of citations and peer-reviewed literature (Ball, 2021). As a result, 518 articles were identified.

The method to analyze these articles was PRISMA (Page et al., 2021), which consists of identifying and selecting the scientific documents, carrying out their curation by eliminating duplicates, and applying the inclusion, exclusion, and quality criteria, then finally reading the abstracts of the articles to include those that are relevant and feasible for quantitative and qualitative analyses. To conduct the curation of the documents, we applied the following criteria:

Research, scientific dissemination, systematic literature review, methodological, and meta-analysis documents that

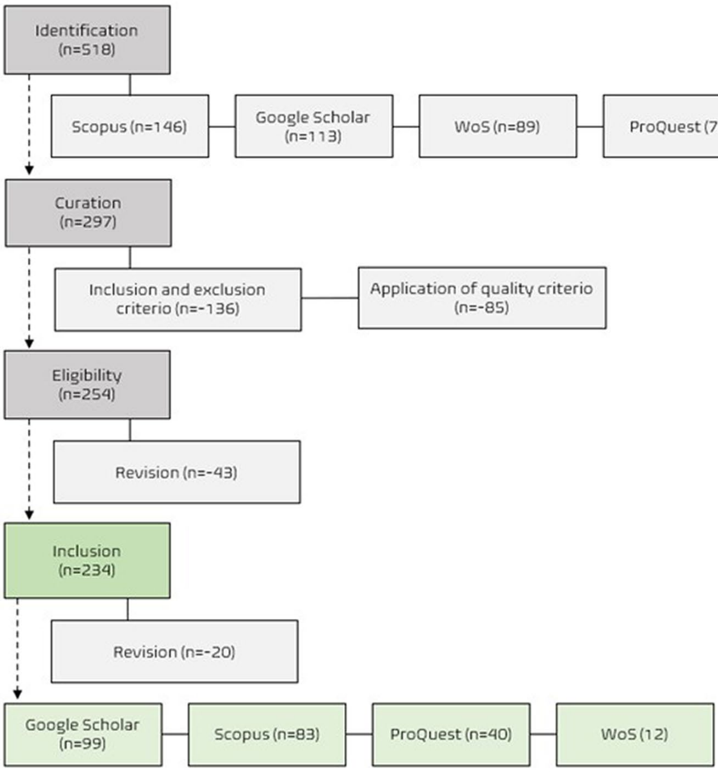

FIGURE 4
PRISMA flow to obtain the bibliography.

included the MV-PC codes in the title, abstract, or keywords were included.

Editorials, errata, and documents not closely related to the subject of study were excluded, as well as publications that did not show the MV-PC codes in the title, abstract, or keywords.

For quality criteria, we established that the articles must be published between and including 2010–2022, written in English or Spanish, focused on studying the Metaverse, and addressing some components of complex thought in its sections or results. The preceding generated 232 documents (link: https://bit.ly/42FXYcc) which a sequential numbering was assigned and with which a bibliographic database was created with the following fields: (a) author(s), (b) job title, (c) year, (d) type document, (e) journal or publisher, (f) country of authors, (g) institutions or organizations, (h) DOI, (i) reference in APA style, (j) abstract, (k) keywords, and (l) language. In Figure 4, the eligibility process can be seen.

3. Results

The first result presented is a general analysis of the coincidences of the scientific production found concerning the components of complex thought, the number of citations, and the keywords that appear most frequently. Figure 5 shows that the Metaverse has had a significant impact on the scientific production related to systemic thinking ($n = 70$), as well as innovative thinking ($N = 69$); however, the articles linked to scientific thinking had the highest number of citations ($n = 292$).

On the other hand, regarding the categories in which the Metaverse can be classified, mirror worlds ($n = 145$) correspond to the most used category referring to the experiences mediated by the Metaverse. The publications related to this classification are also the most cited ($n = 420$). In second place, virtual reality is a topic that has also been analyzed in scientific production ($n = 61$) and has the second-highest number of citations ($n = 286$). This indicates that knowledge about the Metaverse focuses on exploring technological trends that have been incorporated into education; however, it should be noted that an emerging line of research could be found in the analysis of augmented reality technology (six publications with 14 citations) from the perspective of some of the sub-competencies of complex thinking.

The results are presented below, based on the guiding questions defined in the Planning Stage:

> Q1: In what years, languages, and countries are studies of the Metaverse?

Figure 6 shows that the scientific production on the Metaverse increased notably in 2022, with 173 publications. This could be explained by the documentation of strategies employing disruptive technologies to face the challenges of the COVID-19 pandemic. Some were based on using the Metaverse (Rocha et al., 2022). Some resulted from the media effect of the announcement of the creation of Meta by Mark Zuckerberg (Fernandez, 2022), which boosted the use of virtual reality environments to position products and services in cyberspace and education (Akgül and Uymaz, 2022; Kraus et al., 2022).

On the other hand, Figure 7 shows the classification of scientific production from two aspects. Notably, the most significant number of works is related to systemic thinking; that is, with the design of reference frameworks and taxonomies to offer services and propose methodologies to apply the experiences based on the Metaverse, as well as application schemes to generate learning mediated by digital spaces. The second aspect relates to the preference for using mirror worlds to carry out learning, instructional, or customer service experiences, such as designing museums, laboratories, virtual campuses, and three-dimensional exhibition halls to enhance retail sales.

Regarding the languages in which the investigations were out, most of them were published in English (222), followed by Chinese (6), Korean and Spanish (2), and finally, Japanese and Portuguese (1). Regarding the contribution by country, Figure 8 shows that 59 countries contributed studies of the Metaverse. The most significant production came from the United States of America (66), followed by China (53), South Korea (41), Great Britain (36), and Japan (23). Spain (4) and Mexico (1) were the Ibero-American countries with the highest production.

Regarding the collaboration between authors from different countries, Figure 9 shows that the closest relationship is between researchers from the United States of America (316 citations and link strength of 276) and Korea (212 citations and link strength of 236). Collaboration ties have also been generated with Japan (112 citations and a link strength of 83). The studies carried out in the United Kingdom (126 citations and a link strength of 147) have less close links with the United States of America since the scientific

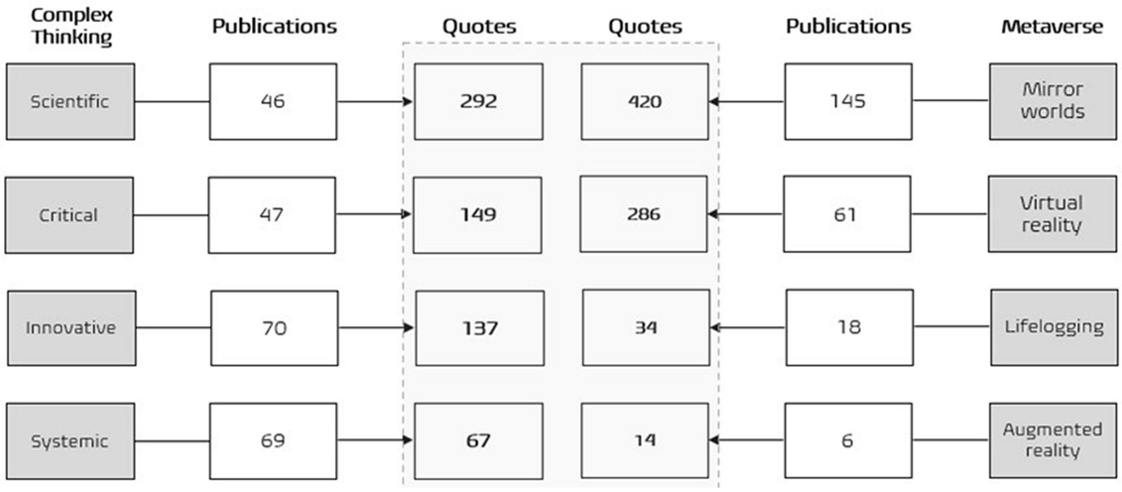

FIGURE 5
The general impact of scientific production.

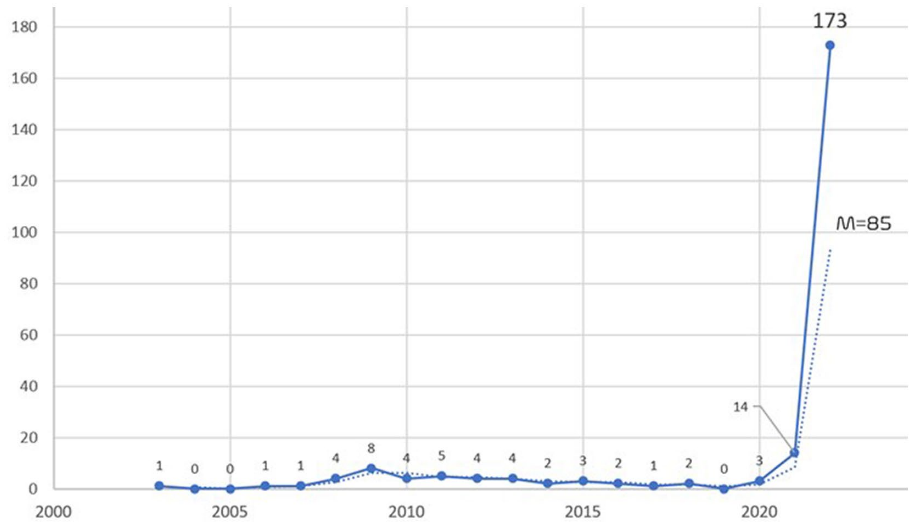

FIGURE 6
Scientific production by year of publication.

production is more related to Belgium, Iraq, Yemen, Malaysia, and Saudi Arabia.

> *Q2*: What are the most scientifically relevant studies?

The most cited document ($n=108$) is an article called 3D Virtual Worlds and the Metaverse: Current Status and Future Possibilities, which explores the definition and meaning of virtual worlds and classifies them into four areas of development: immersive realism, the ubiquity of access and identity, interoperability and scalability, as well as the factors that influence and limit the formation of a viable metaverse to develop both educational and commercial experiences. This study represents the systems thinking approach since it elaborates a historical classification of experiences based on the Metaverse, particularly those related to virtual reality. Table 3 shows that journal articles and conference papers have the highest citations. The information is classified according to the components of complex thought and metaverse classification.

Regarding the conference papers, the document A Metaverse: Taxonomy, Components, Applications, and Open Challenges, was cited 55 times in the same year of its appearance (2022), which indicates that it has had a high relevance in the scientific field since it addresses a redefinition of the Metaverse based on the evolution of digital infrastructure and the development of hardware, software, and content design for instruction and learning, and user interaction experiences.

Figure 10 shows an analysis of co-citation between researchers. The results show that three authors collaborated in the development of the conceptual foundations of the Metaverse. The document Decision Intelligence and Modeling, Multisensory Customer Experiences, and Socially Interconnected Virtual Services across the Metaverse Ecosystem (Nica et al., 2022) was consolidated as a base document for other works such as Multimedia research toward the Metaverse (Chen, 2022) and A survey on Metaverse: Fundamentals, security, and privacy (Wang et al., 2022).

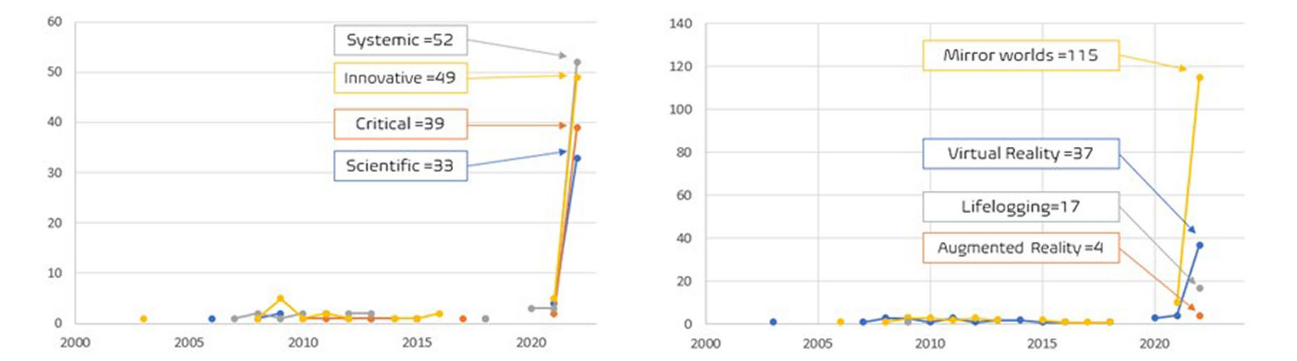

FIGURE 7
Scientific production by type of thought and Metaverse topic.

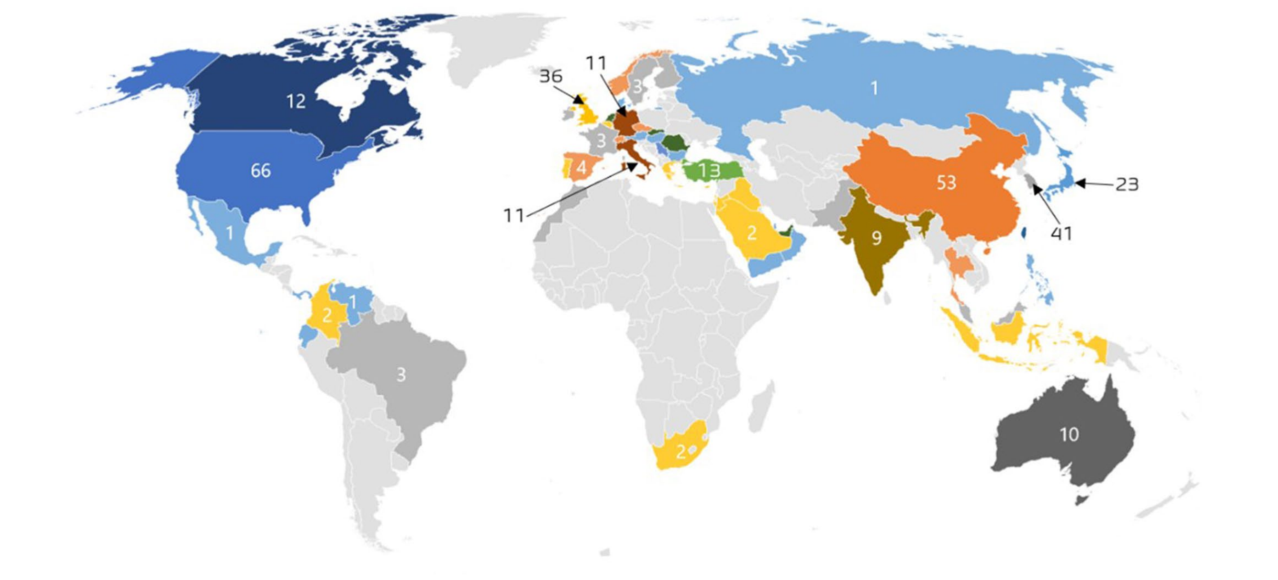

FIGURE 8
Scientific production by country.

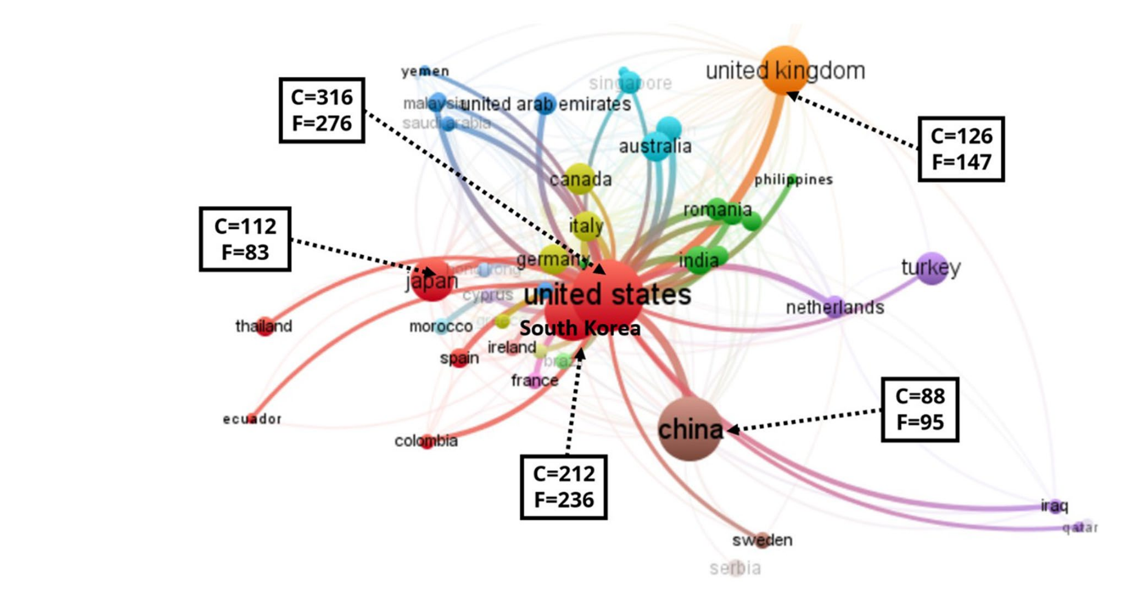

FIGURE 9
Scientific collaboration by country.

> Q3: How can studies be categorized within the framework of complex thinking?

Table 4 classifies according to the concepts related to the components of complex thought (refer to Figure 1). Regarding Scientific Thought (*CF*), the publications aimed to measure the impact of the Metaverse in different digital spaces, such as virtual campuses in universities and laboratories without walls in Industry. Studies that evaluate the digital security and privacy of users who interact in virtual socialization environments were included.

The primary studies analyzed from systemic thinking (ST) are those in which reference frameworks and taxonomies are elaborated to allow differentiating methods of applying the Metaverse in different environments, including marketing, education, and industry, highlighting those with parameters established to design virtual exhibitions either for museums or retail sales products.

Critical Thinking (CR) is explored in the selected documents regarding the challenges that designers of immersive experiences face to achieve greater user engagement and to understand what they want to show in three-dimensional worlds. One of these challenges was to have multidimensional communication channels for better decisions to conduct virtual practices; likewise, most studies analyzed the possibilities of always-on access to the Metaverse, connectivity with virtual currencies, and even the integration of neural networks.

Studies related to innovative thinking (IN) analyzed the experiences of viewing, using, and accepting participants in unconventional virtual interaction spaces in which new communication and collaboration models prevail. Most of the research categorized as IN relates to the evolution of retail sales and how the Metaverse influences its promotion. In this category, it is pointed out that although experiences based on extended reality and other novel forms of telepresence are favorably received by people and generate a positive impact, they are confined to small groups of users. It is also suggested that the Metaverse presents challenges, such as whether Augmented Reality (AR) and Virtual Reality (VR) technologies increase or decrease the difficulties of carrying out tasks in simulated situations.

> Q4: What are the keywords in the Metaverse and complex thinking link?

An analysis of the keywords was carried out, finding the emergence of three clusters (see Figure 11). That is, the publications were organized into three possible lines of research. In the first (Cluster A), note that the investigations articulated data analysis (frequency = 71) that emerged from applying the algorithms (frequency = 40) that define the interactions in the virtual worlds.

The second line (Cluster B) is related to teaching-learning experiences in formal and non-formal study environments (frequency = 70), emphasizing the perceptions of usability and acceptance of the Metaverse by students (frequency = 74) as a means to access content and enrich communicative VR interactions in an internet ecosystem (frequency = 74).

Finally, a third possibility of generating knowledge about the Metaverse (Cluster C) is found in generating reference frameworks and methodologies to design innovative experiences to favor the positive impact of user experiences (frequency = 41) and reconceptualizations (frequency = 44) that make statements about the various spaces of interventions in which the Metaverse can be used. Finally, some studies analyze how the design and use of avatars (frequency = 37) can motivate users to access virtual worlds.

> Q5: What lines of research could arise from the Metaverse and complex thinking link?

An analysis of the summaries of the publications was carried out to determine what lines of research could arise when the Metaverse and Complex Thinking topics overlap. Figure 12 shows that virtual reality (frequency = 456) was a recurring concept in the selected investigations,

TABLE 3 Documents with the greatest scientific relevance.

Title	PC	MV	Year	Journal/Conference	Citations	Type
3D virtual worlds and the Metaverse: current status and future possibilities	ST	RV	2013	ACM Computing Surveys	108	Article
A content service deployment plan for Metaverse museum exhibitions—Centering on the combination of beacons and HMDs	IN	ME	2017	International Journal of Information Management	51	Article
A Metaverse: taxonomy, components, applications, and open challenges	ST	ME	2022	IEEE Access	55	Conference Paper
Metaverse for social good: a university campus prototype	IN	ME	2021	MM 2021–Proceedings of the 29th ACM International Conference on Multimedia	45	Conference Paper
Retail spatial evolution: paving the way from traditional to Metaverse retailing	ST	ME	2009	Electronic Commerce Research	43	Article
The Metaverse–A networked collection of inexpensive, self-configuring, immersive environments	CR	RV	2003	Proceedings of the Workshop on Virtual Environments, EGVE'03	27	Conference Paper
The challenges of entering the Metaverse: an experiment on the effect of extended reality on workload	*CF*	ME	2022	Information Systems Frontiers	20	Article
The social metaverse: battle for Privacy	CR	ME	2018	IEEE Technology and Society Magazine	16	Article
Neuro-symbolic speech understanding in aircraft maintenance metaverse	CR	RV	2021	IEEE Acces	16	Article
Evaluation of students' learning manner using an eye blinking system in Metaverse	*CF*	ME	2015	Procedia Computer Science	15	Conference Paper

CF, scientific thinking; ST, systemic thinking; CR, critical thinking; IN, innovative thinking; ME, mirror world; RV, virtual reality.

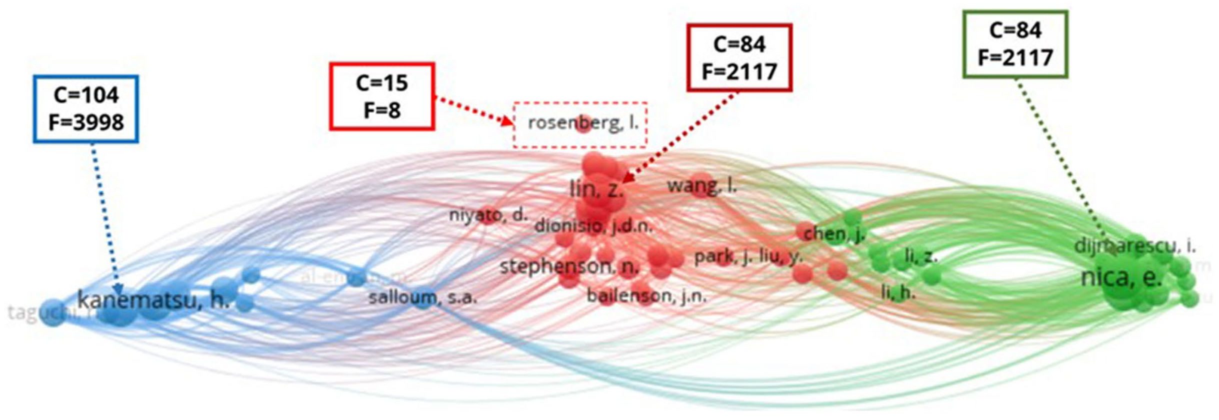

FIGURE 10
Scientific collaboration by author.

especially linked to analyses focused on behavior and the human-computer relationship. Augmented reality (frequency = 190) was also linked to the evolution of 5G communication systems and learning during the COVID-19 pandemic. A correlation between blockchain and internet privacy and security issues was present, which could generate future lines of research.

It was also observed that the Metaverse evolved from the first practices carried out in the Second Life environment, the design of the first accessible virtual spaces, and the creation of e-learning environments (frequency = 96). By 2020, the study of the Metaverse began to be linked to technologies such as immersive reality (frequency = 119). Other research explored topics related to deep learning, blockchain, machine learning, security, and privacy, as well as the design of algorithms for direct purchase offers and retail sales.

Analyzing the Metaverse and its link with the sub-competencies of complex thinking offers the possibility of formulating research proposals that address complex interaction, collaboration, management, and communication schemes in various alternative reality environments that can support learning. Thus, the MV-PC imbrication finds its space for inquiry in environments mediated by

TABLE 4 Categorization of metaverse studies into the components of complex thinking.

PC	MV	Lead author	Title	Journal/Conference	Citations
CF	ME	Duan, H.	Metaverse for social good: a university campus prototype	MM 2021–Proceedings of the 29th ACM International Conference on Multimedia	45
	ME	Falchuck, B.	The social metaverse: battle for privacy	IEEE Technology and Society Magazine	16
	ME	Kanematzu, H.	Nuclear energy safety project in Metaverse	Smart Innovation, Systems, and Technologies	15
ST	ME	Dionisio, J.	3D virtual worlds and the Metaverse: current status and future possibilities	ACM Computing Surveys	108
	RV	Gadalla, E.	Metaverse-retail service quality: a future framework for retail service quality in the 3D internet	Journal of Marketing Management	14
	RV	Ryskeldiev, B.	Distributed Metaverse: creating a decentralized blockchain-based model for peer-to-peer sharing of virtual spaces for mixed-reality applications	ACM International Conference Proceeding Series	9
CR	ME	Chio, H.	A content service deployment plan for Metaverse museum exhibitions—Centering on the combination of beacons and HMDs	International Journal of Information Management	51
	ME	Park, S.	A Metaverse: taxonomy, components, applications, and open challenges	IEEE Access	48
	RV	Kanematsu, H.	Virtual STEM class for nuclear safety education in Metaverse	Procedia Computer Science	15
IN	ME	Bourlakis, M.	Retail spatial evolution: paving the way from traditional to Metaverse retailing	Electronic Commerce Research	43
	RV	Jaynes, C.	The Metaverse–A networked collection of inexpensive, self-configuring, immersive environments	Proceedings of the Workshop on Virtual Environments, EGVE'03	27
	RV	Xi, N.	The challenges of entering the Metaverse: an experiment on the effect of extended reality on workload	Information Systems Frontiers	20

CF, scientific thinking; ST, systemic thinking; CR, critical thinking; IN, innovative thinking; ME, mirror world; RV, virtual reality.

extended environments such as virtual and augmented reality, where people interact in a simulated but realistic way. The above causes new definitions that explain how the Metaverse is being incorporated into people's lives. Questions are generated that can guide future lines of research as complex as the evolution of digital transformations.

To finish the results of this study, Table 5 shows some probable lines of research that can guide future studies related to systemic, scientific, critical, and innovative thinking written as perfectible and debatable questions. These can promote the emergence of teaching-learning methodologies for the new generations of students and contributions by researchers and academicians interested in strengthening the implications of the Metaverse in society.

4. Discussion

The post-COVID trend of interest in the Metaverse and its applications in people's lives includes the educational field. The evident growth of studies on the subject is marked by a difference of 159 publications in 2022 over the 14 publications in 2021, which had the second-highest number of scientific studies. The acceleration during the last 2 years (2022–2021) represents the search for new paths to overcome the educational challenges generated by the COVID-19 pandemic, for example, the disruptive technologies that were implemented in educational institutions (Cortés Rodríguez et al., 2022; Park and Kim, 2022; Rocha et al., 2022). The production highlights the virtues of the Metaverse in educational contexts and the feasibility of implementing these immersive environments through research results.

There is a constant of placing the Metaverse and mirror worlds equally as immersive spaces in educational contexts during the period analyzed. As seen in the results, the distance between the total publications related to mirror worlds and virtual reality is evident (n = 84). However, virtual reality is the second most studied type of Metaverse. Consider that Kye et al. (2021) recognize the enormous potential of mirror worlds with digital laboratories and virtual educational spaces that reflect the real world or software such as Zoom or Google Earth. There is a tendency for studies to analyze disruptive environments where emerging ways of understanding a situation and collaborations in real time can be generated.

Concerning the types of thinking that could be developed in the Metaverse, a predominance of studies focused on innovative thinking and systematic thinking. In the results, it was found that the difference between the publications of innovative thinking ($n = 69$) and systemic thinking ($n = 69$) with critical thinking ($n = 47$) and scientific thinking ($n = 46$) was almost double. According to Ramírez-Montoya et al. (2022), critical thinking is the intellectual process generated through observation, experience, reflection, and reasoning or communication. Scientific thinking is higher-order thinking involving logical, analytical, systematic, inductive, and deductive thinking to solve problems. From this point, it was possible to identify the importance of promoting virtual spaces that encourage developing both types of thinking, critical and scientific, since they are critical thoughts for any professional who enters the labor field. Therefore, the importance of

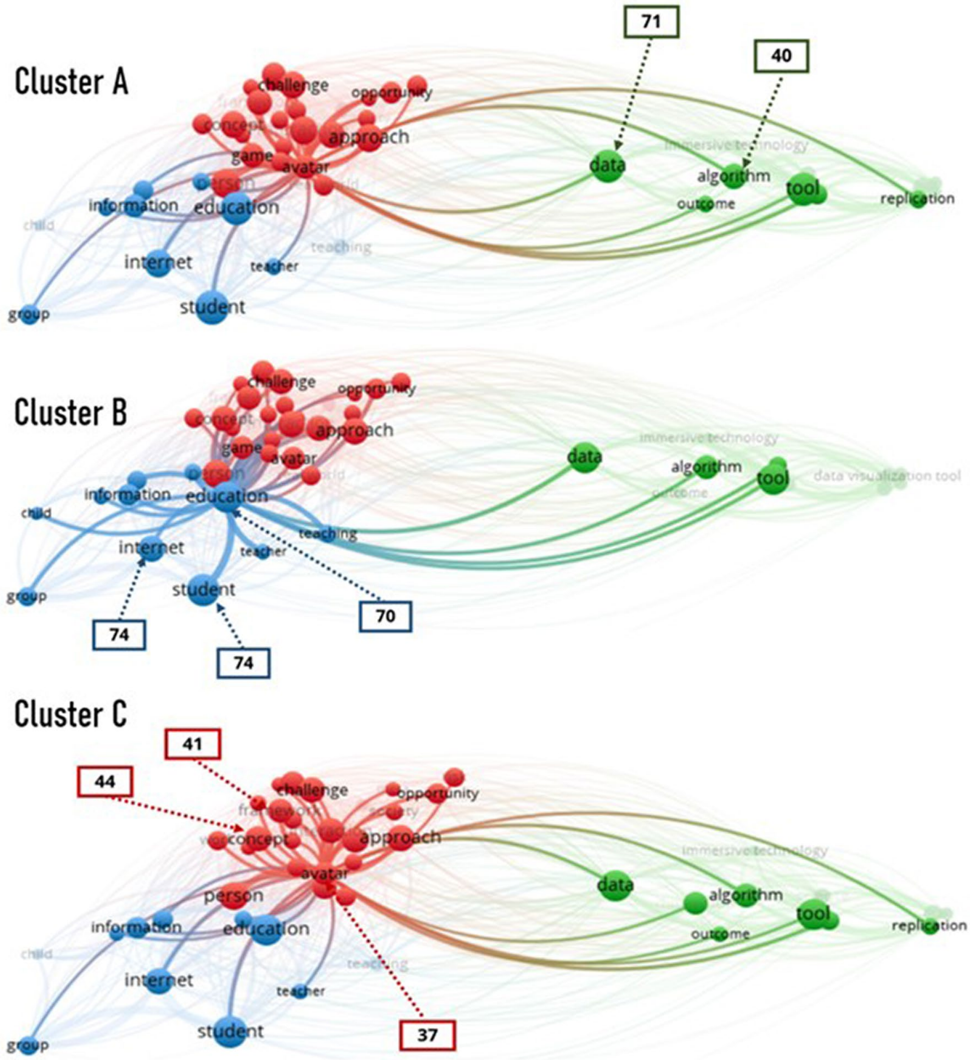

FIGURE 11
Semantic map by keywords.

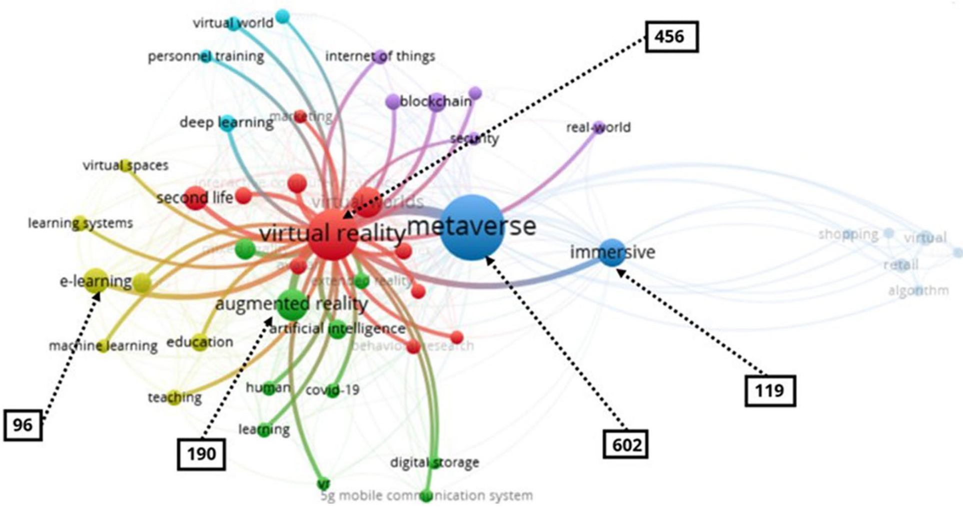

FIGURE 12
Analysis by summary.

TABLE 5 Questions that emerge from the MV-E4.0 linking.

PC components	Possible research questions
ST	What frameworks and taxonomies must be built to design successful learning spaces in the Metaverse?
CF	From the complex thinking perspective, how should instruments be designed to assess the impact, acceptance, and perception of the Metaverse's implementation to offer alternative realities for work, education, health, and marketing?
CR	How must technologies evolve to migrate metaverses to an integrated network of virtual worlds that generate immersive realism, the ubiquity of access and identity, interoperability, scalability, digital security, and personal data protection?
IN	What challenges must be overcome so training methodologies can be developed in the Metaverse that contribute to better understanding?

CF, scientific thinking; ST, systemic thinking; CR, critical thinking; IN, innovative thinking.

immersive environments that promote critical and scientific thinking in future research is recognized.

It is necessary to develop three-dimensional worlds that allow multidimensional communication channels that significantly attract users to promote the development of critical thinking. The studies showed that current academic research concerning the reflection and observation of the students in their environment is limited. However, the Metaverse can promote the ability to actively and skillfully conceptualize, apply, analyze, synthesize, and evaluate information acquired or generated through observation, experience, reflection, reasoning, or communication. Virtual campuses can positively impact society and provide students with an interactive environment that links to and impacts the physical world (Duan et al., 2021). Thus, it is viable to promote more studies that guide students' critical thinking within these immersive environments so that they can transfer these skills to the physical world and their work fields when they finish their professional training.

Finally, there is a study space between Complex Thinking and the Metaverse. The results identified that the Metaverse includes complex virtual spaces where participants develop complex thinking skills such as collaborating, managing, and communicating with their peers. Likewise, studies established that the Metaverse encompasses community spaces where content can be accessed and members can interact. However, Park and Kim (2022) recognized that Metaverse approaches need to be applied concerning user interaction, implementation, and application. Analysis of these new models and approaches within emerging metaverses is still lacking. Therefore, the field is open to generating knowledge and focusing studies on analyzing the development of complex thinking and student learning within the Metaverse with new models and approaches in these virtual environments.

5. Conclusion

Concerning the study's central question, how can research on the Metaverse be categorized within the framework of complex thinking, and what lines of knowledge generation can be promoted? It was found that, after analyzing the systematic literature review, we could corroborate three clusters or organizers of publications in both questions, highlighting the following:

Cluster A is related to data analysis research, where the application of algorithms to assess interaction in virtual worlds comes into play.

Cluster B considers formal and non-formal academic experiences, emphasizing usability and acceptance and a means to access rich content and interactions.

Cluster C refers to the frameworks and methodologies to design innovative experiences and reconfigure environments where the Multiverse can be used.

It is worth mentioning that, in the direct review of the categorization of studies of the Metaverse without links to complex thinking, until 2022, they were mainly organized into four categories: (a) mirror worlds, (b) virtual reality, (c) lifelogging, and (d) augmented reality.

Recognizing that Complex Thinking is made up of four sub-competencies: systemic, scientific, critical, and innovative thinking, we return to the table of questions triggered where the topic of future lines of research between Complex Thinking and the Metaverse was addressed. We highlight that the lines of knowledge generation to be promoted are related to the reference frameworks and taxonomies for the design of learning environments in the Metaverse, the design of instruments to assess the impact, acceptance, and perception of the Metaverse in different areas of life such as education, and the integration of the Metaverse and its different mirror worlds to validate its immersive realism, ubiquity, interoperability, scalability, digital security and protection of personal data. Finally, future research can consider new ways to drive training with better results in immersive environments of the Multiverse.

The Metaverse is a topic with very recent interest, as seen in the SLR, so naturally, more scientific publications should appear that account for formal and non-formal learning experiences in the Metaverse, with which other research lines can contribute to the field of knowledge. In addition, with the imbrication of the Metaverse and Complex Thinking, other lines of study can promote each of the four types of thinking and their relationship with an environment that fosters cognitive abilities sufficient for the Knowledge Society and Education 4.0.

One of the limitations of this study is that the recovery of the selected articles was limited to the first semester of 2022, which surely left out publications that came to light at the end of that year. Another area of opportunity is that as it is a bibliographical investigation, it needs to be periodically updated and renewed to include the generation of knowledge from subsequent years.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

IP, CG-R, and LG-M contributed to conception and design of the study. IP and CG-R organized the database. CG-R performed the statistical analysis and wrote the manuscripts. IP wrote discussion. LG-M wrote the results. All authors contributed to manuscript revision, read, and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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