



INTERNATIONAL JOURNAL OF
MODERN EDUCATION
(IJMOE)

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A BIBLIOMETRIC ANALYSIS OF DIGITAL LEARNING MEDIA IN SPECIAL EDUCATION FOR AGRICULTURE STUDIES

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Article Info:

Article history:

Received date: 02.04.2026

Revised date: 14.04.2026

Accepted date: 25.05.2026

Published date: 21.06.2026

To cite this document:

Subramaniam, J., Abdullah, N., & Raj, V. M. (2026). A Bibliometric Analysis of Digital Learning Media in Special Education for Agriculture Studies. *International Journal of Modern Education*, 8(30), 477-494.

Abstract:

This research provides a bibliometric examination of scholarly research concerning digital learning media in special education for agriculture studies. This emerging interdisciplinary field integrates educational technology, inclusive pedagogy, and vocational agricultural training. Despite the increasing emphasis on digital transformation in education, there remains a limited synthesis of scholarly trends specifically addressing the application of interactive digital learning tools for students with special educational needs in agricultural contexts. To address this gap, this study systematically examines the evolution, impact, and thematic development of relevant publications. The data were extracted from the Scopus database through advanced search strategies based on three core keywords: "special education," "interactive learning," and "agriculture." The dataset, comprising 274 documents published between 2016 and May 2026, was refined and standardized in OpenRefine, followed by performance analysis and science mapping using VOSviewer. The findings indicate a consistent increase in publication output throughout the study period, with a significant rise observed after 2020, demonstrating an intensified global focus on digital as well as inclusive education. Citation analysis revealed highly influential publications that have significantly shaped the field, whereas keyword co-occurrence mapping exposed prevailing thematic concentrations, including inclusive digital pedagogy, assistive technologies, and agricultural skill development, alongside emerging areas like mobile learning and gamification. Furthermore, country-level

co-authorship analysis indicates increasing international collaboration, although research contributions remain concentrated in a few leading countries. To conclude, this research presents a thorough synthesis of scholarly trends and intellectual structures in digital learning media for special education in agriculture studies, providing significant implications for educators, researchers, as well as policymakers to guide future innovation, collaboration, and inclusive educational practices.

DOI: 10.35631/IJMOE.830031

Keywords:

Special Education, Interactive Multimedia, Agriculture



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Introduction

Digital learning media are reshaping how students with disabilities access education, including vocational and agricultural pathways. In special education, technology-supported tools, interactive multimedia, and immersive environments can help address diverse cognitive, sensory, and behavioral needs while preserving hands-on, practical learning central to agriculture (Arpacik et al., 2023; Cheng & Lai, 2019; Dadoukolaei et al., 2021; Lynch et al., 2022; Stalmach et al., 2023). At the same time, agricultural education has maintained a longstanding tradition of supporting learners with special needs, particularly through experiential learning that builds employability, self-efficacy, and social skills (Börnert-Ringleb et al., 2021; Del Rosario Navas-Bonilla et al., 2025; Mikropoulos & Iatraki, 2022; Norris et al., 2025; Teixeira & Edwards, 2020; Wilkins-Brittain et al., 2022). Bringing these strands together, “digital learning media in special education for agricultural studies” sits at the intersection of inclusive technology, vocational preparation, and specialized pedagogy for learners with disabilities.

Across special education, technology-supported learning has expanded in volume and diversity, with tools ranging from mobile devices and assistive technologies to augmented and virtual reality, AI, and large language models (Cheng & Lai, 2019; Dadoukolaei et al., 2021; Derapa et al., 2020; Giffing & Warnick, 2012; Lynch et al., 2022; Mikropoulos & Iatraki, 2022; Stalmach et al., 2023; Voultsiou & Moussiades, 2025). Systematic reviews demonstrate that such technologies can support academic outcomes (e.g., writing, mathematics, science literacy), social skills, and emotion regulation, especially when embedded in structured, teacher-led approaches (Cheng & Lai, 2019; Derapa et al., 2020; Giffing & Warnick, 2012; Nashihin et al., 2024; Stalmach et al., 2023). Digital tools like interactive multimedia, game-based environments, and personalized feedback systems appear particularly promising for learners with learning disabilities as well as those experiencing emotional, social, and

behavioral difficulties, enhancing motivation, engagement, and self-regulation (Arpacık et al., 2023; Derapa et al., 2020; Giffing & Warnick, 2012; Nashihin et al., 2024; Stalmach et al., 2023). However, evidence often remains preliminary, with small samples, short interventions, and limited focus on real-world vocational or agricultural contexts (Derapa et al., 2020; Giffing & Warnick, 2012; Lynch et al., 2022; Nashihin et al., 2024; Stalmach et al., 2023). Moreover, there is a persistent need for robust studies in low- and middle-income nations, alongside clear guidance on integrating technology with curriculum and pedagogy rather than treating devices as stand-alone solutions (Cheng & Lai, 2019; Derapa et al., 2020; Lynch et al., 2022; Voultsiou & Moussiades, 2025).

Types of Digital Tools and Design Requirements

Table 1 Key Digital Tool Types and Benefits in SEN Contexts

Tool / Approach	Main Benefits for SEN Learners	Citations
Interactive multimedia & apps	Individualized, simple, flexible content; engagement	(Arpacık et al., 2023; Cheng & Lai, 2019; Nashihin et al., 2024)
Mobile devices, tablets, & laptops	Access, motivation, participation across settings	(Cheng & Lai, 2019; Derapa et al., 2020; Lynch et al., 2022)
AR / VR / immersive environments	Science/agri-like simulations, social & life skills	(Derapa et al., 2020; Giffing & Warnick, 2012; Voultsiou & Moussiades, 2025)
Assistive & adaptive technologies	Access for sensory/cognitive disabilities	(Cheng & Lai, 2019; Derapa et al., 2020; Lynch et al., 2022)
Digital collaboration tools (e.g., Docs)	Support cooperative, project-based learning	(Lay & Burden, 2012; Nashihin et al., 2024)

Design-based work on interactive multimedia highlights that learning materials for students with special needs ought to be engaging and adaptable, tailored to individual learners, and straightforward in structure, while incorporating sound and visual effects that are lively yet not disruptive. It also stresses that such content should remain adjustable by teachers so it can align with learners' abilities and interests. Other than that, systematic reviews emphasize that positive outcomes depend less on the technology itself and more on how it is used—its “affordances,” the learning strategies applied (often guided or scaffolded), and teacher implementation quality (Cheng & Lai, 2019; Derapa et al., 2020; Lynch et al., 2022; Nashihin et al., 2024; Stalmach et al., 2023). Inclusive digital pedagogy benefits from approaches such as problem-based and project-based learning, service learning, as well as cooperative learning, supported by digital tools that enable reflection, collaboration, and authentic tasks tailored to students' needs (Lay & Burden, 2012; Nashihin et al., 2024). Simultaneously, educators working within special education settings have observed that insufficient student self-regulation skills, along with limited levels of parental involvement, can markedly obstruct the

effectiveness of digital learning, reinforcing the importance of explicit structure, training, and home–school communication (Nashihin et al., 2024).

Within agricultural and vocational education, learners with disabilities have for many years been integrated into School-Based Agricultural Education (SBAE) and similar programs, supported by landmark legislation and evolving inclusive practices (Börnert-Ringleb et al., 2021; Del Rosario Navas-Bonilla et al., 2025; Lynch et al., 2022; Mikropoulos & Iatraki, 2022; Norris et al., 2025; Teixeira & Edwards, 2020; Wilkins-Brittain et al., 2022). Hands-on agricultural curricula, Supervised Agricultural Experiences (SAEs), and Future Farmers of America (FFA) or comparable leadership activities provide pathways to employability, social development, and career exploration, with evidence of positive effects on self-identity, social skills, and post-school outcomes for learners with special educational needs (Börnert-Ringleb et al., 2021; Del Rosario Navas-Bonilla et al., 2025; Lynch et al., 2022; Mikropoulos & Iatraki, 2022; Norris et al., 2025; Teixeira & Edwards, 2020; Wilkins-Brittain et al., 2022). Teachers and specialists in various countries, including Iran and Malaysia, highlighted the need for specific professional competencies and readiness in agriculture-related vocational skills. They cover instructional design, perceived student diversity, technology use, and specialized agricultural and exceptional competencies (Börnert-Ringleb et al., 2021; D’Elia et al., 2025; Norris et al., 2025). Nevertheless, many agricultural teachers were underprepared to differentiate instruction, navigate legal expectations, and fully include students with disabilities across classroom, lab, and extracurricular components (Börnert-Ringleb et al., 2021; Del Rosario Navas-Bonilla et al., 2025; Jdaitawi & Kan’an, 2021; Lynch et al., 2022; Mikropoulos & Iatraki, 2022; Norris et al., 2025; Teixeira & Edwards, 2020; Wilkins-Brittain et al., 2022). Hence, special educators recognize agricultural courses as valuable for work habits and safe, meaningful practice, as well as institutional scepticism, resource constraints, and gaps in teachers’ content knowledge as barriers to sustaining such programs (Börnert-Ringleb et al., 2021; Jdaitawi & Kan’an, 2021; Lynch et al., 2022).

Despite the robust growth of educational technologies and the established role of agriculture in special and vocational education, explicit research at their intersection—digital learning media in agricultural special education—is still sparse. Existing evidence must therefore be bridged: digital media can individualize content, simulate agricultural processes, and support self-regulation and collaboration, while agricultural education offers authentic, practice-based contexts that lend themselves to multimedia, Augmented Reality (AR)/ Virtual Reality (VR), and mobile tools (Arpacik et al., 2023; Cheng & Lai, 2019; Dadoukolaei et al., 2021; Derapa et al., 2020; Giffing & Warnick, 2012; Nashihin et al., 2024; Stalmach et al., 2023; Voultsiou & Moussiades, 2025). Teacher readiness emerges as the central enabling condition: effective integration demands technical self-efficacy and positive attitudes toward digital learning, and specialized competencies in agriculture, understanding of diverse disabilities, and robust collaboration with special education teacher and families (Börnert-Ringleb et al., 2021; D’Elia et al., 2025; Jdaitawi & Kan’an, 2021; Mikropoulos & Iatraki, 2022; Norris et al., 2025; Wilkins-Brittain et al., 2022). As such, a research and practice agenda for digital learning media in special education for agricultural studies should prioritize co-designed, context-rich digital resources, targeted professional development, and rigorous evaluations. They determine how technology-enhanced agricultural learning affects academic, vocational, as well as social development for learners with disabilities across diverse settings.

Conclusion: In sum, the current literature indicates that digital learning media can significantly enhance accessibility, motivation, as well as self-regulatory skills among students with special educational needs, whereas agricultural education offers powerful, experiential environments that foster employability and inclusion. However, evidence directly combining these domains is limited, and success depends largely on thoughtful design, teacher competence, and supportive organizational conditions. Future work should systematically develop, and test digital agricultural learning environments tailored to diverse disabilities, ensuring that technology amplifies—not replaces—the hands-on, relational strengths of agricultural education within special needs contexts.

Research Question

1. What are the temporal trends and developmental patterns in scholarly publications on digital learning media in special education for agricultural studies from 2016 to May 2026?
2. What are the top ten most cited articles in digital learning media for special education in agricultural studies, and what insights do they provide into influential research trends?
3. What are the dominant and emerging research themes in digital learning media for special education in agricultural studies, as identified through keyword co-occurrence analysis?
4. What are the patterns of international research collaboration in digital learning media for special education in agricultural studies, as revealed through country-level co-authorship networks?

Methodology

Bibliometric analysis refers to the structured process of identifying, collecting, organizing, and critically assessing bibliographic information extracted from academic literature (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). In addition to fundamental descriptive metrics, including publication venues, chronological publication patterns, and key contributing authors (Y. C. J. Wu & Wu, 2017), bibliometric methodologies also incorporate more sophisticated analytical procedures such as document co-citation mapping, which enables the revelation of underlying intellectual frameworks within a given field of study. Conducting a robust literature review requires a cyclical and systematic approach that involves carefully defined keyword strategies, exhaustive searches across relevant databases, as well as in-depth analytical assessment. This structured approach facilitates the construction of a robust bibliographic foundation while enhancing the validity and reliability of the findings (Fahimnia et al., 2015).

Accordingly, this study places emphasis on publications of high impact, considering their pivotal influence in forming the theoretical and conceptual foundations of the discipline. For the purpose of ensuring precision and uniformity in the dataset, Scopus was selected as the principal database for retrieving information (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). In addition, to uphold academic rigor, the inclusion criteria were restricted exclusively to peer-reviewed journal articles, whereas non-peer-reviewed materials, including books and lecture notes, were deliberately excluded (Gu et al., 2019). Thus,

leveraging the extensive coverage of Elsevier’s Scopus database, relevant publications spanning from 2016 to May 2026 were systematically extracted for subsequent analysis.

Data Search Strategy

The data acquisition process was carried out through Scopus, chosen due to its broad indexing scope and dependable inclusion of rigorously peer-reviewed scholarly work. A systematic and purpose-driven search approach was formulated using the TITLE-ABS-KEY function to ensure that relevant studies were captured within the core components of each publication (title, abstract, and keywords). The search string combined the primary constructs “special education” and “interactive learning,” alongside temporal constraints (2016–2026) to ensure alignment with contemporary advancements in the discipline. To further refine the dataset, keyword filters were applied using EXACTKEYWORD constraints, focusing on terms such as “students,” “teaching,” “education,” and “e-learning,” which are closely aligned with the study’s pedagogical and technological dimensions. Additionally, subject area filters were imposed, restricting results to Computer Science, Social Sciences, Mathematics, and Agricultural and Biological Sciences, thereby ensuring interdisciplinary relevance while maintaining conceptual alignment with the research scope. Note that this systematic query initially yielded a total of 274 publications for further evaluation.

Subsequently, a rigorous screening process was implemented to improve the dataset’s quality and relevance, as outlined in Table 3. Inclusion criteria were defined to maintain consistency and uphold academic rigor, restricting the corpus to publications written in English to avoid issues related to translation accuracy and interpretative bias. Subject relevance was further reinforced by retaining only studies categorized within the predefined disciplines, while publications outside these domains were excluded to maintain focus. With respect to temporal coverage, the review was restricted to studies published from 2016 through 2026, a decision made to ensure that the analysis reflects contemporary research trends and advancements, whereas older publications were excluded. This multi-stage screening approach ensured that the final dataset comprised studies that were both methodologically sound and contextually relevant, thereby enhancing the overall reliability as well as validity of the subsequent bibliometric analysis.

Table 2: The Search String

Scopus	TITLE-ABS-KEY (Special education AND Interactive Learning) AND PUBYEAR > 2015 AND PUBYEAR < 2027 AND (LIMIT-TO (EXACTKEYWORD , “Students”) OR LIMIT-TO (EXACTKEYWORD , “Teaching”) OR LIMIT-TO (EXACTKEYWORD , “Education”) OR LIMIT-TO (EXACTKEYWORD , “E-learning”)) AND (LIMIT-TO (SUBJAREA , “COMP”) OR LIMIT-TO (SUBJAREA , “SOCI”) OR LIMIT-TO (SUBJAREA , “MATH”) OR LIMIT-TO (SUBJAREA , “AGRI”))
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Table 3: The Selection Criterion is Searching

Criterion	Inclusion	Exclusion
Language	English	Non-English
Subject	Computer Science, Social Sciences, Mathematics and Agriculture and Biological Science	Others
Timeline	2016 – 2026	<2006

Data Analysis

VOSviewer is a broadly utilized tool for bibliometric analysis, created by Nees Jan van Eck and Ludo Waltman at Leiden University (van Eck & Waltman, 2010, 2017). The software is purpose-built to support the visualization and examination of scientific literature, providing sophisticated capabilities for building network representations, grouping interconnected entities through clustering, and producing density-based visual mappings. Its analytical scope is highly adaptable, enabling the investigation of a wide range of bibliometric linkages such as co-authorship structures, co-citation patterns, and keyword co-occurrence networks, which together facilitate an in-depth mapping of academic domains. Equipped with an interactive user interface and sustained through ongoing development, VOSviewer efficiently processes large-scale datasets while offering flexible visualization customization and the ability to integrate information from diverse data sources. Collectively, these characteristics establish VOSviewer as a dependable and powerful instrument for bibliometric research.

A major advantage of VOSviewer is its capacity to convert intricate bibliometric structures into clear and easily interpretable visual forms. The software is particularly strong in network-based examinations, where it detects clusters of interrelated items, reveals patterns of keyword co-occurrence, and generates density visualizations that emphasize prominent research areas. Its accessible interface supports both beginners and seasoned researchers, enabling substantive interpretation of shifting research trajectories. Ongoing updates also reinforce its methodological significance and maintain its flexibility across a wide range of bibliometric contexts, including networks of authorship, citation relationships, and scholarly collaboration. In the present study, bibliographic data comprising article title, publication year, author information, citation metrics, source journals, as well as keywords were retrieved in plaintext form from Scopus, spanning the timeframe from 2016 through May 2026. The compiled dataset was then examined using VOSviewer version 1.6.19, which applied mapping as well as clustering techniques to construct and interpret bibliometric networks. Unlike traditional approaches such as Multidimensional Scaling (MDS), VOSviewer utilizes a visualization of similarities (VOS) mapping technique, which positions items in a reduced-dimensional space, where inter-item distances correspond to their level of relatedness (van Eck & Waltman, 2010). Although it is theoretically comparable to MDS (Appio et al., 2014), the VOS framework integrates specialized normalization processes tailored for co-occurrence data, most notably through the use of Association Strength $[(AS)]_{ij}$, computed as follows (Van Eck & Waltman, 2007):

$$AS_{ij} = \frac{C_{ij}}{W_i W_j}$$

which is defined as “being proportional to the ratio of the observed co-occurrence count of i and j relative to the expected co-occurrence count of i and j , under the assumption that the co-occurrences between i and j are statistically independent” (Van Eck & Waltman, 2007).

Result and Discussion

RQ1: What Are the Temporal Trends and Developmental Patterns in Scholarly Publications on Digital Learning Media in Special Education for Agricultural Studies From 2016 To May 2026?

The temporal distribution of publications (see **Figure 1** and **Table 4**) reveals a fluctuating yet overall upward trajectory in research on digital learning media in special education for agricultural studies. An initial peak was observed in 2016 (33 publications; 12.0%), followed by a moderate decline from 2017 to 2019, after which outputs stabilized at a lower level (16–23 publications). This early prominence in 2016 may be attributed to the growing global emphasis on inclusive education aligned with frameworks such as Sustainable Development Goal 4 (SDG4), which catalyzed initial scholarly attention toward integrating technology in special education contexts. However, the subsequent dip suggests a transitional phase, possibly reflecting limited technological infrastructure, insufficient pedagogical integration, or a lack of domain-specific digital tools tailored for agriculture-based special education. From 2020 onwards, a gradual recovery is evident, indicating renewed scholarly interest, plausibly influenced by progress in educational technologies alongside increasing recognition of digital platforms as essential tools for differentiated instruction.

A substantial surge in publications is observed between 2023 and 2025, culminating in a peak in 2025 (57 publications; 20.8%), which represents the highest output across the examined period (refer to **Figure 1** and **Table 4**). This sharp increase can be strongly associated with the global impact of the COVID-19 pandemic, which hastened the uptake of e-learning and digitally driven pedagogical approaches across all education sectors, including special education. The heightened research activity during this period reflects an urgent need to explore accessible, adaptive, and technology-enriched learning for learners with special needs, especially in vocational training and agriculture-oriented curricula. Furthermore, the incorporation of developing technologies, including mobile learning, interactive multimedia, as well as assistive tools, has further expanded research opportunities in this niche domain. The apparent decline in 2026 (3.3%) should be interpreted with caution, as it likely represents incomplete publication data for that year rather than a genuine downturn in research engagement. In a broader sense, the trajectory reflects a shifting research landscape characterized by increasing digitalization, interdisciplinary integration, and a growing commitment to inclusive and technology-driven agricultural education.

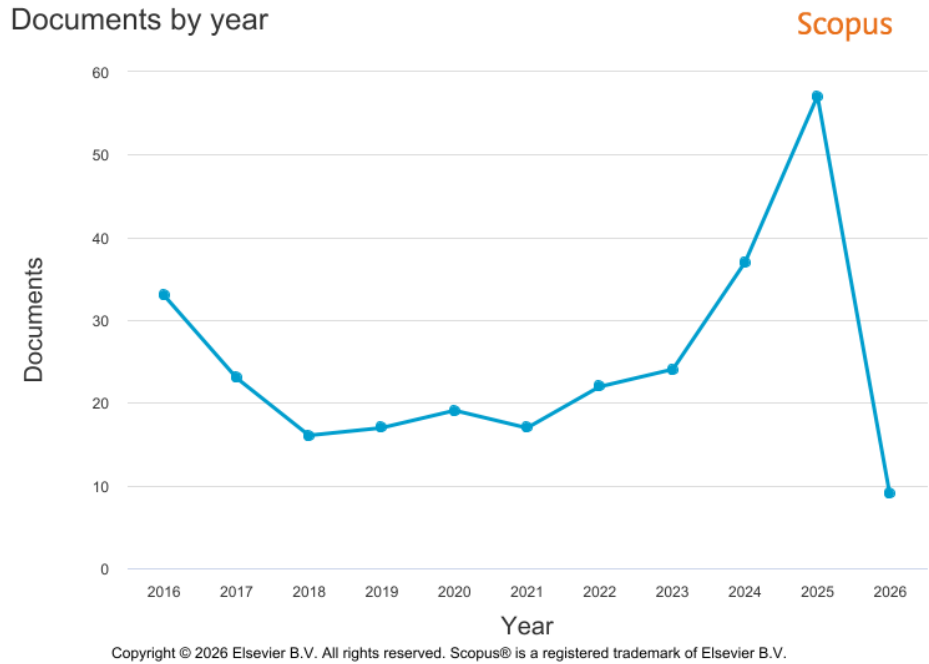


Figure 1: Trend Of Publication by Years 2016-2026

Table 4: Yearly Publication Trends and Percentage Distribution of Retrieved Studies (2016–2026)

Year	Number of Publications	Percentage %
2026	9	3.3
2025	57	20.8
2024	37	13.5
2023	24	8.8
2022	22	8.0
2021	17	6.2
2020	19	6.9
2019	17	6.2
2018	16	5.8
2017	23	8.4
2016	33	12.0

RQ2: What Are the Top Ten Most Cited Articles in Digital Learning Media for Special Education in Agricultural Studies, And What Insights Do They Provide into Influential Research Trends?

The most influential publications in this domain, as presented in Table 5, demonstrate a strong concentration of high citation impact in studies focusing on immersive and interactive technologies within educational contexts. The top-ranked article authored (Potkonjak et al., 2016), which has accumulated 802 citations, underscores the foundational role of virtual laboratories in science and technology education, indicating that early comprehensive reviews tend to accumulate substantial citations due to their broad applicability and theoretical significance. Similarly, studies on augmented reality and virtual/augmented reality adoption (Lai & Cheong, 2022; Lin et al., 2016) reinforce the prominence of immersive technologies as key research frontiers. This pattern suggests that technologies enabling visualization, simulation, and experiential learning are highly valued, especially when serving students with disabilities, where abstract concepts often require concrete representation. Furthermore, publications indexed in high-impact journals like Computers and Education and IEEE Access tend to receive higher citation counts, reflecting the influence of journal reputation and visibility on citation performance.

In addition, Table 5 reveals a thematic shift towards emerging digital paradigms and pedagogical innovation, particularly in more recent publications. Articles related to the metaverse (Dahan et al., 2022), artificial intelligence (Jose & Jose, 2024), and e-learning environment design grounded in constructivist theory (I.-L. Wu et al., 2022) collectively reflect an increasing scholarly focus on emerging, next-generation educational ecosystems. Additionally, the inclusion of studies on game-based learning, blended learning, and interactive assessment further underscores the diversification of digital learning strategies to enhance engagement and learning outcomes. Notably, older publications (e.g., 2016) maintain higher citation counts due to their longer exposure time, while newer studies are rapidly gaining attention, suggesting accelerating research interest in advanced technologies. This distribution reflects both the cumulative advantage effect in citations and the evolving research priorities toward more adaptive, inclusive, and technology-driven educational solutions within special education and agricultural learning contexts.

Table 5: Most Cited Author

No	Authors	Title	Year	Source title	Cited by
1	Potkonjak et al. (2016)	Virtual laboratories for education in science, technology, and engineering: A review	2016	Computers and Education	802
2	Dahan et al. (2022)	Metaverse Framework: A Case Study on E-Learning Environment (ELEM)	2022	Electronics (Switzerland)	157

3	Lin et al. (2016)	Augmented reality in educational activities for children with disabilities	2016	Displays	101
4	Lai & Cheong (2022)	Adoption of Virtual and Augmented Reality for Mathematics Education: A Scoping Review	2022	IEEE Access	99
5	Westerlaken et al. (2019)	Blended learning for postgraduates: An interactive experience	2019	BMC Medical Education	64
6	Westerlaken et al. (2019)	Developing effective e-learning environments through e-learning use mediating technology affordance and constructivist learning aspects for performance impacts: Moderator of learner involvement	2022	Internet and Higher Education	62
7	Görge et al. (2020)	Evaluation of a digital game-based reading training for German children with reading disorder	2020	Computers and Education	54
8	Jose & Jose (2024)	Educators' Academic Insights on Artificial Intelligence: Challenges and Opportunities	2024	Electronic Journal of e-Learning	47
9	Chen et al. (2020)	Formative assessment with interactive whiteboards: A one-year longitudinal study of primary students' mathematical performance	2020	Computers and Education	44
10	Wozniak et al. (2016)	Possible applications of the LEAP motion controller for more interactive simulated experiments in augmented or virtual reality	2016	Proceedings of SPIE - The International Society for Optical Engineering	42

RQ3: What Are the Dominant and Emerging Research Themes in Digital Learning Media for Special Education in Agricultural Studies, As Identified Through Keyword Co-Occurrence Analysis?

The keyword co-occurrence network illustrated in Figure 2 exposes a densely interlinked research landscape organized into multiple prominent thematic clusters. Core keywords such as education (40 occurrences; TLS = 50), interactive learning environments (39; TLS = 47), and special education (30; TLS = 44) occupy central positions in the network, underscoring their essential influence in structuring and defining the field. These high-frequency and high-link-strength terms suggest that the field is strongly anchored in pedagogical contexts, with a clear emphasis on designing interactive and inclusive learning environments. Additionally, technologically oriented keywords—including virtual reality (26; TLS = 48), augmented reality (23; TLS = 47), and educational games (25; TLS = 41)—demonstrate strong connectivity, highlighting the integration of immersive and gamified technologies as key drivers of innovation. The prominence of these terms indicates that research is not only frequent but also structurally central, serving as bridges that connect multiple subthemes within the network.

Furthermore, Figure 2 illustrates the emergence of specialized and application-oriented clusters that reflect evolving research priorities. Keywords such as personalized learning (TLS = 16), learning content adaptation (TLS = 12), and artificial intelligence (TLS = 11) suggest a growing focus on adaptive and intelligent learning systems tailored to individual learner needs, particularly in special education contexts. The presence of terms like autism spectrum disorder, visual impairment, and accessibility indicates that inclusivity and learner diversity are critical considerations driving research directions. Meanwhile, moderate link strengths observed for keywords such as e-learning, mobile learning, and learning management system imply a supporting infrastructure role rather than a central research focus. The relatively lower occurrence but meaningful connectivity of emerging terms such as Extended Reality (XR) (TLS = 19) reflects a transitional phase, where newer technologies are gaining traction but have yet to reach full maturity within the literature. Overall, the network structure underscores a convergence between pedagogical innovation and technological advancement, with increasing emphasis on personalized, accessible, and immersive learning solutions.

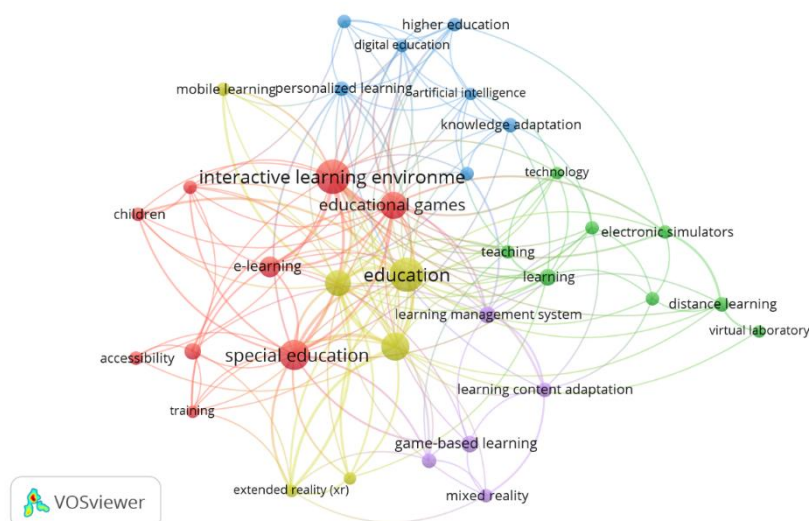


Figure 2: Keyword Co-Occurrence Network Visualization of Digital Learning Media in Special Education for Agricultural Studies (2016–2026)

RQ4: What Are the Patterns of International Research Collaboration in Digital Learning Media for Special Education in Agricultural Studies, As Revealed by Country-Level Co-Authorship Networks?

The country-level co-authorship network depicted in **Figure 3** demonstrates a geographically diverse yet uneven distribution of research productivity and collaboration intensity. The United States stands out as the leading contributor (32 documents; TLS = 4), followed by India (20; TLS = 3) and both China and Germany (18 each), reflecting the dominance of large research ecosystems with strong investments in educational technology and special education. However, productivity does not always correspond with collaboration strength. For instance, Germany and the Russian Federation exhibit moderate publication outputs but a Total Link Strength (TLS) of zero, indicating limited international co-authorship. In contrast, the United Kingdom shows a relatively smaller publication count (14 documents) but the highest citation impact (877 citations) and the strongest collaboration network (TLS = 6), suggesting that its research is both highly influential and well-integrated within global scholarly networks. This pattern highlighted the role of strategic international collaboration and high-impact publication venues in amplifying research visibility and citation performance.

Furthermore, **Figure 3** reveals notable contributions from emerging and mid-tier research countries, particularly within Asia and developing regions. Malaysia (10 documents; 217 citations; TLS = 5), Pakistan (6; 198; TLS = 4), and Taiwan (7; 210; TLS = 3) demonstrate strong citation performance relative to their publication volume, indicating high research quality and relevance despite smaller outputs. Similarly, Australia (7 documents; 851 citations; TLS = 4) exhibits exceptionally high citation impact, likely driven by a few highly cited publications, reflecting a quality-over-quantity dynamic. Conversely, countries such as Indonesia (10 documents; 9 citations) and Ecuador (5; 13) show lower citation counts, which may be attributed to limited research visibility, lower indexing in high-impact journals, or weaker international collaboration networks. Overall, the network structure suggests that citation impact is strongly influenced by both the extent of international collaboration and

publication in high-visibility outlets. Meanwhile, disparities in research capacity, funding, and global integration contribute to uneven scholarly influence across countries.

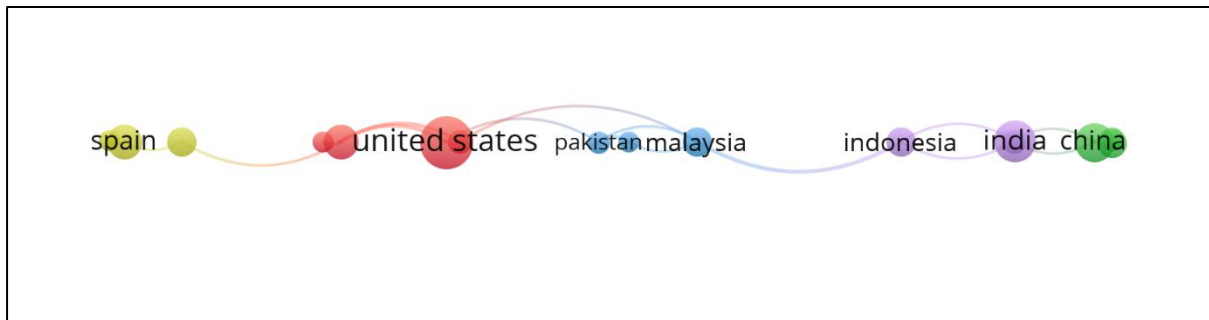


Figure 3: Country-Level Co-Authorship Network Visualization of Publications on Digital Learning Media in Special Education for Agricultural Studies (2016–2026)

Conclusion

This study aimed to investigate the growth, organization, as well as collaborative dynamics of research concerning digital learning media in special education for agriculture studies through a bibliometric approach, guided by four main questions related to publication trends, thematic evolution, influential works, as well as international collaboration. The analysis, based on 274 publications indexed between 2016 and May 2026, reveals several important patterns. First, the overall publication output shows a gradual increase with a strong acceleration after 2020, indicating rising academic attention toward digital and inclusive learning environments, particularly influenced by global shifts in education systems. Second, citation patterns suggest that highly influential studies are often associated with advanced technologies, including augmented reality, virtual reality, as well as interactive learning platforms. This pattern underscores the significance of experiential and visually driven learning approaches in supporting students with special educational needs. Third, keyword co-occurrence mapping identifies dominant themes centered on education, interactive learning environments, and special education, while emerging directions include artificial intelligence, personalized learning, and XR. Fourth, collaboration analysis indicates that research productivity is concentrated in a limited number of countries. At the same time, citation impact is strongly linked to international collaboration networks rather than publication volume alone, as also reflected in the discussion of country-level networks in the uploaded document.

This study advances the field by offering an organized and systematic mapping of its intellectual terrain, while also identifying both established and emerging research directions within this interdisciplinary domain. The findings offer practical implications, particularly for supporting the design of inclusive, technology-enhanced agricultural learning environments that address diverse learner needs. However, several limitations are acknowledged, including dependence on a solitary database, the limitation to publications written in English, as well as the possible omission of pertinent grey literature. Subsequent investigations may expand data sources, include longitudinal impact studies, and explore underrepresented regions and contexts. In conclusion, bibliometric analysis proves to be a valuable method to map research evolution and highlight knowledge gaps, and this highlights the increasing significance of integrating digital learning media within special education for agriculture studies as a pathway toward more inclusive and adaptive educational practices.

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- Acknowledgements:** The authors would like to express their sincere gratitude to Universiti Pendidikan Sultan Idris for providing the necessary resources and support throughout this research. Special appreciation is extended to colleagues and peers who contributed valuable insights and constructive feedback, which greatly enhanced the quality of this paper.
- Funding Statement:** No Funding
- Conflict of Interest Statement:** The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the International Journal of Modern Education (IJMOE).
- Ethics Statement:** This study did not involve any human participants, animals, or sensitive data requiring ethical approval. The authors confirm that the research was conducted in accordance with accepted academic integrity and ethical publishing standards.
- Author Contribution Statement:** All authors contributed significantly to the development of this manuscript. Author A: Johthi A/P Subramaniam was responsible for the conceptualization, methodology, and overall supervision of the study. Author B Noraini handled data collection, analysis, and interpretation of results. Author C: Vikneswray A/P Mani Raj contributed to the literature review, drafting, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.
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