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IMMERSIVE CHILDHOODS AND ALGORITHMIC COMMUNICATION: A BIBLIOMETRIC ANALYSIS OF IDENTITY AND MISINFORMATION IN GENERATIVE METAVERSES (2010–2025)

Rafael Braza Delgado:
University of Cádiz. Spain.
rafael.brazadelgado@alum.uca.es

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ABSTRACT

Introduction: This study explores how immersive childhoods shape emerging forms of identity, learning, and exposure to misinformation within generative metaverses between 2010 and 2025. **Methodology:** Using an exploratory and descriptive bibliometric approach, a systematic review was conducted in accordance with the PRISMA-S guidelines, utilizing the Scopus and Web of Science databases and a process of data cleaning, standardization, and analysis using Bibliometrix and Biblioshiny in R. **Results**: The final corpus, consisting of 383 documents and 216 sources, allowed patterns of productivity, collaboration, and conceptual co-occurrence to be identified regarding algorithmic communication and artificial intelligence as applied to the digital childhood. **Discussion:** Findings reveal steady scientific growth, four major thematic clusters—algorithmic infrastructure, immersive

learning, machine-learning optimization, and semantic communication—and above-average international collaboration within the social sciences. Ethical and educational gaps emerge in child representation and data governance, indicating an early stage of interdisciplinary maturity. **Conclusions:** Research on generative metaverses and digital childhoods demands explainable analytical frameworks, algorithmic literacy, and child-protection strategies grounded in equity, transparency, and responsible design.

Keywords: algorithmic literacy; digital communications; misinformation; child identity; artificial intelligence; generative metaverses.

1. INTRODUCTION

1.1 Generative metaverses and immersive realities

The metaverse has evolved into a socio-technological ecosystem where generative artificial intelligence (AI), extended reality (XR), and digital economies converge. It is configured as a hybrid environment that combines hardware, software, and content for immersive and persistent experiences, materializing the interactivity and embodiment of algorithmic culture (Park & Kim, 2022).

The incorporation of generative models and *machine learning techniques* drives adaptive environments capable of creating and evaluating information in real time. The integration of large-scale language models (LLM) in mixed reality (MR) strengthens collaboration between humans and synthetic agents, giving rise to generative metaverses, where AI acts as a symbolic and cognitive mediator (Xu et al., 2024).

In the educational field, the metaverse transforms teaching through simulation and personalization. Damaševičius and Sidekerskienė (2024) distinguish five types of virtual worlds—adventure, simulation, creation, role-playing, and collaboration—that promote critical thinking and cooperation. In higher education, Garlinska et al. (2023) and Ilić et al. (2021) find that integrating AI and XR leads to greater motivation and retention, while Zhang (2023) highlights their potential for creating safer and more stimulating preschool environments.

Despite its advantages, immersive education with AI raises ethical and social challenges—digital divide, privacy, and algorithmic governance—that demand regulatory frameworks and critical literacy (Almarzouqi et al., 2022; Garlinska et al., 2023; Ilić et al., 2021).

1.2. Immersive Childhoods of Generation Alpha

Generation Alpha, born since 2010, is the first to fully develop within digital and algorithmic ecosystems. Their socialization occurs at the intersection of platforms,

artificial intelligence (AI), and extended reality (XR), generating multisensory learning and identities shaped by predictive systems (Damaševičius & Sidekerskienė, 2024; Ilić et al., 2021; Park & Kim, 2022; Tlili et al., 2022; Zhang, 2023).

On a cognitive level, XR and AI enhance attention and experiential learning (Ilić et al., 2021; Zhang, 2023). In terms of identity, avatars and algorithmic personalization operate as symbolic extensions of the digital self (Park & Kim, 2022; Tlili et al., 2022). In the communicative sphere, generative AI fosters the co-creation of collaborative narratives (Nalbant & Aydın, 2023; Xu et al., 2024).

However, excessive personalization can limit creativity and create tensions between autonomy and algorithmic control, which calls for transparent design policies and explainability principles that strengthen children's digital agency (Almarzouqi et al., 2022; Tlili et al., 2022).

1.3. Algorithmic Communication, Digital Identity and Disinformation

Generative AI applied to mixed reality expands collaboration, but raises dilemmas about authorship, authenticity, and creative attribution (Xu et al., 2024). Symbolic economies based on non-fungible tokens (NFTs) tend to commodify identity and digital representation (Nalbant & Aydın, 2023), while avatars function as symbolic and affective mediations of self-image in immersive educational contexts (Tlili et al., 2022).

The interaction between AI and virtual economies increases exposure to disinformation and opaque recommendation systems. Park and Kim (2022) warn of the ethical and cognitive risks of automatically generated content and the need to promote transparency and algorithmic verification. Without media literacy and data ethics, these processes can reinforce erroneous beliefs and confirmation bias in childhood (Tlili et al., 2022).

1.4. Gaps and Convergences

The specialized literature between 2010 and 2025 identifies four major axes of convergence and structural gaps in the field of immersive childhoods and algorithmic communication:

1. Immersive education with XR and AI: The literature shows evidence of more interactive and personalized learning (Damaševičius & Sidekerskienė, 2024), although still focused on the technological infrastructure rather than the socio-emotional aspect.

2. Algorithmic mediation of cognition, identity, and communication: Generative metaverses reconfigure the cognitive and symbolic processes that underpin identity and agency (Tlili et al., 2022).

3. Child protection and algorithmic transparency: The urgency of ethical frameworks, regulation and data governance that guarantee privacy and explainability is emphasized (Park & Kim, 2022).

4. Lack of longitudinal studies: There are persistent deficiencies in long-term research on identity and childhood misinformation, which limits the pedagogical and political projection of the field.

The study of the link between generative metaverses and childhood is in an incipient phase of maturity: technically sound, but weak in its ethical and normative development.

1. 5. MMAI-GA Model and Ethical Projection

The Algorithmic Mediation Model for Children – Generation Alpha (MMAI-GA) synthesizes three interdependent mediations that structure the experience of childhood in generative environments:

- Cognitive, supported by Ilić et al. (2021) and Zhang (2023)
- Identity-based, based on Park and Kim (2022) and Tlili et al. (2022)
- Communicative, supported by Nalbant and Aydın (2023) and Xu et al. (2024)

The model explains how generative AI shapes children's digital agency, positioning children not as passive users, but as co-creators of digital knowledge and culture.

1.6. Problem-Posing Tension

The rapid growth of immersive environments contrasts sharply with the lack of child-centered pedagogical and ethical frameworks. Generative metaverses amplify AI-generated content production, blurring the lines between the real and the synthetic.

Understanding how these metaverses shape children's identity, agency, and exposure to misinformation requires analyzing how AI models learning, personalizes communication, and redefines the notion of truth in educational contexts. Algorithmic opacity and the automation of socialization generate risks that necessitate critical algorithmic literacy (Tlili et al., 2022) to strengthen children's autonomy in the face of AI's invisible mediations.

1.7. Relevance and Originality of the Study

This work makes a threefold contribution to the field of algorithmic communication and digital childhoods:

1. Theoretical: It proposes the MMAI-GA Model, which integrates cognitive, identity, and communicative mediations of generative AI (Park & Kim, 2022; Tlili et al., 2022; Xu et al., 2024).

2. Methodology: It applies a bibliometric analysis (2010–2025) with Biblioshiny, following the guidelines of Donthu et al. (2021), to map trends, authors and epistemological networks.

3. Critique: It identifies ethical gaps and child representation, proposing a non-adult-centric approach with a digital rights perspective.

The study is situated at the intersection of generative AI, immersive education and children's cognitive justice, contributing to the construction of a communicative paradigm based on algorithmic fairness.

2. OBJECTIVES

2.1. General Objective

To critically analyze, using a bibliometric approach (2010–2025), the evolution, thematic treatment and academic representation of digital identity, communicative agency and disinformation in childhood —with emphasis on Generation Alpha— within the scientific literature on generative metaverses and artificial intelligence.

2.2. Specific Objectives

- To map the scientific evolution of the field of study on metaverses, generative AI and immersive education through analysis of term co-occurrences, thematic maps (centrality/density), co-authorship and co-citation networks, as well as productivity and impact indicators (h-index, g-index, m-index, Bradford's Law and Lotka's Law).
- To identify the thematic and ethical gaps in the corpus, especially regarding child representation, algorithmic transparency, and data governance in XR environments, based on their low frequency, centrality, or density in bibliometric clusters.
- To apply and theoretically contrast the Model of Algorithmic Mediation of Children – Generation Alpha (MMAI-GA) with bibliometric evidence, evaluating its coverage and coherence through the presence and co-occurrence of categories associated with cognitive, identity and communicative mediations.
- To interpret the communicative and educational implications arising from the academic treatment of generative AI in relation to digital identity and disinformation, recognizing emerging trends, narratives, and risks in the international corpus.

- To propose guidelines for the Alpha 2030 Agenda, focused on algorithmic literacy, the protection of digital rights, and the ethical governance of immersive environments for children, based on bibliometric findings and the MMAI-GA theoretical framework.

3. METHODOLOGY

3.1. Nature of the Study

The study adopts an exploratory-descriptive design, without hypothesis testing, to map structural patterns, collaboration, and thematic cores in the literature on generative metaverses, artificial intelligence, and algorithmic communication applied to childhood (Generation Alpha) between 2010 and 2025. From science to science (Fortunato et al., 2018), bibliometrics is conceived as an epistemological instrument that links the evolution of knowledge with the MMAI-GA model. Its selection reflects the early maturity and high interdisciplinarity of the field, offering a systematic and reproducible reading through indicators of productivity, impact, and co-occurrence, consistent with science mapping and performance analysis (Aria & Cuccurullo, 2017; Donthu et al., 2021; Waltman, 2016).

3.2. Objectives of the Review

The bibliometric review was aimed at empirically supporting the MMAI-GA model through five purposes:

1. To characterize the scientific production on metaverses, artificial intelligence and algorithmic communication linked to digital childhoods.
2. To identify networks of collaboration and institutional and international leadership.
3. To delimit thematic clusters by co-occurrence of keywords, linking them with the cognitive, identity and communicative mediations of the MMAI-GA.
4. To describe the phases of domain development in relation to the diffusion of innovations (Rogers, 2003).
5. To ensure traceability and reproducibility by applying PRISMA-S (Rethlefsen et al., 2021).

3.3. Information Sources and Search Strategy

The review was conducted in Scopus and Web of Science (WoS), recognized for their thematic breadth and quality control (Donthu et al., 2021). The objective was to identify publications on generative metaverses, artificial intelligence—including generative AI—and algorithmic communication linked to childhood and digital

education. Key terms and metadata were kept in English to ensure terminological consistency and reproducibility in accordance with PRISMA-S (Rethlefsen et al., 2021).

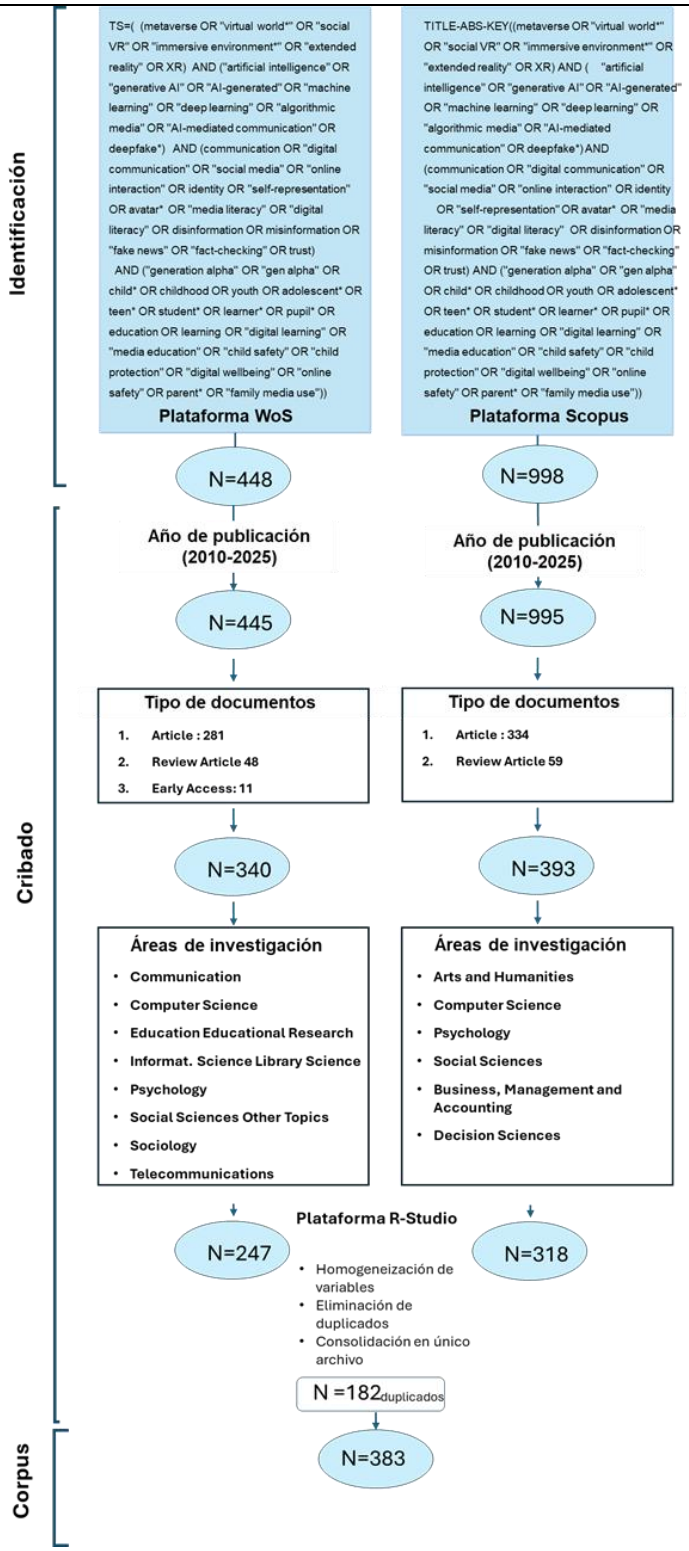
The search sequences, executed in September 2025 (see Figure 1), combined Boolean operators and wildcards: metaverse, virtual world, social VR, extended reality, artificial intelligence, generative AI, deep learning, algorithmic media, AI-mediated communication, disinformation, identity, digital literacy, generation alpha and child safety.

In Scopus, TITLE-ABS-KEY was applied, obtaining 995 initial records, reduced to 318 after filters by year (2010–2025), document type (article, review) and subject areas (Arts and Humanities; Computer science; Psychology; Social Sciences).

In WoS, the TS= (Topic) operator was used, retrieving 445 records, of which 247 met the same filters by area and type. The distinction between TITLE-ABS-KEY and TS= ensured functional equivalence between databases and avoided syntax bias.

Figure 1.

Document Selection Workflow Based on Records Retrieved From Scopus and Web of Science Core Collection for the Period 2010–2025



Source: Elaborated by the author using records retrieved from Scopus and Web of Science Core Collection using searches performed in September 2025. The selection flow was adapted from PRISMA-S (Rethlefsen et al., 2021) and PRISMA 2020 (Page et al., 2021).

Excluded were: grey literature, records without abstracts or keywords, duplicates, studies focused on adult populations, and works outside the time frame.

3.4. Corpus Screening and Purification Process

The data were managed in R using Bibliometrix / Biblioshiny (Aria & Cuccurullo, 2017). A documented process of conversion, integration, and deduplication was applied using DOI and literal title matching, normalizing fields and verifying thematic consistency.

The final corpus, as shown in Table 1, combined 383 unique documents, 216 sources, and 1,274 authors, with 2,432 signatures (average of 4.54 per document) and 41.3% international collaboration.

Table 1

Main Characteristics of the Bibliometric Corpus (2010–2025)

Indicator	Worth
Documents analyzed	383
Academic sources	216
Period	2010–2025
Single author	1,274
Total signatures	2,432
Co-authored average	4.54
International collaboration (%)	41.3

Source: Elaborated by the author using data extracted from Scopus and Web of Science (accessed September 2025) using Bibliometrix / Biblioshiny.

3.5. Conceptual Selection for the Theoretical Framework

From the combined and refined corpus, a semantic filtering was applied in R, based on regular expressions and lexical matching, to identify the most relevant documents according to four thematic axes: (a) childhood and youth, (b) metaverses and extended reality, (c) artificial intelligence and machine learning, and (d) communication, identity and disinformation.

Each record in the derived dataset was classified by the binary presence of terms associated with each axis. For the final selection, an intersection rule was applied (Alpha Generation + at least one additional axis), which allowed the isolation of publications that explicitly link childhood and algorithmic technologies, preserving conceptual relevance.

An impact threshold of the 80th percentile of total citations (TC) was established to prioritize scientific visibility. The combination of thematic relevance and citation impact ensured a balance between representativeness and quality. After validating the time range (2010–2025) and eliminating duplicates due to title matching, a subset of thirteen articles was obtained, forming the empirical basis of the theoretical

framework and the validation of the MMAI-GA model, as they reflect the convergence between cognition, identity, and algorithmic communication in immersive environments.

3.6. Analytical Tool Used

The analysis was performed entirely with Bibliometrix (R) and its Biblioshiny interface, guaranteeing traceability, reproducibility and good scientific practice.

For the analysis of networks and co-occurrence of keywords, a network design was used with automatic layout, normalization by association, elimination of isolated nodes, a minimum of two links per node, and a visualization limited to the 50 most relevant nodes, with repulsion strength set at 0.1.

Community detection was performed using the Walktrap algorithm, without color coding by year of publication.

Five modules were applied: (1) scientific performance, evaluating annual production, citations and h, g and m indices; (2) source structure, using Bradford's law; (3) co-authorship networks, with centrality measures and cluster detection; (4) keyword co-occurrence, through Louvain's algorithm; and (5) thematic mapping, classifying topics into engines, basic, niche and emerging (Callon et al., 1991).

3.7. Performance Analysis

Performance analysis showed sustained growth in scientific output between 2010 and 2025, with four evolutionary phases: exploratory (2011–2013), early adoption (2017–2019), consolidation (2020–2021), and maturity/expansion (2022–2025). An average of 4.54 authors per document and an international collaboration rate of 41.3% demonstrate high levels of interdisciplinary cooperation. Bradford's and Lotka's laws confirmed a productive concentration in IEEE/ACM journals and a dispersion toward educational and ethical-regulatory areas, reflecting a field in its early stages of development.

3.8. Thematic Analysis and Conceptual Mapping

Thematic mapping structured the domain according to centrality and density, based on co-occurrence networks normalized by association and grouped using the Walktrap algorithm, identifying four clusters: (1) algorithmic infrastructure and digital security (metaverse, AI, blockchain, 6G, edge computing); (2) immersive experience and extended learning (virtual/ augmented reality, education); (3) machine learning and optimization (machine learning, federated learning, privacy preserving); and (4) semantic communication and distributed cognition (semantic communication, semantics).

The domain combines consolidated technical cores with emerging peripheries oriented towards immersive education and AI ethics, reflecting the early maturity described by Bornmann and Mutz (2015) and Waltman (2016). Clusters 2 and 4 integrate terms associated with learning, identity and communication — avatar, trust, education, representation —, empirically validating the mediations of the MMAI-GA model.

The methodology combines systematic review and bibliometric analysis, applying criteria of transparency, comprehensiveness, and reproducibility. Triangulation between PRISMA-S and Bibliometrix ensures documentary rigor and analytical depth, placing the study at the forefront of science of science applied to digital communication.

4. RESULTS

4.1. Overview of Scientific Production (2011–2025)

The bibliometric analysis conducted with Biblioshiny (September 2025) reveals a four-part evolution in research on immersive childhoods and algorithmic communication in generative metaverses: an exploratory phase, an early adoption phase, a consolidation phase, and a phase of accelerated maturity and expansion. This behavior mirrors Rogers' (2003) model of technological diffusion and aligns with the maturation patterns of emerging fields described by Donthu et al. (2021) and Waltman (2016), in addition to coinciding with the models of scientific evolution identified by Fortunato et al. (2018) in the science of science.

Table 2 summarizes the temporal evolution, productivity, and average impact of the different cohorts.

Exploratory Phase (2011–2013)

Between 2011 and 2013, only three isolated articles focused on virtual environments and immersive learning platforms were identified (MeanTCperArt = 18–39). This corresponds to the "innovators" stage of Rogers (2003), characterized by low productivity and the absence of cohesive scientific communities.

These initial contributions address augmented reality and 3D virtual campuses, anticipating the edu-metaverse line that will gain relevance in later years.

Early Adoption Phase (2017–2019)

After a period of latency (2014–2016), a reactivation is observed with two articles in 2017, one in 2018, and four in 2019 (MeanTCperArt = 13.75). This phase marks the transition from conceptual exploration to initial applications, with links between artificial intelligence and conversational agents and social virtual worlds.

International co-authorship (30.03%) is beginning to consolidate, although predominantly theoretical approaches persist.

Consolidation Phase (2020–2021)

During 2020 and 2021 the field experienced a qualitative and quantitative leap, with 15 publications and a high average impact (MeanTCperArt = 92.20 in 2020; 34.90 in 2021).

This period coincides with the publication of extensive reviews (surveys) on neural rendering, digital twins and 6G communications, which function as citation anchors of the domain (Tewari et al., 2020).

According to Donthu et al. (2021), this type of methodological synthesis increases the visibility and impact of emerging fields, a phenomenon corroborated in this corpus.

Maturity and Accelerated Expansion Phase (2022–2025)

Between 2022 and 2025 the area enters a stage of exponential growth, with 37 articles in 2022, 85 in 2023, 131 in 2024 and 105 in 2025. More than 93.5% of the total production is concentrated in this four-year period, which suggests the thematic maturity and the expansion towards issues of digital identity, ethics, privacy and algorithmic governance.

The decline of MeanTCperArt (from 82.05 in 2022 to 1.77 in 2025) is interpreted as citation dilution, a phenomenon typical of rapidly expanding areas (Bornmann & Mutz, 2015; Waltman, 2016).

In parallel, the literature is diversifying with the incorporation of *reviews* (42) and empirical studies applied to generative AI, immersive education learning and real-time communication, reflecting a transition towards methodological maturity.

Indicator Analysis

The combined evolution of the MeanTCperArt, N, MeanTCperYear and CitableYears indicators (Table 2) confirms a progressive consolidation, with an average annual growth rate of 39.43%.

The 2020 and 2022 cohorts show the highest citation intensity, while the 2024–2025 cohorts express a sustained expansion typical of tech-driven domains.

This dynamic mirrors the diffusion curve described by Rogers (2003) and the maturation models of Donthu et al. (2021), with the cognitive expansion and diversification observed in the analyses by Fortunato et al. (2018) on disciplinary evolution.

Table 2

Overview of Scientific Production (2011–2025)

Phase	Year	MeanTCperArt	N	MeanTCperYear	CitableYears
Exploratory Phase	2011	27	1	1.80	15
	2012	18	1	1.29	14
	2013	39	1	3.00	13
Early Adoption	2017	91	2	10.11	9
	2018	11	1	1.38	8
	2019	13.75	4	1.96	7
Consolidation	2020	92.20	5	15.37	6
	2021	34.90	10	6.98	5
Maturity And Accelerated Expansion	2022	82.05	37	20.51	4
	2023	28.35	85	9.45	3
	2024	11.02	131	5.51	2
	2025	1.77	105	1.77	1

Source: Elaborated by the author based on Biblioshiny (September 2025).

The metadata and keywords of the corpus reveal four main lines in the thematic evolution of the field:

1. Infrastructure and communications: 6G, edge computing, semantic /multimodal communication, federated learning and digital twin.
2. Immersive experience and avatarization: neural rendering, gesture generation, lip-sync, BCI (brain-computer interface) and embodied agents.
3. Applications in education and health: edu-metaverse, XR learning [extended learning] and healthcare metaverse, focused on children's digital identity and data governance.
4. Security and trust: intrusion detection, privacy-preserving, blockchain identity and federated unlearning.

These fronts explain the citation peaks of 2020 —synthesis on neural rendering (Tewari et al., 2020)— and 2022 —edu-metaverse ecosystem and digital twin /6G (Khan et al., 2022; Tlili et al., 2022)—, which served as cognitive bases for the field.

The early maturity phase (2024–2025) is characterized by methodological refinement based on semantic-aware XR, human digital twins, and QoE/QoS [quality of experience and service] metrics in XR streaming. At the same time, evaluation focused on user experience, privacy-by-design, and governance is being consolidated, highlighting the transition from a technical approach to a socio-communicative perspective.

Quantitative and thematic evidence shows that research on generative metaverses and algorithmic communication in digital childhoods has moved from scattered contributions to a consolidated, interdisciplinary, and collaborative core.

The accelerated growth, an average co-authorship of 4.54, and the citation peak between 2020 and 2022 reflect a field in early maturity, oriented toward epistemological diversification and interdisciplinary integration. This pattern coincides with the models of cognitive maturity and thematic expansion described by Bornmann and Mutz (2015) and Fortunato et al. (2018) for frontier technologies.

4.2. Publications

Analysis of academic sources reveals a high concentration in a small core of journals, consistent with Bradford's Law (Bradford, 1934; Pope, 1975; Yu, 2022) and with the concentration/dispersion patterns identified in tech-driven fields (Donthu et al., 2021; Waltman, 2016). Applied to the 383 documents analyzed using Biblioshiny (September 2025), the law made it possible to categorize three productivity areas based on frequency and impact (h, g, and m).

Bradford Distribution (383 items; 216 sources)

- Area 1 – Core: 15 sources, 127 articles (33.2%).
- Area 2 – Intermediate: 75 sources, 130 articles (34.0%).
- Area 3 – Peripheral: 126 sources, 126 items (32.9%).

  Bradford multiplier: 1: 5: 8.4 (core: zone 2: zone 3).

4.2.1. Publication Core (Area 1)

Area 1 brings together 15 journals that concentrate a third of the corpus and define the theoretical and methodological framework of the field as can be seen in Table 3.

Headers from the IEEE/ACM/Elsevier sphere predominate, focusing on communications, internet of things, networks, computer vision and electronics, indicating a predominance of infrastructural approaches in the consolidation of the generative metaverse.

Table 3

Most Productive and Influential Journals in the Core

Journal	Articles	H-Index	G-Index	M-Index	Total Quotes
IEEE Access	34	14	34	2	1,599
IEEE Internet of Things Journal	11	9	11	1.8	356
IEEE Communications Surveys y Tutorials	9	8	9	1.6	718
IEEE Journal on Selected Areas in Communications	10	8	10	2.7	237
IEEE Communications Magazine	9	5	9	1	503
IEEE Network	9	5	9	1	89
Sensors	7	7	7	1.2	402
IEEE Open Journal of the Communications Society	6	3	6	1	83
ACM Transactions on Multimedia Computing, Communications, and Applications	5	2	3	1	11
Electronics	5	3	5	1	76
IEEE Transactions on Consumer Electronics	5	3	5	1.5	58
IEEE Wireless Communications	5	3	5	1	53
ACM Transactions on Graphics	4	3	4	0.3	171
Computer Networks	4	3	4	0.8	120
IEEE Consumer Electronics Magazine	4	3	4	1	102

Source: Elaborated by the author based on Biblioshiny (September 2025).

Interpretive Reading

1. Methodological framework: *IEEE Access* and *IEEE Communications Surveys* and *Tutorials* act as citation anchors, consolidating frameworks on 6G, edge computing, semantic /multimodal communication and digital twin.

2. Visual and expressive axis: *ACM Transactions on Graphics* articulate neural rendering, gesture Generation and avatarization, which are essential to understanding digital identity.

3. Consumption and experience axis: *IEEE Transactions on Consumer Electronics* and *IEEE Wireless Communications* analyze devices and quality of experience (QoE) and service (QoS) metrics in immersive environments.

The core area exhibits high h and g indices, a predominance of recent surveys (2019–2025) and a clear technological maturity, although attention remains focused on infrastructure rather than on communicative and ethical dimensions.

4.2.2. Intermediate and Peripheral Areas (Area 2 and 3)

Area 2 (75 sources; 130 articles) broadens the focus to include human-computer interaction, immersive learning, digital psychology, and AI-powered educational systems. Journals highlights: *Interactive Learning Environments* (4 articles; h = 3; TC = 105), *IEEE Transactions on Learning Technologies* (3; h = 3; TC = 174), *International Journal of Human–Computer Interaction* (3; h = 1; TC = 6), *Cyberpsychology, Behavior, and Social Networking* (2; h = 2; TC = 17) and *Smart Learning Environments* (1; h = 1; TC = 245), with high impact in edu -metaverse.

Area 3 (126 sources; 126 articles) evidence thematic and disciplinary diversification, integrating publications about Ethics, law, media, education, health and culture (*LAWS, Journal of Law, Medicine and Ethics, Media and Communication, Technology, Knowledge and Learning, Spanish Journal of Marketing – ESIC),* among others. Its role is exploratory and cpmprehensive, addressing governance, privacy-by-design, AI ethics, algorithmic transparency and protection of children's identity.

This pattern confirms Bradford's Law, where each area contributes about a third of the total, reflecting the coexistence between a consolidated technological core and dynamic and specialized peripheries.

4.2.3. Disciplinary Coverage

1. Infrastructure bias: The core emphasizes networks and telecommunications (IEEE, ACM), with relative underrepresentation of sources in ethics, law or education.

2. Interdisciplinary bridges: Area 2 acts as an interface between computer science and communication, particularly in human-computer interaction. interaction, educational technology and healthcare metaverse.

3. Ethical and regulatory coverage: Journals such as *LAWS* (2025) and *Journal of Law, Medicine and Ethics* (2022) open space for frameworks of AI accountability, data governance and privacy for minors.

4. Geographic dimension: High presence of European (Elsevier, MDPI) and Asian (IEEE, Springer) journals, with a predominance of international collaborative production.

The structure of sources reproduces a cognitive gap between the technical (core) and the normative (periphery), reflecting the structural duality of the field: accelerated development of infrastructure versus slowness in ethical and communicational institutionalization.

4.2.4. Impact Based on the Source and Qualitative Reading

- *IEEE Access* (h = 14; TC = 1.599) is the most productive and influential header, acting as a vehicle for methodological consolidation (open access, high impact factor).
- *IEEE Communications Surveys & Tutorials* (h = 8; TC = 718) promotes cross-cutting theorizing through *surveys* of 6G architecture and connected metaverses.
- *ACM Transactions on Graphics* excels in neural rendering and avatarization, integrating technological and expressive dimensions.
- *Interactive Learning Environments* and *Smart Learning Environments* function as bridge journals between metaverse and education, addressing edu-metaverse, XR learning and immersive literacy.
- *LAWS* and *Journal Law, Medicine, and Ethics* are emerging as regulatory spaces on algorithmic governance and data protection in digital childhoods.

4.2.5. Areas for Progress

1. Epistemological balance: Promoting special interdisciplinary issues that integrate human- computer interaction interaction, algorithmic transparency and social communication.
2. Methodological standardization: Incorporating checklists for privacy-by-design, child data protection, and fairness auditing in core journals.
3. Empirical reinforcement: Encouraging longitudinal studies on children's digital identity, misinformation, and exposure to algorithmic content in XR environments.
4. Latin American agenda: Encouraging the inclusion of Ibero-American journals in visibility circuits, reducing the North-South gap in the scientific production of the educational metaverse.

4.3. Authors and Co-Authorship Networks

The analysis of scientific authorship reveals a concentrated and collaborative structure, where a small group of researchers articulates the core research on generative metaverses, artificial intelligence, and algorithmic communication. This pattern aligns with Lotka's (1926) Law and coincides with the maturity curves of tech-driven fields described by Donthu et al. (2021) and Waltman (2016).

The corpus processed in Biblioshiny (September 2025) comprises 383 articles, 1,274 unique authors, and 2,432 signatures, with an average of 4.54 per document, an indicator of high collaboration, typical of engineering and computing applied to immersive environments. The average authorship fraction (0.22) demonstrates distributed co-authorship and inter-institutional teams.

International collaboration (41.3%) confirms a transnational dynamic with a predominance of Asia (63.7% of core authorships), followed by Europe and North America, which reinforces the global orientation of the field and the relevance of multilateral academic networks in the production of knowledge on immersive technologies.

4.3.1. Core Authorship and Impact Metrics

The core group of authors (top 10) comprises the researchers with the highest productivity and impact during the period 2019–2025, primarily affiliated with universities in Asia and the Middle East. Table 4 summarizes their productivity and impact metrics, calculated using the corpus metadata.

Table 4

Productivity and Impact Metrics

Author	Main Institution	Articles	h - Index	g - Index	m - Index	Total Quotes
Dusit Niyato	Nanyang Technological University (Singapore)	14	10	14	2.5	622
Zehui Xiong	Singapore University of Technology and Design (Singapore)	11	8	10	1.8	404
Mohsen Guizani	Qatar University (Qatar)	10	8	9	1.7	368
Latif U. Khan	Kyung Hee University (South Korea)	8	6	7	1.5	315
Khaled M. Rabie	Manchester Metropolitan University (United Kingdom)	6	4	6	1.2	187
Huanhuan Wang	Beijing Institute of Technology (China)	5	4	5	1	164
Faizan Ahmad	University of Technology Malaysia (Malaysia)	5	3	5	0.9	139
Noor Zaman	King Faisal University (Saudi Arabia)	5	3	4	1.1	102

Source: Elaborated by the author based on Biblioshiny (September 2025).

The research group has h-index and g-index values above 6 and an average m-index of 1.6, indicators of consistent productivity and sustained visibility. The group's average tenure (3.7 years) indicates a young cohort, linked to recent developments

in federated learning, 6G communication and digital twin networking. These authors constitute an international scientific leadership community, in which the intensive production of articles is combined with the capacity for interdisciplinary articulation.

4.3.2. Collaboration Networks and Interpretive Synthesis

The co-authorship analysis performed in Biblioshiny (2025) was based on a normalized adjacency matrix (Fruchterman –Reingold), weighted by the number of joint publications. The network shows a density of 0.028, a mean closeness of 0.44, and an average betweenness of 13.7, with a core-periphery pattern and four interconnected clusters.

1. Infrastructure and edge intelligence, led by Dusit Niyato, Zehui Xiong and Mohsen Guizani; it is focused on semantics communication, federated learning and digital twin systems.

2. Immersive learning and XR education, led by Huanhuan Wang and Faizan Ahmad; it is focused on smart learning environments and immersive pedagogy.

3. Governance, privacy, and ethics, led by Khaled M. Rabie and Noor Zaman; it addresses privacy-preserving computing, data governance and AI accountability.

4. Social interaction and avatarization, with nodes in Korea, Japan, and China, it is dedicated to neural rendering, embodied agents and semantic XR.

The PageRank identifies Dusit Niyato (0.082), Zehui Xiong (0.067), and Mohsen Guizani (0.052) as the most influential nodes, acting as inter-cluster bridges. The network is cooperative but moderately fragmented, with technological cores progressively integrating with educational, social, and ethical areas.

Epistemologically, it reflects an early maturity of the field:

- The core maintains high technical inbreeding, concentrated in IEEE and ACM journals.

- The thematic peripheries show increasing interdisciplinarity with contributions from communication, psychology and law on identity, disinformation and child protection.

- Low density and multinodal links between communication algorithms and immersive learning marks a transition towards cognitive convergence, in line with Bornmann and Mutz (2015).

The authorship network creates a balanced ecosystem between technical consolidation and thematic diversification, articulated around Asian leadership with international projection, confirming the collaborative and interdisciplinary expansion of generative metaverses and their orientation towards an ethics of AI applied to digital childhoods.

4.4. Keyword Co-Occurrence Network

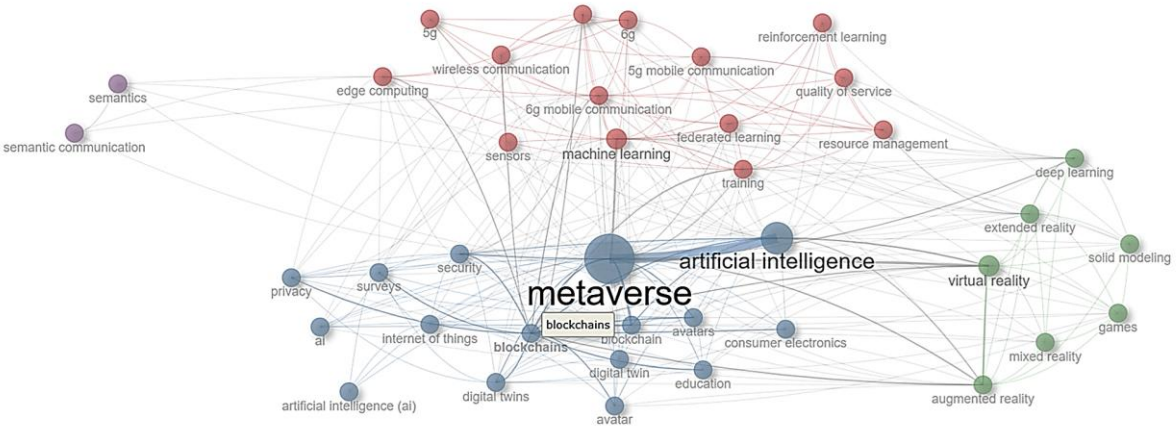
The analysis of the keyword co-occurrence network, generated in Biblioshiny (September 2025) and shown in Figure 2, identifies the semantic structure of the field on generative metaverses, artificial intelligence and algorithmic communication.

The network, with 73 nodes and 412 links, presents a heterogeneous and multi-core configuration, where "metaverse" is at the center (betweenness = 488.24; PageRank = 0.137), articulating technical, immersive and semantic subdomains.

The modular distribution obtained with the Louvain algorithm (resolution = 0.8) distinguishes four thematic clusters, interpreted according to centrality and density metrics (Donthu et al., 2021; Waltman, 2016).

Figure 1

Semantic Structure of the Field



Source: Elaborated by the author based on Biblioshiny (September 2025).

Cluster 1 – Algorithmic Infrastructure and Digital Security (Red)

It includes 46 terms related to the technological support of metaverses. The following stand out: "metaverse," "artificial intelligence," "blockchain," "6G mobile communication," "edge computing," and "security." High betweenness metrics (>100 in "metaverse" and "artificial intelligence") confirm their role as epistemological bridges.

The core articulates two axes:

1. Network infrastructure: "6G," "edge computing" and "wireless communication" supports the connectivity of the metaverse.
2. Technological governance: "blockchain," "privacy," "security" and "digital twin" form the layer of trust and traceability.

Bibliometrically, it constitutes the foundational core of the field, with high density and centrality, where communications engineering and artificial intelligence converge.

Cluster 2 – Immersive Experience and Extended Learning (Green)

With 18 nodes, it groups terms from the experiential and educational dimension: "virtual reality," "augmented reality," "extended reality," "deep learning," "education," "games" and "mixed reality."

"Virtual reality" (betweenness = 41.278; PageRank = 0.047) acts as a central peripheral node that links the technical aspect with "user experience". Its moderate density and connection to Cluster 1 through "artificial intelligence" and "digital twin" demonstrate an emerging consolidation, focused on the convergence between "extended reality" and "AI- driven education".

The group reflects the expansion of the metaverse towards immersive learning (XR learning) and digital literacy, with an impact on identity and children's socialization, in accordance with "educational data ethics".

Cluster 3 – Machine Learning and Resource Optimization (Light Red)

Compound for 16 terms, it is organized around "machine learning" (betweenness = 29.106; PageRank = 0.041), "federated learning," "reinforcement learning," and "resource management." It represents the most technical component of the ecosystem, oriented towards the development of predictive and adaptive models.

The connection between "federated Learning" and "privacy-preserving" reveals an attempt to balance algorithmic efficiency and data protection. Its intermediate density indicates early methodological maturity, with potential for expansion into digital health and adaptive education. This subspace supports the hypothesis of the progressive technologization of the metaverse, where optimization gradually replaces human interaction (Waltman, 2016).

Cluster 4 – Semantic Communication and Distributed Cognition (Purple)

Less dense and the main nodes are "semantic communication" and "semantics." This cluster presents low centrality (betweenness < 1.2; PageRank ≈ 0.01) but high

disruptive potential, by connecting semantics, communicative efficiency and contextual understanding of AI.

It reflects the transition from syntactic communication to semantic-aware networking models, which enables interoperability between humans, virtual agents, and smart devices. This anticipates the shift from a graphical metaverse to a cognitive infrastructure, where semantics will be central to interaction.

The global network (Figure 2) exhibits a hierarchical topology dominated by "metaverse" and "artificial intelligence," pivotal terms with high betweenness and PageRank that articulate the other domains.

Clusters 1 and 3 concentrate a higher density of associations, demonstrating technical and infrastructural hegemony, while clusters 2 and 4 act as emerging areas oriented towards immersive experience and cognitive semantics.

Epistemologically, the coexistence of consolidated cores and active peripheries confirms the transition toward early maturity (2022–2025) with increasing interdisciplinary integration. However, the scarce presence of terms such as "ethics," "transparency," or "governance" reveals a normative gap, consistent with the patterns described in AI bibliometrics (Donthu et al., 2021).

The co-occurrence network reflects a technologically robust but ethically nascent ecosystem, where advances in infrastructure and machine learning outpace the adoption of communicative and child-protection approaches. This imbalance suggests the advisability of jointly analyzing technical efficiency and ethical responsibility in future research on algorithmic communication and immersive childhoods.

4.5. Thematic Areas

The thematic map, generated with Biblioshiny (September 2025), organizes the domain according to centrality (structural relevance) and density (degree of development), following the model of Callon et al. (1991) and Cobo et al. (2011). The interpretation combines betweenness, closeness, and PageRank (Donthu et al., 2021; Waltman, 2016) calculated for each cluster.

Motor themes (high centrality and density)

In the upper right quadrant, three consolidated poles stand out:

- Metaverse – artificial intelligence – machine learning: greater centrality (betweenness ≈ 3,900; PageRank ≈ 0.06) and includes "deep learning," "virtual reality," "blockchain," "security," and "digital twins" constitute the techno-infrastructural backbone of the field.

- Federated learning – training – 6G mobile communication: the core of distributed computing with high value regarding "resource management "(betweenness = 436.7) and links with "edge intelligence, an indicator of methodological maturity.
- Semantics communication – semantics – sensors: high density block (betweenness = 1,075.3) that positions semantics as a vector of communicative efficiency.

The corpus literature places distributed learning, 6G/ edge infrastructures and the semantic layer associated with the optimization of transmission and meaning as central axes (Aria & Cuccurullo, 2017).

Basic themes (High Centrality, Low Density)

It brings together consolidating labels that link technical and communicative domains: "communication," "social networks," "virtual worlds" and "affective" computing systems act as bridges between infrastructure and interaction.

The cluster "applications" (betweenness ≈ 1,000) maintains low density, and "gamified learning" and "cyberbullying" link immersive technology with education and child protection.

These topics serve as a basis for transferring the infrastructure to the communicative-educational level, although they require greater theoretical cohesion (Cobo et al., 2011).

Niche Topics (High Density, Low Centrality)

With specialized lines such as "cyberstalking detection," "constraint deep reinforcement learning," "educational technology" and "automation" exhibit high local development but low structural connectivity. They represent advanced methodological cores that can be integrated with engines using semantics or FL-6G architectures.

Emerging or Declining Themes (Low Centrality and Density)

It groups "metaverse security," "AI ethics," "character animation," "technology acceptance model," and "higher education – intercultural communication." The low centrality of AI ethics (5 occurrences) highlights its potential relevance but limited integration within the field.

The low centrality of these themes indicates limited integration into the core of the domain; greater articulation with the core themes could contribute to developing

frameworks on transparency and child protection in future research (Donthu et al., 2021).

Tendencies

1. Driving triad: the convergence of "metaverse–AI/ML", "federated learning – 6G/ edge" and "semantic communication" sets the technical tone (Callon et al., 1991; Cobo et al., 2011).

2. Social shift: "communication," "social networks" and "applications" connect the infrastructure with education, health and culture, although they require greater theoretical densification.

3. Normative-ethical gap: the low centrality of "AI ethics" and "metaverse security" reveals a deficit in algorithmic governance and "safety-by-design" in immersive childhoods.

4. Disconnected specialization: niche areas such as cyberstalking detections present potential for greater structural connection if they are articulated with the motors via semantics and FL-6G.

5. CONCLUSIONS AND DISCUSSION

5.1. Critical interpretation of the findings

Bibliometric analysis shows that research on generative metaverses, artificial intelligence (AI), and algorithmic communication grew between 2010 and 2025, shifting from traditional virtual education toward immersive environments where Generation Alpha engages in cognitive and communicative processes (Table 5). The nodes "metaverse," "AI/ML," "federated learning" and "semantics communication" They exhibit greater density, with still limited integration of child-centered and educational communication approaches.

Co-occurrences suggest that "avatar, agency, identity, ethics" and " learning" have gained centrality since 2022, pointing to an openness toward socio-communicative and rights-based readings. Taken together, the findings indicate that generative metaverses not only extend the digital classroom but also function as spaces for identity mediation in which interaction with non-human agents intensifies.

Table 5

Bibliometric Nodes and Implications for Generation Alpha

Node	Interpretation	Implications for Generation Alpha
Metaverse – AI/ML	Hybrid ecosystem of learning and entertainment supported by generative AI	It configures multisensory learning experiences, but also algorithmic control dynamics that demand specific ethical and pedagogical frameworks.
Federated learning – 6G/ edge	Data distribution and extreme personalization	It expands educational adaptability, but increases the risk of child surveillance; transparency and data minimization are urgently needed.
Semantics communication	Contextual understanding and efficient transmission of meaning	It introduces algorithmic semantics as a communicative mediation; it requires literacy in algorithmic reading and writing.
Edu- metaverse / XR learning	Integration of immersive learning and avatarized socialization	It fosters creativity and collaboration, but demands accessibility and diversity policies for children.
Adoption (TAM/DOI)	Intention of use conditioned by utility and satisfaction	Generation Alpha adopts technologies for playful motivation; pleasure, safety, and critical thinking must be balanced.
LLM+MR co-orchestration	Human-AI interaction through generative models	The figure of the "algorithmic cognitive partner" is born, which redefines the role of teachers and learners.

Source: Elaborated by the authors.

Evidence suggests that generative metaverses not only extend the digital classroom, but also transform it into a space for identity mediation, where Generation Alpha learns through conversation with non-human intelligences.

5.2. Theoretical and Epistemological Implications

In the corpus, children appear primarily as users of XR systems rather than as subjects of cognitive co-production, suggesting the need to shift the focus from technological consumption to children's algorithmic agency. We propose the IAA-GA Framework (Childhood–Agency–Algorithms–Generation Alpha), which synthesizes: (1) digital childhood; (2) distributed agency; (3) algorithms as symbolic mediators; and (4) conditions of legitimacy (transparency, equity, explainability).

- Digital childhood: a continuum of immersion and datafication mediated by generative AI.
- Distributed agency: shared action with algorithmic agents (avatars, chatbots, LLMs).
- Algorithms as symbolic mediators: they model meanings and act communicatively.
- Conditions of legitimacy: transparency, fairness and explainability.

In this article, its support is of a bibliometric and interpretive nature (co-occurrences and thematic patterns of the corpus), so it does not constitute a direct empirical validation in child populations or in XR environments.

This framework, supported by Park and Kim (2022), Tlili et al. (2022) and Xu et al. (2024), offers an integrative reading of algorithmic communication not as data transmission, but as a formative process of co-creation of meaning.

5.3. Ethical, Regulatory and Political Implications

a) Consent and algorithmic literacy. Generation Alpha interacts with predictive systems that collect data (voice, movement, emotion), and their consent may precede critical literacy (Ilić et al., 2021; Park & Kim, 2022). In this framework, educational explainability is linked to understanding how and why content is personalized.

b) Generative disinformation and NEO-NPCs. NEO-NPCs, autonomous avatars based on generative AI, can promote playful learning, but they also strain authorship and authenticity, increasing vulnerability to narratives without origin markers (Tlili et al., 2022). Three safeguards are proposed: (1) visible labeling of non-human agents; (2) pedagogical verification of generative content in education; (3) audits of child impact (bias, accessibility, wellbeing).

c) Governance and digital rights. The literature highlights frameworks for algorithmic governance and accountability (Garlinska et al., 2023; Park & Kim, 2022), and cites the international agenda—SDGs 4, 10, and 16; the UNESCO Recommendation on AI Ethics, 2021—as a reference for an approach tailored to children. The principle of "rights-based XR explainability" is formulated for experiences aimed at minors.

5.4. Applied Contributions and Professional Action Scenarios

1. Immersive education and critical thinking: Integrating generative media literacy and valuing algorithmic ethics/cognitive autonomy in XR rubrics (Garlinska et al., 2023; Tlili et al., 2022).
2. Participatory design: Highlighting the potential of AI-guided co-design (Xu et al., 2024) and propose child co-creation laboratories.
3. Institutional communication and brands: The need for verifiable identity, AI labeling and protection of avatarized self-image; shared responsibility between industry, educators and communicators.
4. Immersive journalism and generative fact-checking: This approach involves fact-checking in XR (watermarking, narrative traceability, visual authentication) to reduce exposure to unverified synthetic content (Tewari et al., 2020).

5.5. Limitations and Delimitations of the Study

The bibliometric corpus, although extensive (2010–2025), is predominantly Anglophone and concentrated in engineering and technology journals, with limited representation of qualitative studies on children's communication. This distribution may favor a techno-dominant reading of the field, prioritizing infrastructural approaches over socio-communicative perspectives centered on children. Furthermore, the co-occurrence analysis reflects underrepresentation of Latin American and African studies, suggesting the need to internationalize the perspective

on Generation Alpha in contexts of digital inequality, avoiding implicit generalizations based on dominant publishing circuits.

Methodologically, the use of Biblioshiny and centrality metrics allowed the quantification of the maturity of the field, but it does not by itself capture how categories such as childhood, identity or misinformation are discursively constructed; therefore, it is necessary to complement it with discursive analyses to identify how childhood is narrated, protected or instrumentalized in the scientific literature (Waltman, 2016).

5.6. Future Lines of Interdisciplinary Research: Alfa Agenda 2030

Table 6

Future lines of research

Line	Gap Addressed	Suggested Methodology	Expected Impact	SDGs
1. Algorithmic cognition in children	Lack of studies on how AI models the attention and reasoning of Generation Alpha	XR experiments + ethical neuroeducation	Understanding cognitive and regulatory effects	4, 10
2. Avatarized identity and self-image	Lack of longitudinal studies on children's digital identity	Panel studies (6–12 years) + XR interviews	Welfare policies and inclusive avatar design	3, 4, 10
3. Generative disinformation	Without verification protocols in educational XR environments	Experimental design with synthetic marking and immersive fact-checking	Age-appropriate media literacy	4, 16
4. Algorithmic ethics applied to NEO-NPC	Lack of frameworks on human-AI interaction in children	Delphi with experts in AI, education and communication	Codes of conduct for AI in educational settings	10, 16
5. AI-child co-design	Limited child participation in technological creation	Participatory research + *AI design labs*	Revaluing children's agency and inclusive design	4, 10
6. Data justice and digital equity	Gap between adoption and digital rights	SEM-ML with equity variables	Governance strategies and universal accessibility	10, 16
7. Metaversal Governance and Transparency	Global policy deficit	Comparative analysis of regulations	UNESCO-UNICEF Protocol on AI and Digital Childhood	16

Source: Elaborated by the authors.

These lines also serve as avenues for future empirical testing of the proposed frameworks, beyond the bibliometric support of this study.

5.7. Towards an Alpha Agenda 2030

The results place Generation Alpha within a communicative ecology marked by generative metaverses, conversational AI, and mixed realities, with implications for learning, identity, and sociability. Within this framework, the IAA-GA Framework proposes balancing algorithmic efficiency and communicative equity, recognizing children as interlocutors.

As a work agenda, five lines of action are proposed: (1) critical immersive education and algorithmic literacy; (2) XR transparency and labeling of generative agents; (3) media literacy for synthetic information; (4) transdisciplinary research on identity, cognition, and agency; and (5) institutional monitoring of digital rights and algorithmic well-being.

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AUTHOR(S)
Rafael Braza Delgado
University of Cádiz
The focus of my teaching and research is in the areas of strategic marketing, digital transformation, and artificial intelligence, with an emphasis on their impact on consumer behavior and business performance. My work aims to integrate academic theory with professional practice, fostering innovation and critical thinking in business management. At the same time, I have gained extensive experience at Telefónica España, where I have held positions such as Marketing Strategist and Head of Market Research. This professional background allows me to bring a practical and up-to-date perspective on the market to the academic world, enriching my teaching and strengthening the connection between research, business, and society.
rafael.brazadelgado@alum.uca.es
Orcid ID: https://orcid.org/0009-0005-7740-2221
Google Scholar: https://scholar.google.es/citations?hl=es&authuser=1&user=D4dyO2sAAAAJ

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