

Game-Based Mathematics Learning for Autism: A Bibliometric Analysis of Educational and Technological Trends

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Abstract – Game-based interventions are increasingly recognized as promising tools to enhance mathematics learning for children with autism spectrum disorder, yet systematic evidence on their development and effectiveness remains limited. This study aims to map the research landscape in this field through a bibliometric review of 931 articles indexed in an international database between 2015 and 2025. Bibliometric techniques were applied to generate co-occurrence networks, thematic clusters, and temporal visualizations. The analysis revealed 33 recurring terms grouped into four major thematic clusters: Social and behavioral interventions, developmental and cognitive disorders, mathematics education supported by technology, and methodological studies with a focus on serious games. A notable research peak occurred in 2021–2022, reflecting an increased integration of game design, educational innovation, and inclusive learning practices. These findings demonstrate a shift toward strength-based approaches and highlight the importance of interdisciplinary collaboration across game design, special education, and developmental psychology. The implications suggest that adaptive and immersive technologies can provide more effective, relevant, and socially inclusive mathematics learning experiences for autistic learners.

Keywords – Autism spectrum disorder, mathematics education, serious games, educational technology, bibliometric analysis.

1. Introduction

Inclusive education provides the foundation for equal access to quality learning for children with special needs, particularly those with autism spectrum disorder (ASD). It emphasizes environmental adaptation [1], individualized support and collaboration [2], and recognition of neurodiversity as part of the right to quality education [3]. In Indonesia, this principle is supported by Law No. 20 of 2003 on the National Education System, Law No. 8 of 2016 on Persons with Disabilities, and Ministerial Regulations No. 70 of 2009 and No. 48 of 2023, which ensure access, facilities, and specialized teachers [4], [5], [6].

Technological advancement has significantly shaped inclusive practices through assistive devices, mobile technologies, Augmented Reality, and Artificial Intelligence supporting adaptive learning [7], [8]. These tools improve accessibility and participation in safe learning environments [9], [10], with VR and AR offering controlled simulations for social training in autism [11], [12]. In Indonesia, communication aids and multimedia applications have been introduced [13], [14], though limited teacher training (44.3%) and access to infrastructure (33.2%) remain challenges [15].

Game-based learning has become a promising approach in inclusive education. The integration of gamification and educational games [16], [17], including AR-based applications [18], [19], [20] and neurofeedback systems [21], has been adopted to create engaging and responsive learning experiences for autistic learners [22]. These interventions enhance motivation, attention, and social interaction, thus supporting inclusive education in the digital era [7], [23].

DOI: 10.18421/TEM153-74

<https://doi.org/10.18421/TEM153-74>

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Received: 07 September 2025.

Revised: 18 February 2026.

Accepted: 09 March 2026.

Published: 27 August 2026.

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Over the past decade, serious games have consistently improved social, communication, and cognitive skills in children with ASD [24], [25], [26], [27], [28]. They align with autistic learners' preference for predictable and structured environments [29], [30] and provide consistent reinforcement [31], [32]. Importantly, such approaches also enhance academic skills, particularly mathematics learning, which often presents difficulties for ASD students, with evidence of measurable improvements [33], [34].

Game design for ASD must consider sensory sensitivities, visual preferences, and the need for predictability [35], [36]. Effective design includes clear visuals, minimal distractions, structured feedback, and reward systems [16] alongside customization to learners' abilities and interests [24]. Games developed within universal learning design enhance engagement, reduce frustration, and facilitate skill transfer [26], [37].

Despite promising evidence, research gaps remain in mapping broader trends, methodologies, and the effectiveness of mathematics-related interventions. Bibliometric analysis can address this by identifying thematic clusters, central concepts, and temporal developments. This study therefore analyzes the literature on educational games in mathematics learning for ASD, aiming to map research evolution and gaps, while contributing both theoretical insights and practical implications for researchers, educators, and policymakers.

2. Methodology

This study analyzed game-based mathematics learning for autism with bibliometric analysis of education and technological trends.

2.1. Research Design

A bibliometric research design using VOSviewer was employed to analyze publication patterns and conceptual structures related to autism, mathematics education, and game-based learning. This approach enabled quantitative exploration of thematic relationships without assessing individual study effectiveness.

Bibliometric analysis is a quantitative approach that employs statistical and mathematical techniques to analyze scientific publications, detect research patterns, and visualize conceptual structures within a discipline [38]. It enables the identification of research trends, collaboration networks, and conceptual evolution while systematically highlighting knowledge hotspots and research gaps without evaluating individual publication quality.

Network visualization analysis was further used to explore conceptual linkages, identify thematic clusters, and uncover emerging or underdeveloped areas of research [39].

2.2. Data Source

The data were collected from the Scopus database, selected for its comprehensive coverage of peer-reviewed international journals and advanced bibliometric features. Scopus was chosen as it is the largest citation database with broad subject representation. The search strategy combined key concepts including *autism*, *mathematical education*, *mathematics learning*, *game design*, and *game element*. The inclusion criteria required publications between 2015 and 2025, written in English, and focused on educational games for learners with autism spectrum disorder. Articles were included if available in full text or with comprehensive abstracts. The chosen time span reflects the era of digital transformation in education, increasing awareness of ASD, and rapid development of game-based learning and serious games.

Data were retrieved from the Scopus database due to its broad international coverage. The search query combined: (“autism” OR “ASD”) AND (“mathematics learning” OR “mathematics education”) AND (“game” OR “serious game” OR “gamification”).

A total of 931 articles were retrieved, with inclusion and exclusion criteria presented in Table 1.

Table 1. Criteria for retrieved literature

Criterion	Inclusion	Exclusion
Publication date	2015–2025	Before 2015
Publication type	Peer-reviewed journal articles presenting original research	Review, Note, Retracted, Editorial, Letter, Erratum
Subject area	Computer Science, Neuroscience, Health Professions, Arts & Humanities, Nursing, Mathematics, Multidisciplinary, Pharmacology, Toxicology & Pharmaceuticals, Environmental Science	Materials Science, Biochemistry, Engineering, Physics, Agriculture, Chemistry, Decision Sciences, Economics, Business, Immunology, Energy, Earth & Planetary Sciences
Article count	363	568

2.3. Data Analysis

Bibliometric mapping was performed using VOSviewer 1.6.20, developed by the Centre for Science and Technology Studies (CWTS), Leiden University. This software allows visualization of bibliometric networks, co-occurrence mapping, and clustering [40]. The analysis applied several techniques [41], [42], [43]:

- (i) **Co-occurrence analysis:** Keyword co-occurrence was used to identify major themes. A minimum threshold of 15 occurrences was set to ensure statistical relevance. Association strength normalization was applied to optimize visualization. Density visualization highlighted knowledge hotspots.
- (ii) **Network analysis:** Network visualization mapped the strength of keyword relationships. Larger nodes represent higher frequency, while line thickness and proximity indicate co-occurrence strength [41].
- (iii) **Cluster analysis:** Automatic clustering grouped terms based on conceptual proximity. Cluster colors represented gradations of frequency and connectivity, resulting in the identification of four main thematic clusters.
- (iv) **Temporal analysis:** Overlay visualization mapped temporal evolution of themes between 2015 and 2025, enabling the identification of emerging and declining research trends.

3. Results

This study provides data from 2015 to 2025 to outline the analysis of the use of game-based mathematics learning. This data enhances understanding of the research findings. Data were collected from Scopus publications over a 10-year period. The complete data is presented in the following explanation.

3.1. Dataset Characteristics and Publication Distribution

From the initial 931 documents retrieved, 363 publications met the inclusion criteria, forming the dataset for analysis in the domains of autism, mathematics education, and game design. Figure 1 presents the temporal distribution of publications. Research output increased steadily over the last decade, peaking in 2024 (48 documents) after a slight decline in 2023 (38 documents), most likely due to incomplete indexing for the most recent year. Between 2020–2024, publication activity accelerated significantly, partly reflecting the adoption of digital technologies during the COVID-19 pandemic. The dataset accumulated more than 5,700 citations, with an average of 15.7 citations per article, peaking at over 1,200 citations in 2024.

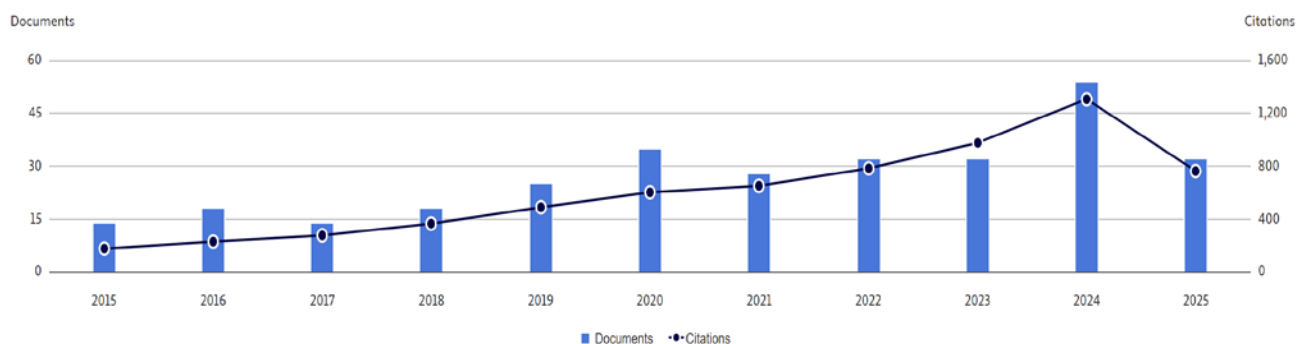


Figure 1. Temporal distribution of Scopus publications (January 2015 – June 2025)

Analysis by subject area (Figure 2) highlights the multidisciplinary nature of the field. Psychology dominates with 149 publications (41.05%), followed by social sciences (36.08%) and medicine (35.53%).

Other domains such as computer science (75) and neuroscience (40) reflect the role of technology and neurobiology in ASD research. Mathematics (15) and environmental science (5) are less represented, suggesting gaps in integrating mathematics education with autism interventions.

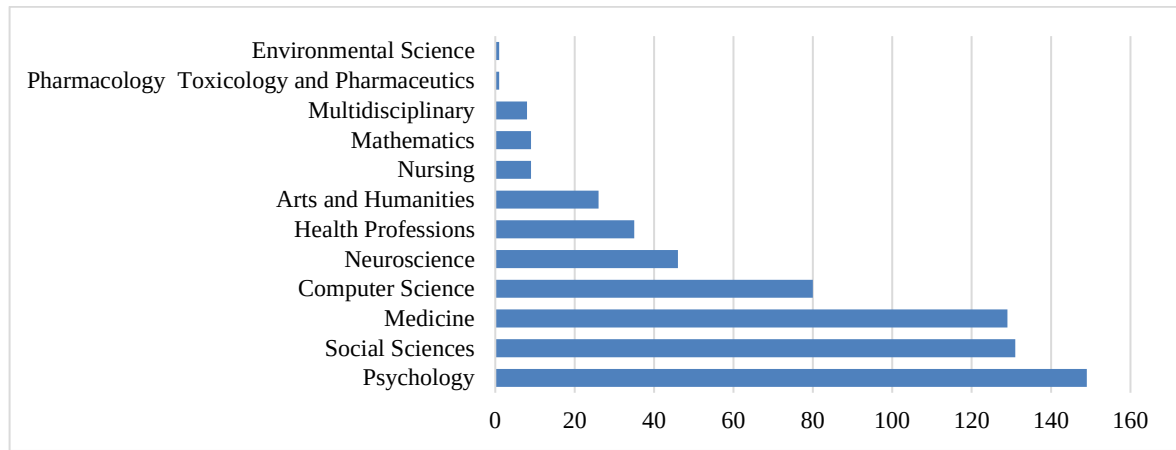


Figure 2. Distribution by subject area

Author productivity analysis (Figure 3) shows that the top 20 authors contributed 35% of total publications.

Notable contributors include Yakubova (8 publications, 187 citations) and Lee (7 publications, 189 citations), indicating a stable group of leading researchers.

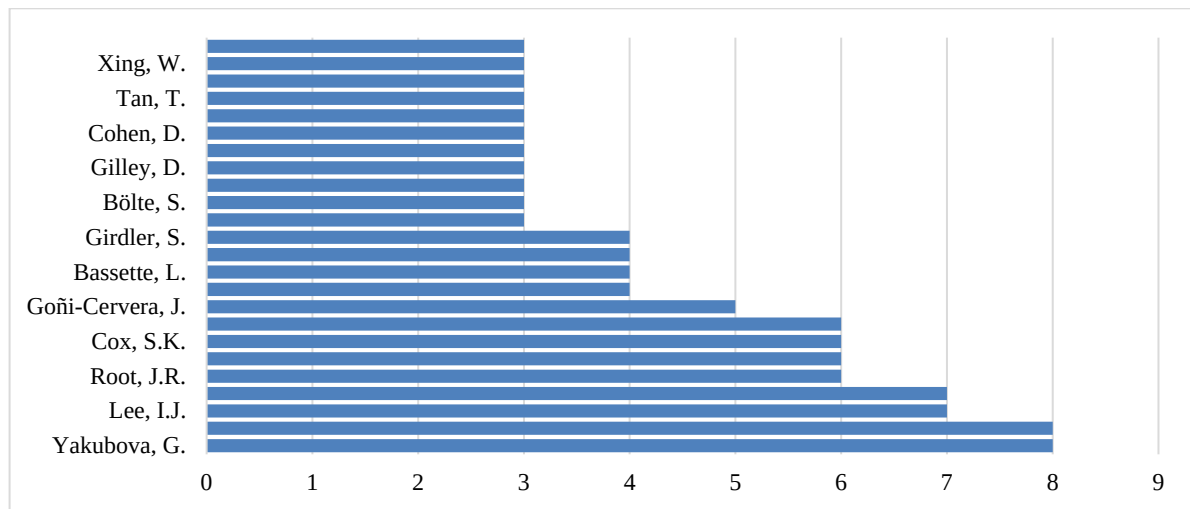


Figure 3. Author productivity distribution

Notable authors listed are presented in Table 2.

Table 1. Leading authors and contributions

Rank	Author	Focus area	Institution	ND	NC	CP	Start
1	Yakubova, G.	Mathematics education for students with disabilities	University of Maryland, United States	8	187	23.38	2015
2	Polo-Blanco, I.	Game-based learning and special needs education	Universidad de Cantabria, Spain	8	53	6.63	2019
3	Lee, I.J.	Educational technology and autism interventions	National Taipei University of Technology, Taiwan	7	189	27.00	2018
4	Hughes, E.M.	Language and communication in autism education	Pennsylvania State University, United States	7	180	68.57	2015
5	Root, J.R.	Mathematics interventions for special populations	Florida State University, United States	6	64	10.67	2021

Note: ND: Number of Document, NC: Number of Citation, CP: Citation per papers

Institutional contributions (Figure 4) reveal leadership from North America and Europe.

Pennsylvania State University and Michigan State University lead with 10 publications each, followed by Universidad de Cantabria (Spain, 8) and National Taipei University of Technology (Taiwan, 7).

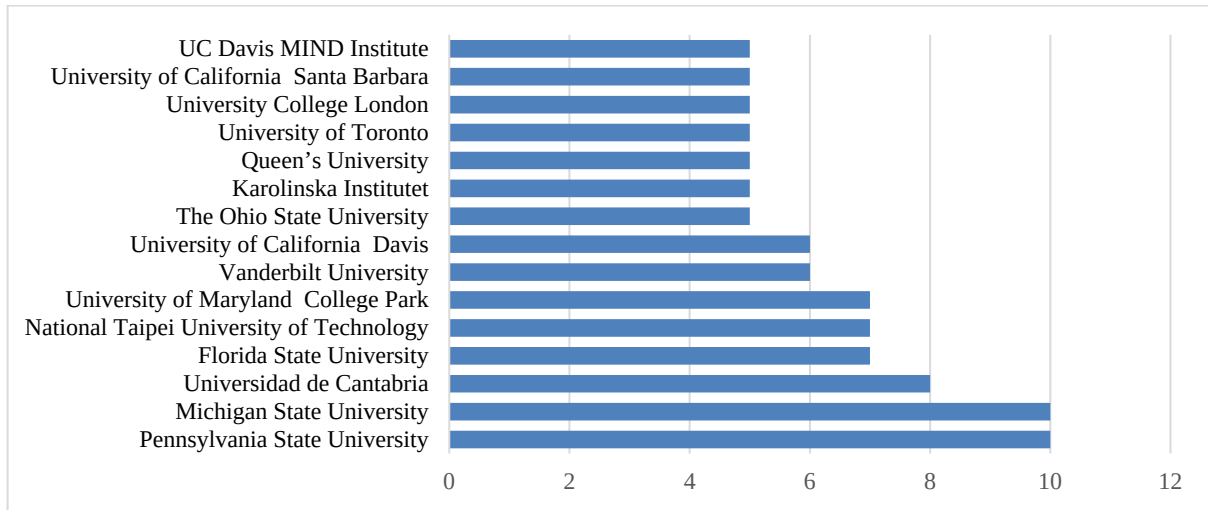


Figure 1. Institutional contribution distribution

Geographical analysis (Figure 5) shows the United States as the largest contributor (145 publications, 39.9%), followed by the United Kingdom (42), Spain (28), and China (20). Most research is concentrated in developed countries, underscoring limited contributions from developing regions.

The dataset consisted of 363 publications showing steady growth across the decade, with the highest output in 2024. Psychology and social sciences dominated the research areas, whereas mathematics-focused studies appeared less frequently.

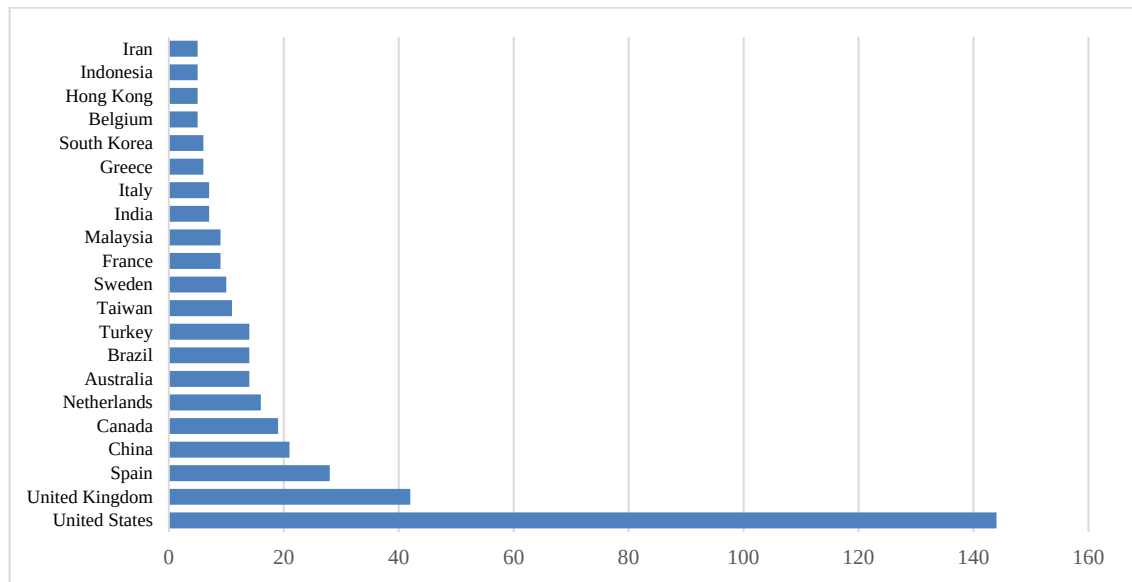


Figure 2. Geographical distribution of authors

3.2. Overview of Bibliometric Network Analysis

The refined dataset of 363 articles yielded 54 keywords (minimum occurrence ≥ 15) from 2,623 terms. Figure 6 shows the network visualization, which revealed four major clusters.

Core nodes include “autism” (225 occurrences), “autism spectrum disorder” (120), “human” (168), “child” (116), and gender-related terms (“male” and “female”). These keywords form central hubs of research, indicating strong emphasis on human-centered and clinical dimensions. The visualization of the keyword network is presented in Figure 6.

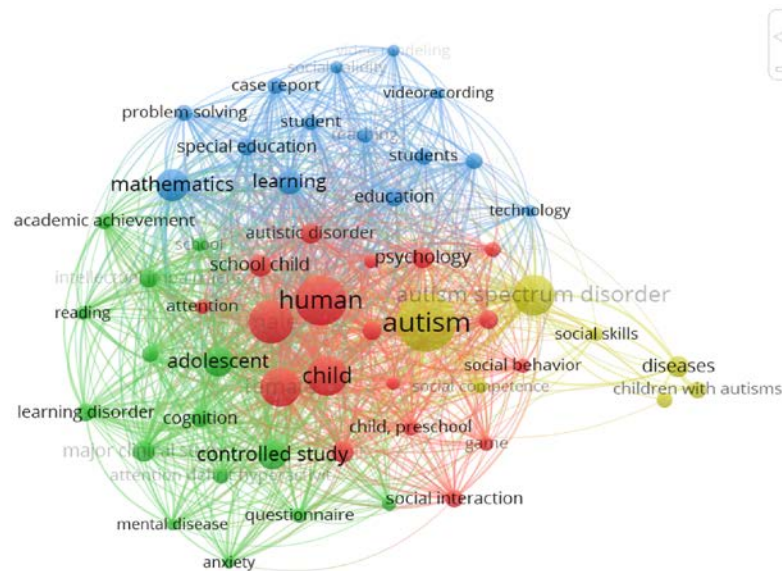


Figure 3. Keyword network visualization

Table 3 presents the highest co-occurrence frequencies and the strongest network connections of these terms, with the exception of “mathematics.” This finding implies the significance of their positions within the research domain. Table 3 also demonstrates that these terms function as central nodes in the literature, indicating a research focus on the core aspects of autism and population characteristics. Specifically, the term “mathematics” in Table 3 appears as a key term observed in this study. Referring to the main keywords, the focus of this research lies in the implementation of educational games in mathematics learning, particularly for interventions in the autism spectrum.

Table 2. Terms with highest co-occurrence frequency

Keyword	Occurrences	Total link strength
Autism	225	2039
Autism spectrum disorder (ASD)	120	1046
Human	168	2086
Child	116	1542
Male	134	1801
Female	110	1522
Mathematics	78	94

3.3. Thematic Cluster Analysis

Cluster analysis consists of several themes: The red cluster is about social and behavioral interventions, green cluster relates to developmental and cognitive disorders, blue cluster highlights education and technology, and yellow cluster reflects autism spectrum and social competence. A more complete explanation follows.

3.3.1. Red Cluster: Social and Behavioral Interventions

The first cluster, consisting of 18 items, highlights a focus on social and behavioral aspects in the context of autism. The visualization of the red cluster keyword network is presented in Figure 7.

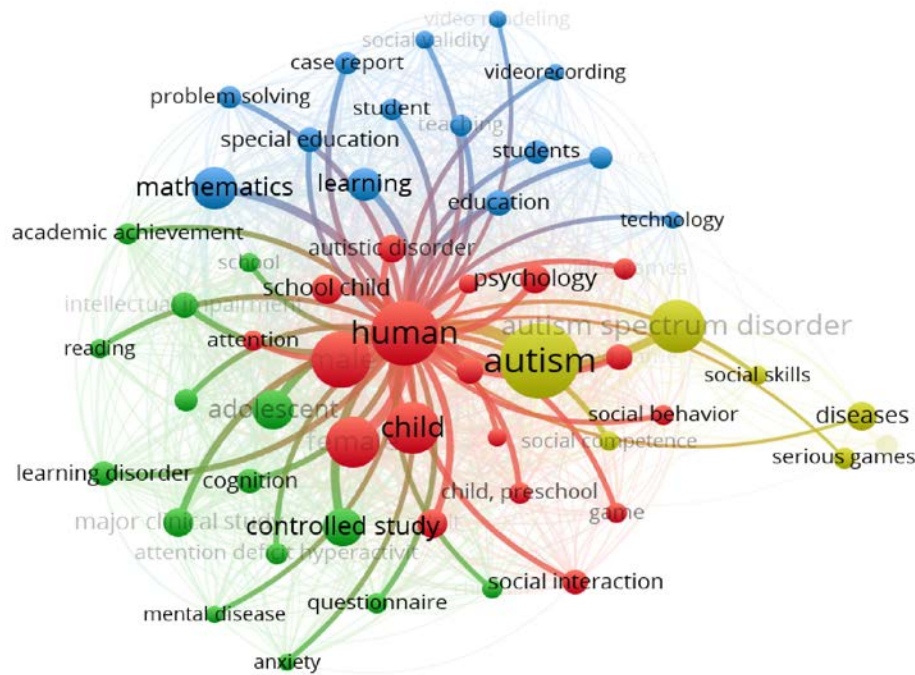


Figure 4. Visualization of the red cluster keyword network

This cluster encompasses key terms as listed in Table 4. The keyword “human” occupies a central position with the highest connectivity, confirming that research in this domain is centered on human aspects and individual differences. Gender distribution reveals a significant pattern, with “male” being more dominant than “female.” The keywords “child” and “school child” indicate that research concentration on school-aged children is higher compared to “adult.” The terms “preschool child” and “Child, preschool” suggest increasing attention toward early intervention approaches. The keyword “psychology” holds an important position within the cluster, reflecting a strong theoretical foundation in psychological sciences. “Social behavior,” “social interaction,” and “interpersonal communication” form a cohesive sub-network in the social domain. Although “game” shows a relatively low occurrence, “video game” and “video games” indicate growing development in digital game applications for autism interventions. Finally, “attention” highlights the crucial role of attentional mechanisms in autism interventions.

Table 3. Red cluster keyword

No	Keyword	Occurrences	Total link strength
1	Human	168	2086
2	Male	134	1801
3	Child	116	1542
4	Female	110	1522
5	School child	41	574
6	Psychology	39	573
7	Adult	38	531
8	Autistic disorder	35	243
9	Video game	31	408
10	Preschool child	30	446
11	Social interaction	29	314
12	Video games	22	269
13	Child, preschool	21	314
14	Social behavior	20	237
15	Attention	19	243
16	Game	19	229
17	Physiology	17	246
18	Interpersonal communication	16	215

The red cluster represents the core conceptual foundation of autism research, encompassing demographic characteristics, developmental considerations, psychological frameworks, and emerging technological interventions. The dominance of human-centered concepts, with a strong emphasis on child populations, reflects the maturity of the field in understanding autism as a developmental condition requiring individualized and age-appropriate interventions. The integration of game-based approaches within this cluster indicates a paradigm shift toward evidence-based, technology-mediated interventions, with particular strength in fostering social skills development. This cluster functions as a conceptual bridge linking traditional clinical understandings with innovative technological applications in autism education.

The dominance of this cluster further reflects the importance of social aspects in autism research. Study [44], through a comprehensive meta-analysis, also confirmed that digital interventions demonstrated medium-to-large overall effects, with Hedges' $g = 0.62$, 95% CI [0.36, 0.88], $p < 0.001$, in improving socio-emotional skills. This finding is reinforced by [45], which reported growing interest in the use of games to support social skills training for autistic children and adolescents.

The effectiveness of tablet-mediated interventions is highlighted, particularly for young children with ASD, showing larger effect sizes in the 5–8 age group compared to adolescents [46]. The success of online video-based learning for 5-year-old autistic children is confirmed, emphasizing the importance of early mathematics interventions [25]. Furthermore, in a meta-analysis, showed that students with ASD performed lower than their typically developing peers ($g = 0.49$), with effects moderated by age, verbal intellectual functioning, and working memory, underscoring the importance of individualized diagnostic considerations [47]. Study confirmed the effectiveness of immersive VR environments compared to desktop applications for developing social skills, with specific benefits for emotion recognition and emotional regulation [37]. Finally, students with ASD can acquire mathematical skills when taught using evidence-based strategies across different age ranges [33].

3.3.2. Green Cluster: Developmental and Cognitive Disorders

The second cluster identifies the domain of developmental and cognitive disorders with 15 items. The visualization of the keyword network map for the green cluster is presented in Figure 8.

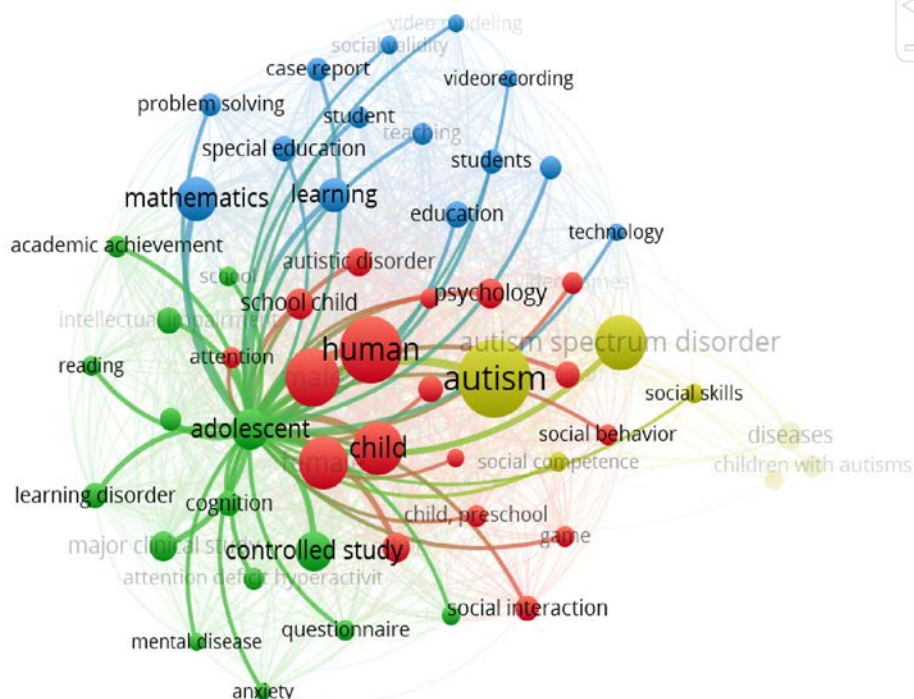


Figure 5. Visualization of the green cluster keyword network

This cluster encompasses the key terms listed in Table 5. Based on the analysis results presented in Table 5, it can be interpreted that this cluster represents a strong research focus on adolescent and young adult populations with various neurodevelopmental and psychological conditions. The keyword “adolescent” dominates, indicating that most studies in this cluster are centered on this age group. This dominance aligns with the findings of [48], which emphasizes that adolescence is a critical phase in adaptive, interpersonal, and academic development consistent with compulsory education stages. This period is further supported by recent data from [49] reporting that the prevalence of ASD among 8-year-old children has increased to 1 in 36, underscoring the importance of research focus on the adolescent age group.

Table 4. Green cluster keywords

No	Keyword	Occurrences	Total link strength
1	Adolescent	68	962
2	Controlled study	64	892
3	Major clinical study	39	558
4	Intellectual impairment	32	449
5	Cognition	29	408
6	Learning disorder	29	418
7	Intelligence quotient	23	366
8	Academic achievement	22	335
9	Attention deficit hyperactivity disorder (ADHD)	21	283
10	Questionnaire	20	259
11	Children	18	214
12	Reading	18	287
13	School	18	276
14	Anxiety	15	216
15	Mental disease	15	222

From a research methodology perspective, the presence of “controlled study” and “major clinical study” indicates that this cluster is dominated by research employing rigorous and high-quality methodological designs. This reflects an effort to generate reliable evidence-based findings in the field of neurodevelopmental research. Recent longitudinal studies have shown that ASD diagnosis and Intelligence Quotient remain highly stable over time, whereas executive functioning, theory of mind, and central coherence tend to improve, although deficits persist compared to typically developing controls [48].

The main clinical domains identified within this cluster encompass three broad areas. First, cognitive and learning disorders, as reflected by the keywords “intellectual impairment”, “cognition”, “learning disorder”, and “intelligence quotient”. It was reported that 39.6% of 8-year-old children with ASD experience intellectual disability, with variations across race and ethnicity [49]. Second, academic achievement and educational contexts, represented by “academic achievement”, “reading”, and “school”. It was demonstrated that anxiety traits significantly predict executive functioning in high school students, and executive functioning positively impacts academic outcomes [50]. Third, comorbid conditions such as “ADHD”, “anxiety”, and “mental disease”.

Recent data from the United States reveal that among children diagnosed with ASD, approximately 42% also have ADHD, while 17% have both ADHD and a learning disorder [51]. Findings from [52] showed that nearly 77.9% of children with ADHD present with at least one additional comorbid condition. About half experience behavioral or conduct problems, and around 40% experience anxiety disorders. Moreover, recent studies indicate that adolescents with intellectual disability are at greater risk of ADHD (risk ratio 3.38:1) compared to typically developing adolescents.

The presence of “questionnaire” in this cluster underscores the importance of standardized assessment tools in this line of research. According to [53] the availability of structured questionnaires facilitates evidence-based synthesis for clinical formulation regarding the presence or absence of a condition, which is critical given the diverse clinical presentations in neurodivergent populations. Due to cognitive deficits, individuals with intellectual disability often struggle to participate interactively in clinical processes, with three-quarters (77%) of patients with moderate-to-profound disability limited in their ability to meaningfully contribute to diagnostic assessments or treatment [54]. Within resource-limited healthcare systems, questionnaires provide efficient pre-screening before more comprehensive and costly diagnostic assessments [55], [56].

In the context of education and academic achievement, recent studies have uncovered complex relationships between anxiety and achievement. Working memory has been found to mediate the relationship between trait anxiety and academic skills, suggesting that anxiety can enhance executive functioning, which may, in turn, improve academic performance [50]. However, among underserved populations, while no relationship was observed between anxiety or hyperactivity and spelling or math scores, depression and attention problems were significantly and negatively associated with spelling and math performance [57].

Overall, the green cluster represents a body of research focusing on comprehensive assessment and intervention for adolescents with neurodevelopmental conditions. This cluster reflects an evolution in research toward more holistic and evidence-based approaches in understanding and addressing the complexity of neurodevelopmental conditions in adolescent populations. It emphasizes rigorous research methodology, multidimensional assessment encompassing cognitive, academic, and behavioral aspects, and a comorbidity perspective that acknowledges the interconnected nature of conditions within specific developmental contexts.

Integrated cognitive remediation approaches that combine social and non-social cognition demonstrate promising effectiveness in improving both cognitive domains and functional outcomes among children and adolescents with ASD [58].

3.3.3. Blue Cluster: Education and Technology

The third cluster, consisting of 14 items, demonstrates the convergence between education and technology. The visualization of the blue cluster keyword network map is presented in Figure 9.

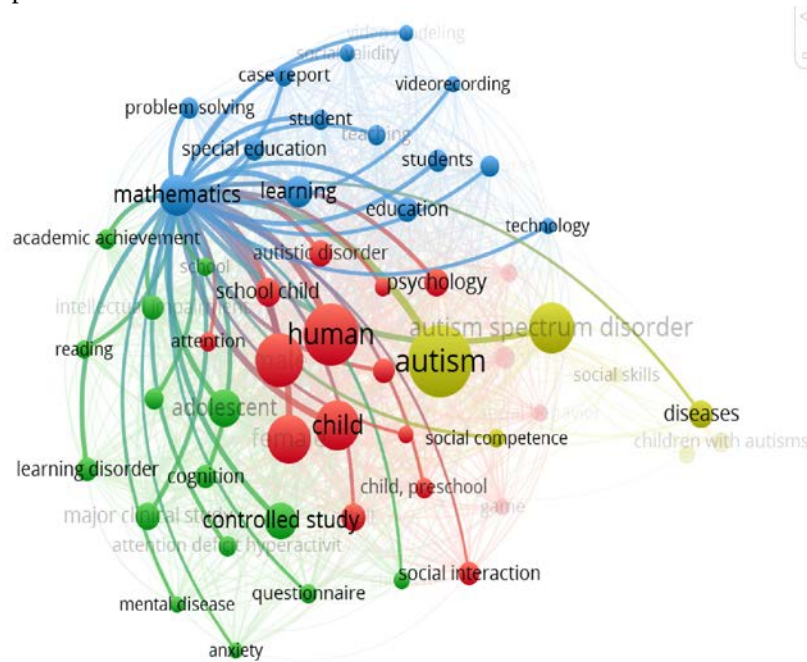


Figure 6. Visualization of the blue cluster keyword network

Table 6 presents the keywords that constitute the blue cluster. This cluster represents a research focus on pedagogical and technological approaches in mathematics education for special needs populations. The keyword “mathematics” dominates with 78 occurrences and the highest link strength (944), indicating that research within this cluster is centered on mathematics learning as the main academic domain among the keywords. The dominance of “mathematics,” “learning,” and “problem solving” further suggests that this cluster is specialized in studies of mathematics learning. Studies [33], [59] revealed that among adolescents with ASD, receptive language ability was found to be a stronger predictor of academic achievement, including mathematics, as limited language comprehension can hinder the interpretation of mathematical concepts delivered both verbally and symbolically. This is supported by [33], [34], who reported that ASD samples without intellectual disability and ADHD demonstrated significant and comparable delays in problem-solving and calculation skills.

Table 6 can be presented below:

Table 5. Blue cluster keyword

No	Keyword	Occurrences	Total link strength	Rasio
1	Mathematics	78	944	12.10
2	Learning	50	645	12.90
3	Education	30	376	12.53
4	Special education	28	243	8.68
5	Students	26	339	13.04
6	Case report	23	317	13.78
7	Problem solving	23	304	13.22
8	Procedures	23	331	14.39
9	Student	21	341	16.24
10	Teaching	21	241	11.48
11	Social validity	16	234	14.63
12	Technology	15	195	13.00
13	Video modeling	15	165	11.00
14	Videorecording	15	226	15.07

The educational context and special services are reflected in the emergence of the keywords “education,” “special education,” and “students,” which indicate a focus on formal educational settings with specialized services. Revealed that students with extensive support needs namely autism spectrum disorder, intellectual disability, or both are capable of learning a wide range of mathematical skills when taught using scientifically validated strategies [60]. The research methodology within this cluster is represented by “case report,” indicating the dominance of single-case experimental design approaches in evaluating the effectiveness of mathematics instruction interventions for students with special needs. This methodology is particularly appropriate for populations with heterogeneous characteristics such as ASD and intellectual disability, where single-case designs allow for in-depth individual evaluation of each student’s response to intervention [61], [62], [63]. Visual analysis from case reports confirmed a functional relationship between the evaluated interventions and mathematical outcomes in 71% of cases, with interventions generally producing moderate to large effect sizes [64]. The case report approach provides flexibility to accommodate individual variability in abilities and learning responses, while also enabling replication across participants to strengthen the internal and external validity of research findings [65].

The technological aspect of learning is reflected in the emergence of the keywords “technology,” “video modelling,” and “video recording,” which highlight the growing trend of technology use in educational interventions. Video-based intervention (VBI) has been established as an evidence-based practice for teaching various skills to autistic individuals from early childhood to young adulthood [25]. Research has explored the use of technology to support instruction for students with disabilities, with video modelling identified as one of the technologies with a growing research base in the field of special education. Video modelling provides an additional instructional resource using age-appropriate technology to support student learning [66], [67].

Social validity and the practical implementation of interventions are reflected in the keywords “social validity” and “teaching”.

It was reported that in an intervention using a virtual manipulatives-based instructional sequence, only one of three students aged 15 to 17 was able to maintain mastery of basic mathematical skills (equivalent fractions) for up to eight weeks, whereas the other two students retained the skills only after the addition of a self-monitoring strategy [68]. Similarly, [69] demonstrated a functional relationship between the application of the concrete–representational–abstract (CRA) sequence and improvements in the mastery of cardinal principles, further supported by positive perceptions from teachers and families regarding the effectiveness of the intervention.

Overall, the blue cluster reflects a paradigmatic evolution in special mathematics education, moving toward the integration of evidence-based technology with individualized approaches. This cluster demonstrates the convergence of rigorous single-case experimental design methodologies, the use of video-based interventions as evidence-based practices, and an emphasis on social validity that ensures the practical acceptance of developed interventions. The unique characteristic of the blue cluster lies in its capacity to address the challenges of heterogeneity within ASD and intellectual disability populations through approaches that are both flexible and scientifically grounded. In this context, technology-enhanced learning environments not only increase student engagement but also facilitate individualized instruction that is responsive to variability in abilities and learning outcomes. Thus, the blue cluster represents a shift toward more inclusive, evidence-based, and technology-mediated mathematics education, one that acknowledges the complexity of learners’ developmental disabilities while maintaining high methodological rigor and a practical orientation for implementation in real educational settings.

3.3.4. Yellow Cluster: Autism Spectrum and Social Competence

The fourth cluster, consisting of 7 items, is presented in Figure 10. This cluster represents the paradigm of technology-based social interventions, which has become a dominant focus in autism spectrum disorder research.

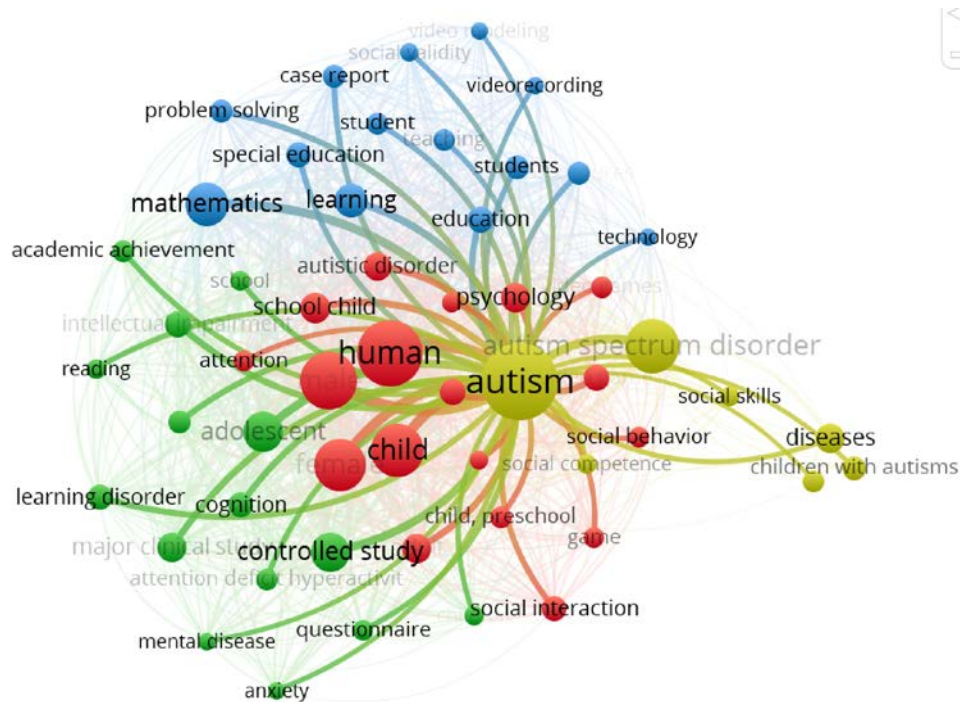


Figure 7. Visualization of the yellow cluster keyword network

Table 7 presents the keywords defined within the fourth cluster, which is the smallest yet highly specific. The dominance of the keywords “autism” and “autism spectrum disorder” indicates that these two terms function as super-connectors, linking various domains of autism research. Their exceptionally high connection strength ratio highlights their role as foundational anchors in the broader autism literature. The presence of “children with autism” reinforces the pediatric focus of this cluster, supported by findings from [70], which revealed that the effectiveness of transfer interventions varies by age and type of intervention: Digital interventions are more effective for adolescents and adults, whereas face-to-face and behavioral interventions are more effective for children. Cognitive interventions, however, demonstrated weak transfer effects across all age groups.

Table 6. Yellow cluster keyword

No	Keyword	Occurrences	Total link strength	Ratio
1	Autism	225	2039	9.06
2	Autism spectrum disorder	120	1046	8.72
3	Diseases	39	129	3.31
4	Children with autisms	26	72	2.77
5	Serious games	22	73	3.32
6	Social competence	17	230	13.53
7	Social skills	17	115	6.76

The social intervention aspect of this cluster is reflected through the keywords “social competence” and “social skills.” Social competence demonstrates an exceptionally high link strength ratio (13.5:1), indicating that this concept functions as a bridge concept, connecting clinical research and interventions more effectively than its frequency alone would predict. Confirmed through structural equation modeling that social cognition and social behavior represent distinct yet related constructs in the development of social competence, supporting the field’s focus on comprehensive social competence rather than isolated skill training [71]. Demonstrated that integrating Theory of Mind with social skills training resulted in substantial improvements in social competence among adolescents with autism [72]. In line with this, it was found that high-dosage behavioral interventions (>50 hours) achieved strong transfer effects (0.63), explaining why social competence has emerged as a central organizing concept with high connectivity in autism intervention research [70].

The emergence of “serious games” reflects the technological transformation of the field, accelerated by recent global events. During the COVID-19 pandemic, 92% of children with ASD were unable to continue traditional special education during lockdowns, which prompted the rapid adoption of digital interventions and demonstrated their necessity for accessible and scalable service delivery. A recent systematic review by [12] confirmed that teaching social skills through serious games has emerged as a highly promising educational strategy to address the specific characteristics associated with autism.

Unlike traditional games, serious games are designed with a dual purpose: To entertain and to meet specific educational or therapeutic objectives. Evidence synthesized from nine randomized controlled trials indicates that serious games significantly enhance core components of social competence, including emotion recognition, emotional regulation, eye gaze, and joint attention. These findings substantiate the prominent co-occurrence of *serious games* and *social competence* observed in the bibliometric mapping [37]. Demonstrated that Behavioral Intervention Technologies (BITs) achieved effect sizes ($g = 0.93$) comparable to face-to-face social skills training ($g = 0.81$) [73], [74], while digital health interventions produced significantly greater improvements in core ASD symptoms compared to controls (Cohen's $d = 1.89$) [73]. Moreover, that serious games can enhance independence in children's daily routines, although for certain neurodevelopmental profiles (ASD or ADHD), the addition of parental support yielded greater clinical improvements [75].

Overall, the yellow cluster represents the successful integration of clinical understanding with technological innovation, positioning technology-enhanced social interventions as a significant and distinct area within the broader autism research ecosystem. This cluster stands in sharp contrast to other autism research paradigms, such as biomedical domains focused on etiology or genetics. Instead, it emphasizes intervention outcomes, behavioral change, and child-centered engagement, while leveraging intrinsic motivation through gaming.

The coherence of this cluster reflects a mature and stable research domain that bridges traditional intervention science with innovative technology delivery methods. It signifies a fundamental paradigm shift toward more engaging, scalable, and child-centered approaches to addressing the core challenges of social communication in individuals with autism spectrum disorder.

3.4. Temporal Evolution and Research Trends

The network visualization with temporal overlay in Figure 11 illustrates the dynamic evolution of research on autism, mathematics education, and game design from 2016 to 2021, meeting the minimum threshold for network analysis. The color gradient from blue (2016) to yellow (2021) reveals significant patterns of research development. The 2016–2017 period (blue–purple) was dominated by fundamental concepts such as “case report,” “controlled study,” “autistic disorder,” “social behavior,” “social competence,” and “attention.” This indicates that early research was still focused on the identification and characterization of disorders. A significant shift occurred during the 2018–2019 period (green–teal), toward the integration of technology and education. Concepts such as “autism,” “child,” “adolescent,” “video game,” and “mathematics” began to occupy more central positions in the network. This period marked the emergence of a new paradigm that integrates technology into special education, particularly for autistic children and adolescents.

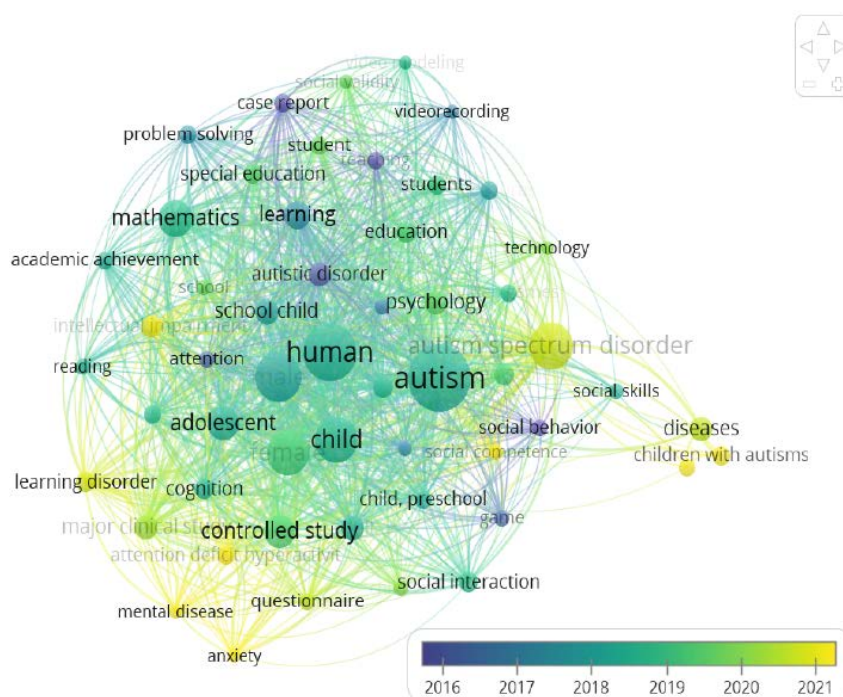


Figure 8. Timeline analysis from 2016 to 2025

The most recent period, 2020–2021 (yellow–light green), demonstrates a full convergence between technology, games, and mathematics education. Concepts such as “serious game,” “children with autism,” “autism spectrum disorder,” “children with autisms,” “special education,” and “learning” exhibit high color intensity, indicating a mature research focus on practical applications. This evolution reflects the maturation of the field, moving from theoretical understanding toward evidence-based practical applications.

In addition, research on mathematics games for autism remains relatively new and opens new possibilities for connecting emerging topics not yet represented in Figure 11. Examples include the relationship between adaptive mathematics games, Artificial Intelligence in special education, neurofeedback-based learning, and higher-order mathematics skills for autistic junior high school students. Furthermore, many pedagogical approaches remain underexplored, such as the tradition of culturally based mathematics learning in Indonesia, deep learning approaches in educational games, and the integration of occupational therapy with digital mathematics instruction. Result of the study by [22] confirmed this trend, emphasizing that innovative technologies will become increasingly prominent in autism interventions in the coming years, although they still require broader accessibility and improved cost-effectiveness.

4. Discussion

The findings of the network analysis reveal a significant research gap between the domains of serious games for autism and mathematics learning, despite both areas showing rapid development independently. The shift from clinical approaches toward practical educational applications identified in the analysis aligns with global evolutions in autism interventions, which increasingly emphasize strength-based and inclusion-oriented approaches rather than deficit-focused models [76], [77]. Strength-based approaches that leverage the abilities and interests of autistic students are increasingly recognized as essential for meeting their school-related needs [78]. Future ASD services are expected to implement strength-based approaches, whose effectiveness can be tested through specially designed programs by [76], and scientifically validated as evidence-based [60].

The results also indicate a structural imbalance between technological innovation and mathematics-focused research within ASD education. While serious games are widely explored for social and behavioral outcomes, their application in mathematics learning remains limited.

This suggests that technological development has progressed faster than pedagogical integration.

Strength-based and inclusive approaches have become increasingly prominent, emphasizing learner-centered educational design. However, effective implementation requires alignment between technology, instructional strategies, and individual learner characteristics. The limited presence of family-related themes in the network highlights a potential research direction involving participatory and collaborative design.

Systematic research has shown that serious games exert a positive influence on social skills and related domains, including emotion recognition, emotional regulation, and eye contact among autistic children and adolescents [37]. Confirmed that educational technologies, particularly tablet-based applications, have proven effective in teaching academic skills such as sequencing and literacy to autistic children, especially within home-learning contexts that became highly relevant during the COVID-19 pandemic [79]. These findings are consistent with meta-analytic results showing that digital-based interventions generally improve mathematics performance with a moderate effect size ($ES = 0.55$), although video games do not provide additional advantages compared to digital drilling and tutoring approaches [22]. This discrepancy underscores the complexity of implementing learning technologies for populations with special needs, where effectiveness depends on the alignment between technological design, pedagogical goals, and the individual characteristics of learners.

The gap between serious games research and mathematics learning in autism becomes more apparent when compared with findings that autistic children face persistent challenges in mathematics learning. Mathematics education is now shifting toward more inclusive, evidence-based, and technology-mediated models that acknowledge the complexity of learners with developmental disabilities, while maintaining methodological rigor and practical implementation in authentic learning environments [7], [80], [81]. This highlights the complex mathematical profiles within the autism spectrum, which require more contextualized and multifaceted intervention approaches. Moreover, gameful approaches in educating autistic children must also take behavioral aspects into account, where virtual and augmented reality technologies can provide better evaluation opportunities by enabling more realistic behavioral interactions [44]. This is aligned with the principles of Applied Behavior Analysis (ABA), which emphasize the importance of behavioral context in autism interventions, thereby implying that the choice of platform for serious games in mathematics education for autism requires more thoughtful technological considerations.

The absence of the concept “parent” in the network analysis indicates a significant research gap, given that teaching strategies are rarely considered as direct inputs in the design of games to be used by educators in their instructional practice [82]. This contradicts existing evidence that highlights the importance of family involvement in autism interventions [83], particularly in the context of home-based learning, which became especially relevant during the COVID-19 pandemic.

The network analysis findings also reveal that while serious games offer intelligent learning environments that support lifelong learning for individuals with autism [84], their specific application to mathematics learning among adolescents remains limited. This is concerning given that the majority of academically gifted students with autism demonstrate excellent reading and writing skills but struggle with mathematics [85]. The implications of this research gap underscore the need for interdisciplinary approaches that integrate expertise in game design, special education, and developmental psychology. Structured mathematics education plays a vital role in the cognitive development of autistic children by providing predictable methods tailored to their unique learning needs; however, the identified research gap indicates that this potential has not yet been fully realized within the context of serious games.

The study relied solely on Scopus-indexed publications, which may exclude regional research contributions. Furthermore, bibliometric analysis identifies research patterns rather than evaluating instructional effectiveness.

Future research must explore how the heterogeneous characteristics within the autism spectrum can be accommodated through adaptive learning systems that are responsive to individual cognitive and behavioural profiles. Additionally, investigations into the transfer of learning from game contexts to real-world mathematics applications are crucial, given the frequent generalization challenges faced by autistic individuals. The integration of participatory design approaches involving autistic individuals, families, and educators in the game development process is also necessary to ensure that technological solutions are not only innovative but also meaningful and accessible to the autism community. Moreover, interdisciplinary collaborations that bring together experts in educational technology, developmental psychology, and special mathematics education are essential to produce mathematics games that are not only technologically engaging but also pedagogically sound and therapeutically beneficial for autistic students, particularly adolescents.

5. Conclusion

This bibliometric analysis delineates the intellectual and thematic evolution of research at the intersection of autism spectrum disorder (ASD), serious games, and mathematics education between 2015 and 2025. Four dominant research clusters emerged: (1) Social and behavioral interventions, (2) Developmental and cognitive disorders, (3) Technology-enhanced mathematics education, and (4) Autism spectrum and social competence. Temporal mapping suggests a discernible paradigm shift from predominantly clinical-diagnostic orientations toward technology-mediated, individualized, and pedagogically grounded interventions, particularly in the post-2020 research landscape. Despite growing evidence supporting the efficacy of serious games in fostering social competence and emotional regulation, their systematic integration into mathematics education remains comparatively underdeveloped, indicating a structural misalignment between technological innovation and mathematics-specific pedagogical frameworks for autistic learners.

The findings advocate a transition from deficit-oriented models toward adaptive, strength-based, and interdisciplinary paradigms. The convergence of game design, special education, and developmental psychology appears pivotal in constructing mathematics interventions that accommodate the heterogeneous cognitive and behavioral profiles characteristic of ASD. Emerging technological affordances including adaptive learning architectures, artificial intelligence-driven personalization, virtual and augmented reality environments, and neurofeedback systems demonstrate considerable potential to enhance learner engagement while facilitating meaningful learning transfer. Moreover, participatory co-design involving families, educators, and autistic individuals is positioned as a critical mechanism for ensuring ecological validity, pedagogical relevance, and therapeutic responsiveness.

From a conceptual standpoint, this study advances the field by clarifying the structural contours of existing scholarship and foregrounding underexplored intersections between serious games and mathematics learning within ASD contexts. Methodologically, the application of bibliometric network analysis enables the identification of latent conceptual configurations and evolving research trajectories that may remain obscured within traditional narrative syntheses. Practically, the results offer strategic implications for researchers, developers, educators, and policymakers seeking to design inclusive, data-informed digital learning ecosystems aligned with contemporary inclusive education agendas.

Notwithstanding its contributions, several limitations warrant consideration. The reliance on the Scopus database and English-language publications may constrain the representativeness of the mapped research landscape, while bibliometric approaches inherently lack the capacity to assess the methodological rigor of individual studies. Additionally, keyword-driven mapping may inadvertently obscure nuanced pedagogical constructs embedded within broader research narratives. Future investigations should therefore prioritize experimental, longitudinal, and design-based methodologies that rigorously evaluate the effectiveness of serious mathematics games across diverse ASD profiles, examine mechanisms of knowledge transfer into authentic learning contexts, and expand scholarly representation from underrepresented regions, particularly within the Global South. Ultimately, strengthening the integration of serious games into mathematics education for individuals with ASD should be understood not merely as a technological innovation trajectory, but as a transformative pathway toward sustainable, evidence-based inclusive education that advances both academic development and socio-emotional empowerment for autistic learners.

Acknowledgements

The authors gratefully acknowledge the financial support provided by the Directorate of Research and Community Service, Directorate General of Research and Development, Ministry of Higher Education, Science and Technology of the Republic of Indonesia under Grant No.0991/LL3/AL.04/2025. Additional support was also provided by the Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM) Universitas Muhammadiyah Jakarta. The authors further extend their appreciation to Universitas Muhammadiyah Jakarta and Universitas Multimedia Nusantara for academic and institutional contributions during the completion of this work.

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