

Review

Mapping Research on Generational Differences in Learning Performance in Digital Education Environments: A Bibliometric Analysis (2010–2025)

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Abstract: Generational differences have become an increasingly important topic in education research as digital transformation and technology-enhanced learning environments reshape student experiences. Millennials, Generation Z, and the emerging Generation Alpha exhibit distinct technological familiarity, learning preferences, and communication patterns that may influence learning performance and educational outcomes. Despite the growing body of literature on generational learning differences, the overall intellectual structure and global development of this research domain remain insufficiently understood. This study aims to map the intellectual landscape and global research trends on generational differences in learning performance within digital and technology-enhanced educational environments. A bibliometric analysis was conducted using data from the Scopus database, yielding 1,007 documents from 754 sources published between 2010 and 2025. The study integrates descriptive bibliometric indicators with scientific mapping techniques, including thematic mapping, Multiple Correspondence Analysis, and keyword co-occurrence network analysis. The findings reveal a strong upward trend in publication output, indicating rapidly increasing scholarly interest in generational learning dynamics. The results also demonstrate the field's interdisciplinary nature, with significant contributions from the social sciences, computer science, business, engineering, and health-related disciplines. Emerging research themes highlight the growing importance of digital learning environments, artificial intelligence, and technology-mediated education in shaping generational learning experiences. This study contributes to understanding generational learning in contemporary digital education environments and identifies key thematic directions that may inform future research, including the development of more immersive, technology-driven learning systems.

Keywords: Artificial intelligence in education; Digital learning environments; Generational differences; Generation Z; Millennials; Learning performance; Technology-enhanced learning

1. Introduction

Education systems worldwide are undergoing a profound transformation driven by rapid advances in digital technologies, artificial intelligence, and technology-enhanced learning environments. Over the past two decades, the expansion of online learning platforms, mobile technologies, learning analytics, and intelligent tutoring systems has fundamentally reshaped how knowledge is delivered, accessed, and experienced [1–3]. These developments have enabled more flexible, interactive, and data-driven learning environments that extend beyond traditional classroom settings and support new forms of student engagement and knowledge construction [4–6].

As education becomes increasingly digital, understanding how learners from

different generational cohorts interact with technology-based learning systems has become an important research priority [7–9]. Contemporary educational institutions serve diverse student populations whose technological exposure, communication practices, and learning preferences vary significantly [10]. Millennials (Generation Y), Generation Z, and the emerging Generation Alpha have developed within distinct technological and socio-cultural contexts, shaping how they engage with digital tools, learning platforms, and educational environments [11–13]. These generational differences may influence learning performance, engagement, collaboration, and overall educational outcomes, particularly in technology-mediated learning contexts [14,15].

Recent research has increasingly examined generational differences in areas such as digital literacy, technology adoption, learning preferences, and academic performance [16–18]. Millennials, who experienced the transition from analog to digital systems, differ from Generation Z, who have grown up in fully networked digital environments characterized by constant connectivity and social media interaction [19–21]. More recently, Generation Alpha is emerging as a cohort shaped by highly integrated digital ecosystems, including artificial intelligence-driven technologies and adaptive learning platforms [22,23]. These generational shifts highlight the importance of understanding how technological familiarity and learning behaviors evolve across cohorts within modern education systems [24–26].

At the same time, the rapid development of technology-enhanced learning environments, including online learning platforms, blended learning systems, and AI-supported educational tools, has intensified scholarly interest in how learners engage with digital education [27–29]. These environments require new forms of interaction, self-regulation, and collaboration, which may be experienced differently across generational groups [30–32]. As a result, research on generational learning performance has expanded across multiple disciplines, including education, computer science, business, engineering, and health sciences [33,34].

Despite the growing volume of literature, the broader intellectual structure and global development of research on generational differences in learning performance remain insufficiently understood. Existing studies often focus on specific cohorts, technologies, or localized contexts, limiting the ability to identify overarching research trends, dominant thematic areas, and interdisciplinary connections [35,36]. In particular, there is a lack of comprehensive analyses that map how this research field has evolved over time and how different knowledge domains contribute to understanding generational learning in digital education environments [37,38].

Bibliometric analysis provides a systematic and quantitative approach for addressing these gaps. By examining large-scale bibliographic data, bibliometric methods enable researchers to analyze publication trends, citation patterns, collaboration networks, and conceptual structures within a research field. In education research, such approaches have been widely used to map emerging topics, identify influential contributors, and reveal the thematic evolution of scholarly domains. Applying bibliometric techniques to generational learning research can therefore provide valuable insights into its intellectual landscape and future development.

Building on this approach, the present study aims to map the intellectual structure and global research trends on generational differences in learning performance within digital and technology-enhanced educational environments. Using bibliographic data retrieved from the Scopus database, the study integrates

descriptive bibliometric indicators with scientific mapping techniques to examine publication growth, key contributors, collaboration patterns, and thematic structures within this evolving research domain

Specifically, the study addresses the following research questions:

1. How has scientific production on generational differences in learning performance evolved over time?
2. Which disciplines, authors, institutions, and countries contribute most significantly to this research field?
3. What thematic structures and conceptual domains characterize the intellectual development of generational learning research?
4. What collaboration patterns and emerging research themes shape the future direction of this field?

This study makes three main contributions. First, it provides a comprehensive bibliometric mapping of global research on generational differences in learning performance over a fifteen-year period. Second, it identifies the intellectual structure and thematic evolution of the field, highlighting the increasing role of digital learning environments, artificial intelligence, and technology-mediated education. Third, while the study does not directly examine metaverse-based education, it situates its findings within broader trends in digital transformation, suggesting potential directions for future research on advanced, immersive learning systems. The study contributes to a deeper understanding of how generational differences shape learning in contemporary digital education environments and provides a foundation for future research on emerging forms of technology-enhanced and immersive education.

2. Methodology

2.1 Research design

This study adopts a bibliometric research design to systematically examine the global development of research on generational differences in learning performance. Bibliometric analysis is a quantitative method used to analyze large bodies of scientific literature in order to identify publication trends, citation structures, collaboration networks, and thematic relationships within a research field. By combining descriptive bibliometric indicators with scientific mapping techniques, the present study aims to reveal the intellectual structure, conceptual evolution, and emerging research themes related to generational learning performance.

2.2 Data source and search date

The bibliographic dataset used in this study was retrieved from the Scopus database, one of the largest and most comprehensive abstract and citation databases of peer-reviewed literature. Scopus was selected for its extensive coverage of international scholarly publications and suitability for bibliometric analysis. The database search was conducted on January 15, 2026, ensuring that the dataset included all relevant publications indexed in Scopus up to the end of 2025.

2.3 Search strategy and scope of the dataset

To identify relevant publications, a structured search query was developed based on combinations of keywords related to learning performance and generational cohorts. The search query was applied to the title, abstract, and keyword fields of the Scopus database. The search query used was:

TITLE-ABS-KEY ((("learning performance" OR "academic performance" OR "student performance" OR "learning outcomes" OR

"student achievement" OR education OR learning) AND (millennial* OR "Generation Y" OR "Gen Y" OR "Generation Z" OR "Gen Z" OR "Generation Alpha" OR "Gen Alpha") AND (compar* OR difference* OR "generational differences" OR "generational comparison")) AND PUBYEAR >= 2010 AND PUBYEAR <= 2025 AND (LIMIT-TO (PUBSTAGE, "final")))

The search period was restricted to 2010–2025 to capture the rapid expansion of research on generational learning in the context of digital transformation in education. The search strategy was designed to capture a comprehensive body of literature related to generational differences in learning performance. To achieve broad coverage, the search query included general terms such as “education” and “learning,” along with performance-related terms (e.g., “learning performance,” “academic performance,” and “student achievement”), and generational cohort identifiers. While the inclusion of broader terms such as “education” and “learning” increased the sensitivity of the search and ensured comprehensive retrieval of relevant studies, it may have also expanded the dataset beyond a narrowly defined construct of “learning performance.” As a result, the final corpus reflects a broader landscape of generational learning research within educational contexts, encompassing studies that examine learning outcomes, engagement, and technology-mediated learning processes. This approach was considered appropriate for the study’s objective of mapping the intellectual structure and global research trends of generational learning research. However, this broader scope is acknowledged as a limitation, and the findings should be interpreted as representing the wider domain of generational learning in education rather than a strictly delimited subset of performance-focused studies.

2.4 Inclusion and exclusion criteria

To ensure the relevance, consistency, and reproducibility of the bibliometric dataset, a structured screening process was conducted using predefined inclusion and exclusion criteria. Following the initial retrieval of records from the Scopus database, a two-stage screening procedure was applied. In the first stage, titles and abstracts of all retrieved records were manually reviewed to assess their relevance to the study’s focus on generational differences in learning performance within educational contexts. Records were excluded at this stage if they: (1) were not related to education or learning environments; (2) did not explicitly refer to generational cohorts (e.g., Millennials, Generation Z, or Generation Alpha); or (3) addressed demographic or generational issues without clear relevance to learning, academic performance, or educational outcomes. In the second stage, the remaining records underwent an eligibility assessment based on full bibliographic information. Additional exclusions were applied to: (1) studies lacking sufficient bibliographic metadata required for bibliometric analysis; (2) duplicate records; (3) non-English publications; and (4) documents that did not meet the inclusion criteria upon closer inspection of their abstracts and keywords. Ambiguous cases were re-evaluated against the predefined criteria to ensure consistency in inclusion decisions. To enhance methodological rigor and reproducibility, the screening criteria were applied systematically across all records using a consistent decision framework. The complete screening process is summarized using a PRISMA-style flow diagram (**Figure 1**), which details the number of records identified, screened, excluded, and retained at each stage.

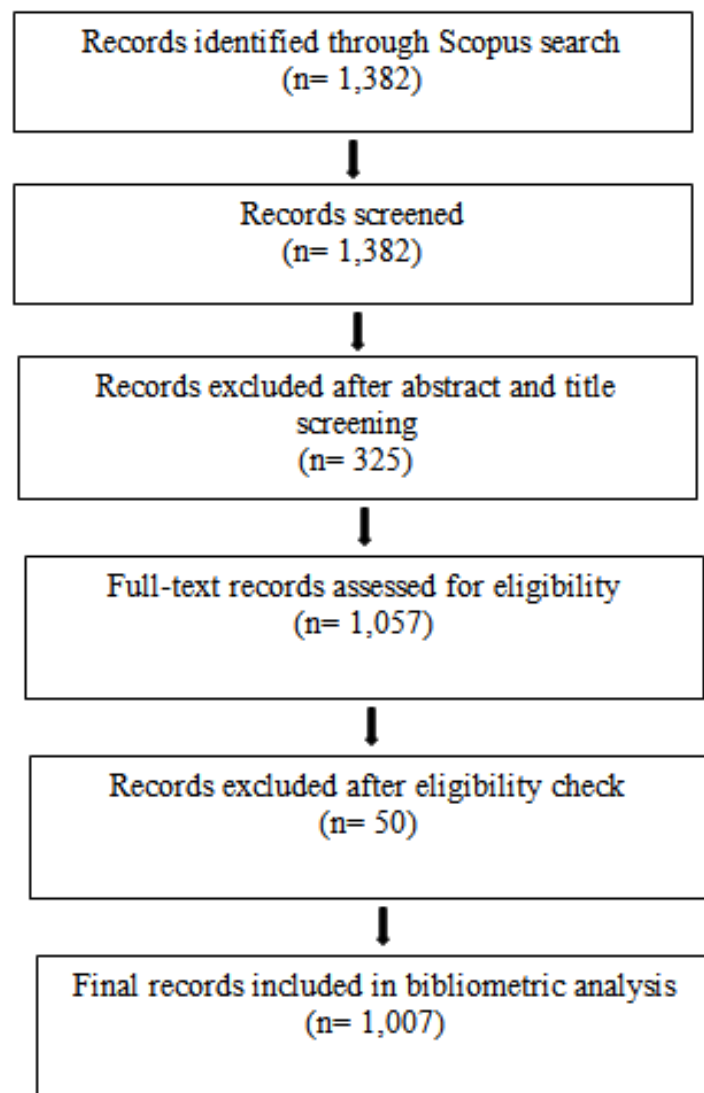


Figure 1. PRISMA Diagram bibliometric dataset selection process

2.5 Data export procedure

After the final search query, the retrieved records were exported from Scopus in CSV format to facilitate bibliometric analysis. The export procedure included the following metadata fields of bibliometric visualization tools such as authors, article title, abstract, keywords, source title, publication year, author affiliations, country information, citation counts and references. This information was necessary for conducting co-authorship analysis, citation analysis, and keyword co-occurrence mapping.

2.6 Data cleaning and duplicate removal

Before conducting the bibliometric analysis, the dataset underwent a data cleaning process to ensure consistency and accuracy. Duplicate records were removed using bibliometric data-cleaning procedures. Author names were standardized to correct minor variations in spelling or formatting. Keywords with identical meanings but different spellings (e.g., “e-learning” and “elearning”) were harmonized. Incomplete records lacking essential bibliographic information were excluded. After cleaning, the final dataset comprised 1,007 publications from 754 sources, representing the global research output on generational differences in

learning performance.

2.7 Data analysis procedures

The bibliometric analysis used a combination of descriptive indicators and scientific mapping techniques to examine the intellectual structure, thematic evolution, and collaboration patterns within the research field. The analysis was carried out using two complementary bibliometric software tools: Bibliometrix (via the Biblioshiny interface in R) and VOSviewer. First, descriptive bibliometric indicators were generated to examine the dataset's overall characteristics. These indicators included annual publication trends, citation patterns, document types, authorship structures, and international collaboration rates. Productivity analysis was also conducted to identify the most influential authors, institutions, journals, and countries contributing to research on generational differences in learning performance. Second, scientific mapping techniques were applied to explore the conceptual and thematic structure of the research field. Bibliometrix (Biblioshiny) was used to generate thematic maps and perform Multiple Correspondence Analysis (MCA), which identifies conceptual clusters and relationships among keywords within the literature. These analyses help reveal the dominant research themes, emerging knowledge domains, and the evolving conceptual structure of generational learning research. Third, VOSviewer was used to construct and visualize bibliometric networks, including keyword co-occurrence networks and international collaboration maps. Keyword co-occurrence analysis identifies clusters of frequently associated terms that represent major research topics, while collaboration network analysis illustrates patterns of scholarly cooperation across countries and institutions. By integrating descriptive indicators with scientific mapping techniques, this combined analytical approach provides a comprehensive overview of the publication trends, conceptual structures, and collaboration patterns shaping research on generational differences in learning performance within digital and technology-enhanced educational environments.

3. Results

Table 1. General information of the dataset

Variables	Result
Data Set	
Timespan	2010: 2025
Sources (journals, books, etc.)	754
Documents	1007
Annual growth rate (%)	18.8
Document average age	5.61
Average citations per document	13.48
Document Contents	
Index keywords of all documents	3133
Author's keywords of all documents	2833
Authors	
Authors	2961
Authors of single-authored documents	149
Authors Collaboration	
Single-authored documents	180

Continuation Table:

Variables	Result
Co-authors per doc	3.09
International co-authorships (%)	14.6
Document Types	
Article	692
Book	14
Book chapter	70
Conference paper	156
Conference review	26
Data paper	1
Editorial	4
Erratum	2
Note	4
Retracted	1
Review	36
Short survey	1

Table 1 summarizes the bibliometric characteristics of the dataset, covering 1,007 publications from 754 sources between 2010 and 2025, indicating a broad, multidisciplinary research landscape on generational differences in learning performance. The field shows a strong annual growth rate of 18.8%, reflecting rapidly increasing scholarly interest in understanding learning outcomes across Millennials, Generation Z, and Generation Alpha. The literature remains relatively recent, with an average document age of 5.61 years and 13.48 citations per document, suggesting growing academic influence. Research production is highly collaborative, involving 2,961 authors with an average of 3.09 co-authors per paper, although international collaboration remains modest (14.6%). Journal articles dominate the publication types (692 documents), followed by conference papers and book chapters, indicating that peer-reviewed journals serve as the primary channel for disseminating research in this emerging and rapidly expanding field. Overall, the bibliometric indicators suggest that research on generational differences in learning performance is an emerging and rapidly expanding field within education studies. The increasing number of publications, strong collaborative authorship patterns, and diverse keyword structure indicate growing scholarly attention to how generational characteristics influence learning outcomes. Collectively, these trends highlight the evolving academic interest in understanding generational dynamics in education, particularly in response to changing learning environments and technological advancements. The bibliometric pattern indicates that research on generational learning performance is in a rapid growth phase typical of an emerging research domain. The high publication growth rate, relatively young literature, and moderate citation levels suggest that the field is still consolidating its theoretical and empirical foundations. At the same time, the strong collaborative authorship structure reflects the interdisciplinary, network-driven nature of contemporary education research, in which scholars from multiple domains contribute to understanding generational learning dynamics. However, the relatively low level of international collaboration implies that the field still has significant potential for greater cross-national research integration, which could

further enhance comparative insights into generational learning across diverse educational contexts.

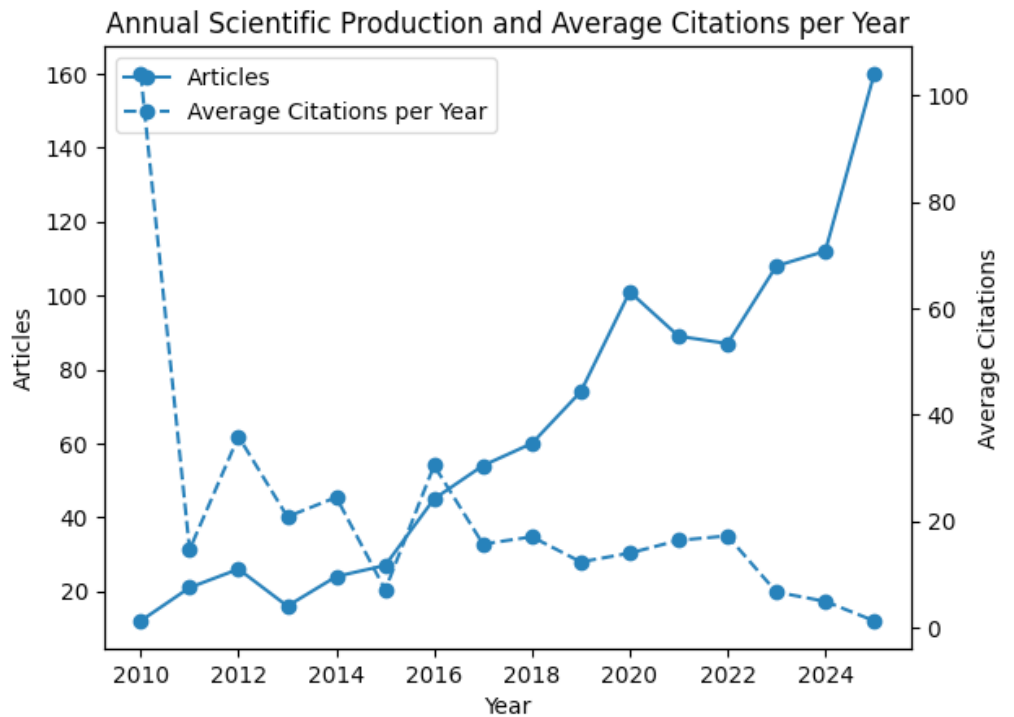


Figure 2. Annual publication and citation trends

Figure 2 illustrates the temporal evolution of research on generational differences in learning performance between 2010 and 2025. The results demonstrate a clear upward trajectory in annual scientific output, with publications increasing from fewer than 20 in 2010 to approximately 160 by 2025. This rapid growth indicates the increasing scholarly relevance of generational learning dynamics within contemporary education research. Two notable phases of expansion can be identified. The first moderate growth period occurred between 2015 and 2018, coinciding with the increasing integration of digital technologies and learning management systems in higher education. During this period, researchers began examining how digitally connected learners, particularly Generation Z, interact with technology-enhanced learning environments.

A second and more pronounced surge in publication activity occurred after 2018, with a particularly steep increase beginning around 2020. This acceleration can be linked to two major developments in global education systems. First, the COVID-19 pandemic triggered a rapid shift toward online and hybrid learning worldwide, prompting scholars to investigate how different generational cohorts adapt to remote, technology-mediated learning contexts. Second, the rapid development of artificial intelligence and data-driven educational technologies has generated new research interest in how digital-native learners engage with intelligent learning systems, adaptive platforms, and digital collaboration tools. Together, these trends suggest that generational learning research is closely connected to broader transformations in digital education. The increasing publication volume, therefore, reflects not only growing academic interest in generational cohorts but also the expanding role of digital technologies in shaping contemporary learning environments.

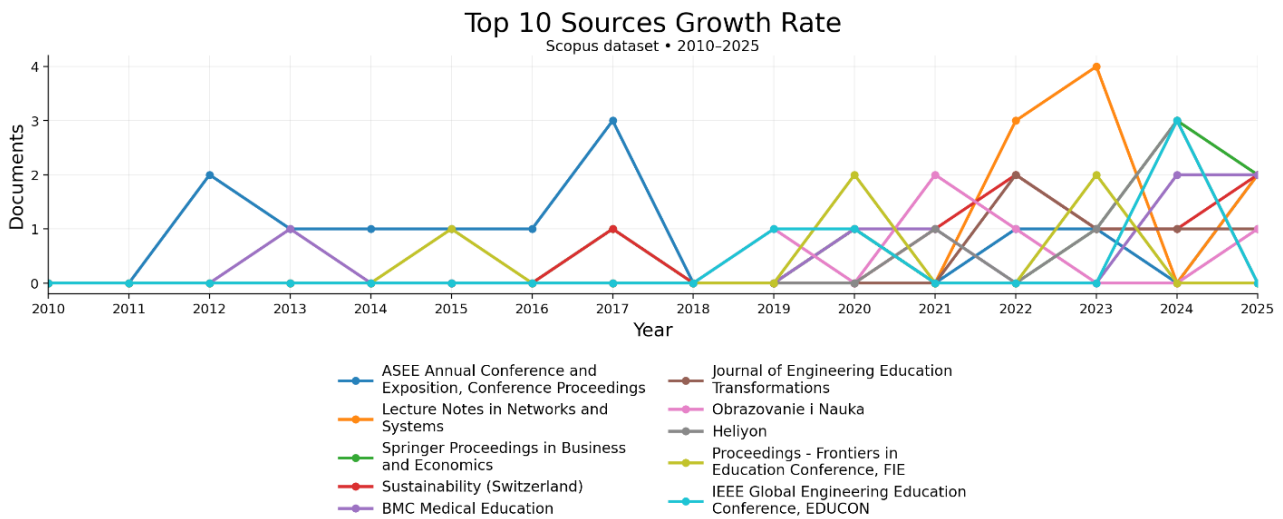


Figure 3. Documents by source

Figure 3 presents the publication growth patterns of the top ten sources contributing to research on generational differences in learning performance between 2010 and 2025. The results indicate that several outlets show intermittent but increasing contributions, particularly after 2020, reflecting the growing academic interest in generational learning dynamics. Among the sources, *Lecture Notes in Networks and Systems* demonstrates the most noticeable growth, reaching the highest number of publications in recent years. Other outlets, such as *Springer Proceedings in Business and Economics*, *Journal of Engineering Education Transformations*, and *BMC Medical Education*, also show increasing activity, particularly in the later years of the study period. Conference proceedings, including the *ASEE Annual Conference and Exposition* and the *IEEE Global Engineering Education Conference (EDUCON)*, contribute periodically, highlighting the role of conference platforms in disseminating emerging research. Overall, the distribution suggests that the field is supported by a diverse range of interdisciplinary publication outlets spanning engineering education, business education, and broader educational research. These patterns indicate that generational learning research is increasingly disseminated across interdisciplinary academic outlets, reflecting its expanding scope and relevance within global education research.

Figure 4 illustrates the disciplinary distribution of publications related to generational differences in learning performance. The results show that Social Sciences dominate the research landscape, accounting for 27.4% of all publications, reflecting the central role of education and social research in examining generational learning behaviors. Other notable contributions come from Business, Management and Accounting (11.0%) and Computer Science (10.5%), highlighting the growing interest in organizational learning contexts and technology-enhanced education. Additionally, Medicine (8.4%) and Engineering (8.3%) indicate that generational learning research is also relevant in professional and technical education fields. Smaller yet meaningful contributions emerge from Economics (5.1%), Arts and Humanities (4.0%), Psychology (3.8%), Environmental Science (3.1%), and Nursing (2.7%), demonstrating the multidisciplinary nature of the topic. Overall, the subject area distribution indicates that research on generational learning performance is highly interdisciplinary, with strong foundations in social science, while increasingly integrating perspectives from technology, management, and health-related disciplines. The observed distribution reveals a core-periphery disciplinary structure, in which

the Social Sciences serve as the primary knowledge base for studying generational learning differences. At the same time, the strong presence of Computer Science, Business, and Engineering suggests an increasing integration of technology-driven learning environments, digital pedagogy, and organizational education contexts. The involvement of Medicine, Nursing, and Psychology further indicates that generational learning dynamics are being examined in professional and applied education settings, particularly where training, competency development, and behavioral adaptation are critical. This pattern suggests that research on generational learning performance is increasingly expanding beyond traditional educational studies toward a more technology-oriented, cross-sector, interdisciplinary research domain.

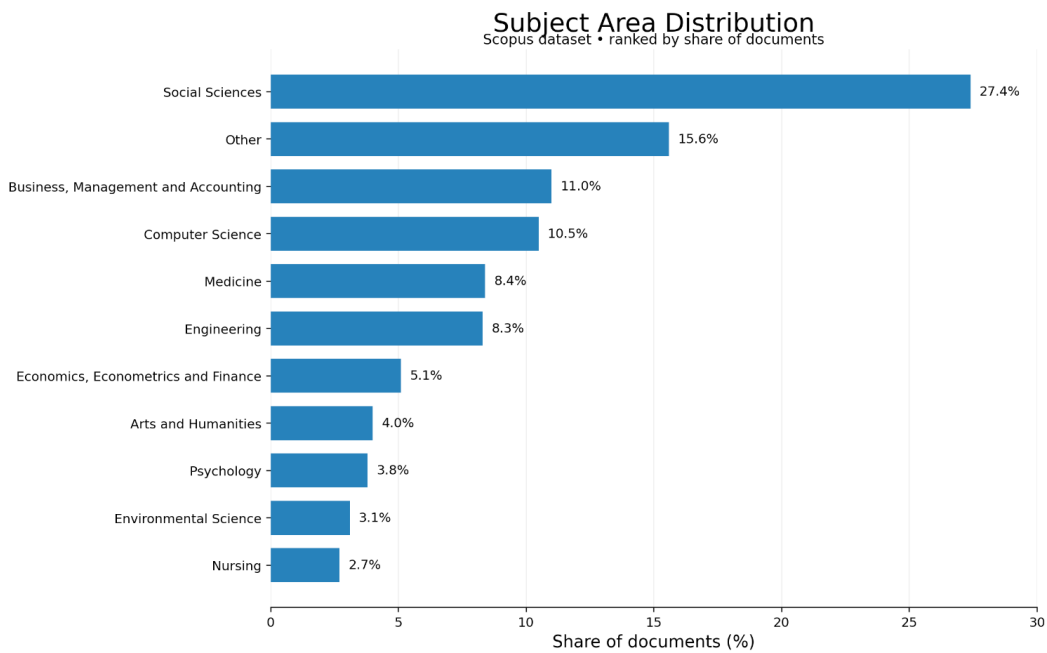


Figure 4. Documents by subject area

Note: Percentages represent the distribution of publications across the subject areas displayed in the figure. Because a single document may be indexed under more than one subject area in Scopus, the percentages may not sum to 100%.

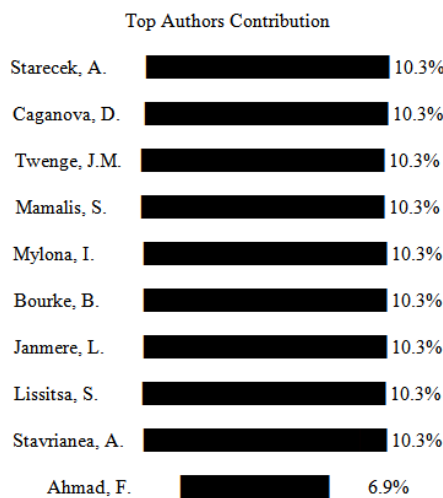


Figure 5. Documents by author

Note: Percentages represent the relative distribution of publications among the top-ranked authors displayed in the figure and are not calculated from the full dataset of 1,007 documents.

Figure 5 presents the most productive authors contributing to research on generational differences in learning performance. The distribution indicates that several scholars have comparable levels of contribution within the ranked group of leading authors. Starecek, A.; Caganova, D.; Twenge, J.M.; Mamalis, S.; Mylona, I.; Bourke, B.; Janmere, L.; Lissitsa, S.; and Stavrianea, A. each account for 10.3% of the publications within the top-author subset, while Ahmad, F. contributes 6.9% within the same ranked group. These percentages reflect the relative distribution of contributions among the top authors displayed in the figure, rather than the full dataset of 1,007 publications. The relatively balanced distribution among the leading authors suggests that research on generational learning performance is not dominated by a single scholar but is supported by multiple active researchers contributing to the field's development. This pattern reflects a decentralized, collaborative intellectual structure in which diverse scholars contribute perspectives on generational behavior, digital learning environments, and educational outcomes. Overall, the authorship structure indicates an evolving research domain characterized by distributed scholarly participation and interdisciplinary contributions.

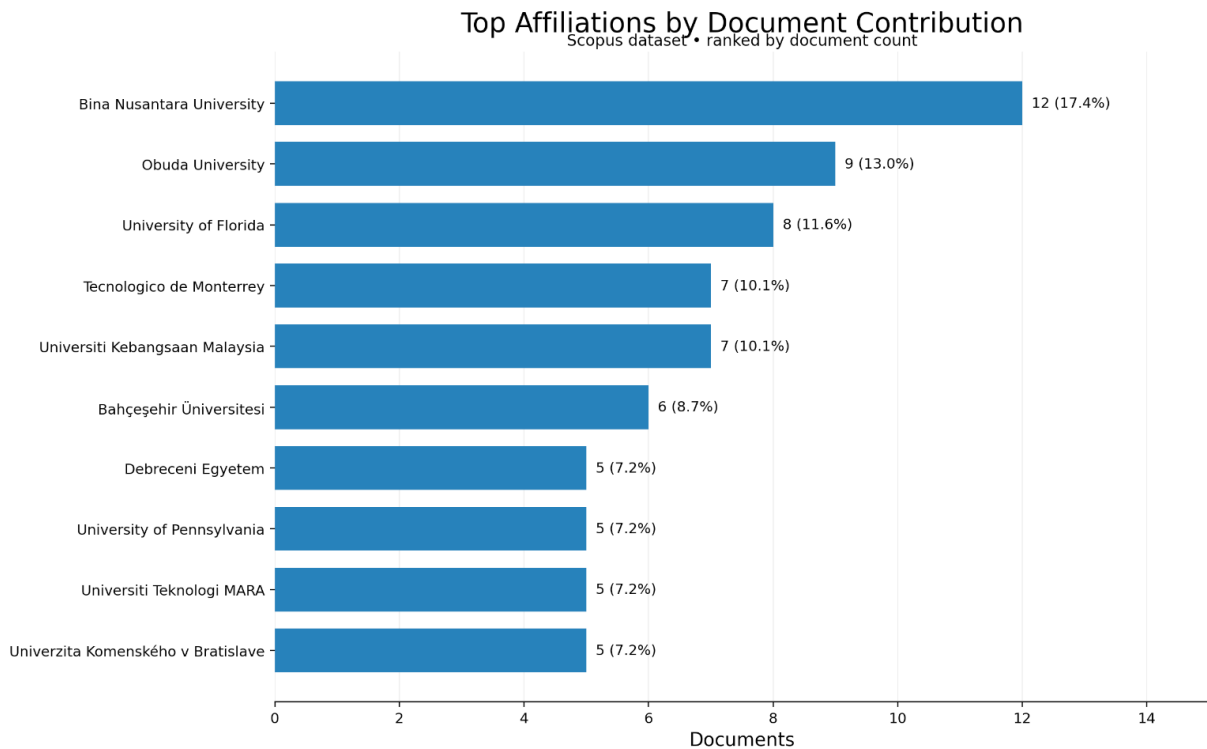


Figure 6. Documents by affiliation

Note: Percentages represent the relative distribution of publications among the top-ranked institutions displayed in the figure and are not calculated from the full dataset of 1,007 documents.

Figure 6 presents the leading institutional affiliations contributing to research on generational differences in learning performance. The results indicate that Bina Nusantara University leads with 12 publications (17.4%), highlighting its strong research engagement in this area. This is followed by Obuda University with 9 publications (13.0%) and the University of Florida with 8 publications (11.6%), demonstrating significant contributions from institutions across different geographic regions. Other notable institutions include Tecnologico de Monterrey and Universiti Kebangsaan Malaysia, each contributing 7 publications (10.1%), while Bahçeşehir

Üniversitesi accounts for 6 publications (8.7%). Several institutions, including Debreceni Egyetem, University of Pennsylvania, Universiti Teknologi MARA, and Univerzita Komenského v Bratislave, contributed 5 publications each (7.2%), reflecting a relatively even distribution of institutional participation. Overall, the institutional distribution suggests that research on generational learning performance is globally distributed across universities in Asia, Europe, and the Americas, indicating the growing international relevance of this topic within educational research. The institutional pattern reveals a geographically dispersed but moderately concentrated research network, in which a small group of universities demonstrates relatively higher productivity, while many others contribute at comparable but lower levels. The prominence of institutions from Asia, Europe, and North America suggests that interest in generational learning differences is shaped by diverse educational systems and demographic contexts. The leading role of universities such as Bina Nusantara University also reflects the growing research capacity of emerging academic institutions, particularly in regions experiencing rapid expansion in higher education and digital learning environments. This pattern indicates that the field is evolving toward a globally interconnected research community in which multiple institutions collectively advance knowledge of generational learning dynamics.

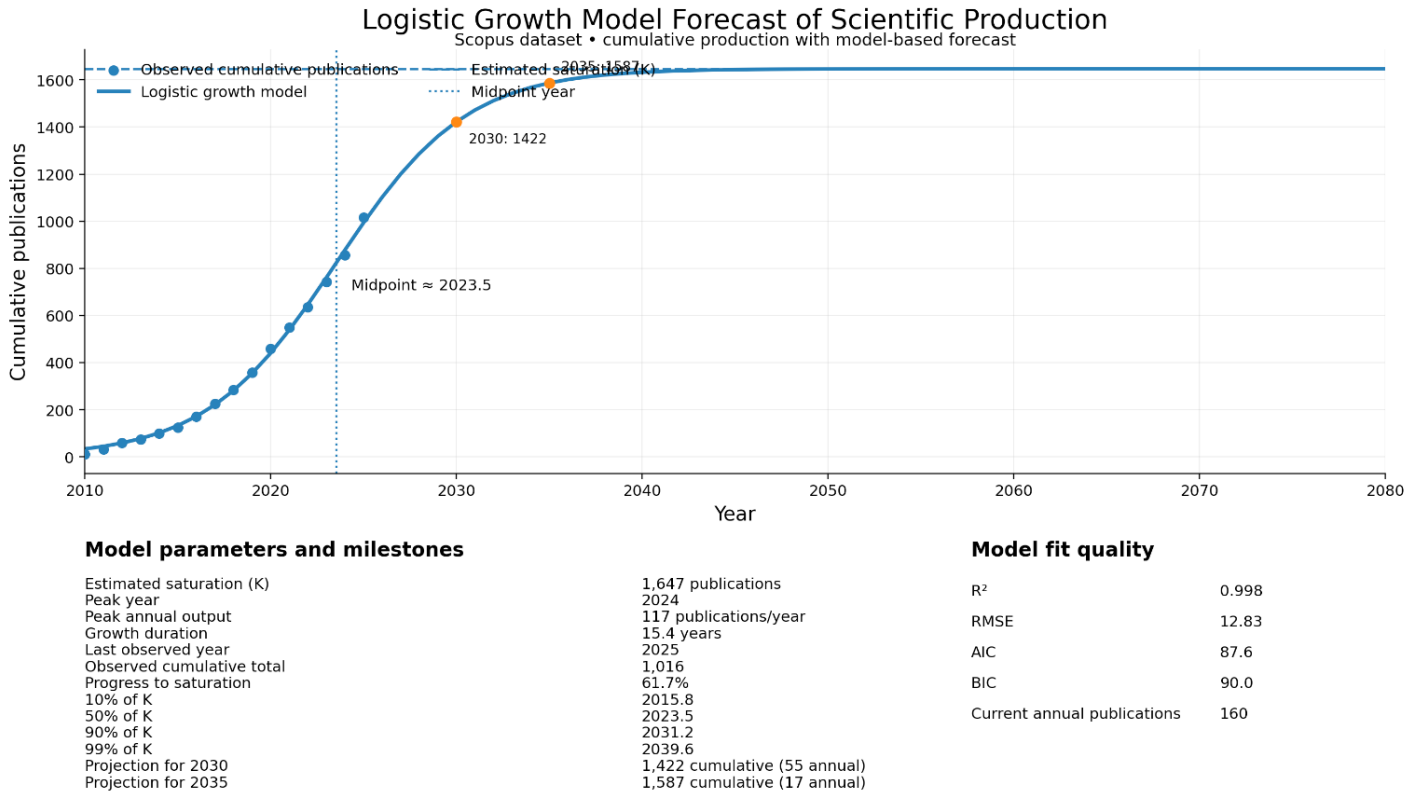
Table 2. Documents by country

Country	Documents	Contribution
United States	310	43.8%
Indonesia	90	12.7%
India	70	9.9%
United Kingdom	45	6.4%
Malaysia	38	5.4%
Poland	35	4.9%
Turkey	32	4.5%
Canada	31	4.4%
Spain	29	4.1%
Russian Federation	28	4.0%

Note: Percentages represent the relative distribution of publications within the ranked subset of the top contributing countries displayed in this table, rather than the full dataset of 1,007 documents

Table 2 presents the most productive countries contributing to research on generational differences in learning performance. The percentages represent the relative distribution within the ranked subset of the top contributing countries, rather than the full dataset of 1,007 publications. The United States leads with 310 publications (43.8%), indicating its dominant role in advancing research in this field. It is followed by Indonesia (90 publications, 12.7%) and India (70 publications, 9.9%), highlighting the growing contribution of emerging research communities in Asia. Several European countries also show notable research activity, including the United Kingdom (6.4%), Poland (4.9%), and Spain (4.1%). Additional contributions come from Malaysia, Turkey, Canada, and the Russian

Federation, each accounting for approximately 4–5% of the publications within the ranked subset. Overall, the distribution indicates that while research output remains concentrated in a few leading countries, scholarly activity is increasingly distributed across multiple global regions..



Interpretation: the field is still in the early-to-rapid growth stage, with the midpoint projected near 2024 and the asymptotic saturation around 1,647 cumulative publications.

Figure 7. Life cycle of scientific publication

Figure 7 presents a logistic growth model forecasting the cumulative scientific production on generational differences in learning performance. The model indicates a rapid increase in cumulative publications from 2010 onward, reflecting the field's accelerating development. The estimated midpoint of growth occurs around 2023–2024, marking the stage when publication expansion transitions from early growth to a more mature phase. The model suggests a potential saturation level of approximately 1,647 cumulative publications, with projections suggesting that the field may reach around 1,422 publications by 2030 and 1,587 publications by 2035. The high model fit indicators ($R^2 = 0.998$) suggest that the logistic model accurately captures the current growth trajectory of the research domain. Overall, the logistic growth forecast indicates that research on generational differences in learning performance is currently in a rapid expansion phase, approaching the midpoint of its growth cycle while continuing to accumulate scholarly output. The growth pattern reflects the typical lifecycle of an emerging scientific field, with initial exploratory studies followed by accelerated publication growth as the field gains broader academic recognition. The projected stabilization toward saturation suggests that the field may gradually transition from rapid expansion to knowledge consolidation, with future research likely focusing on deeper theoretical development, methodological refinement, and comparative studies across educational contexts.

Table 3. Country scientific production

Country	SCP	MCP	Total	SCP %	MCP %
USA	170	15	185	91.9%	8.1%
Indonesia	50	15	65	76.9%	23.1%
India	30	7	37	81.1%	18.9%
Malaysia	17	6	23	73.9%	26.1%
Turkey	21	0	21	100%	0%
China	11	8	19	57.9%	42.1%
United Kingdom	10	6	16	62.5%	37.5%
Germany	15	2	17	88.2%	11.8%
Poland	15	3	18	83.3%	16.7%
Canada	12	4	16	75.0%	25.0%

Notes: SCP = Single-country publications; MCP = Multiple-country publications. SCP (%) and MCP (%) represent the proportion of publications within each country's total output (SCP + MCP), rather than percentages of the full dataset of 1,007 publications

Table 3 presents the distribution of single-country publications (SCP) and multiple-country publications (MCP) among the most productive countries. The percentages reported for SCP and MCP are calculated relative to each country's total publications, rather than the overall dataset of 1,007 documents. The United States leads with 185 total publications, of which 91.9% are single-country publications, indicating that research output is largely driven by domestic collaborations. Similarly, Turkey (100% SCP) and Germany (88.2% SCP) show predominantly nationally produced research. In contrast, some countries demonstrate stronger international collaboration. China records the highest MCP share (42.1%), followed by the United Kingdom (37.5%) and Malaysia (26.1%), indicating greater participation in cross-national research partnerships. Overall, the results suggest that while generational learning research is primarily driven by national research networks, international collaboration is gradually increasing in several countries.

The thematic map in **Figure 8** illustrates the conceptual structure of research on generational differences in learning performance, organized by centrality (relevance) and density (development). The distribution of themes indicates a field characterized by a concentration of core topics and emerging areas, with limited thematic diversification.

The Motor Themes quadrant comprises highly developed, central topics that drive the field's intellectual structure. In this study, keywords such as education, learning, and medical education, along with broader indexing terms such as human, humans, and article, are located in this quadrant. Their position reflects strong conceptual development and high relevance, indicating that these themes form the primary foundation of the research domain.

The Emerging/Declining Themes quadrant includes generational cohort-related keywords such as students, Generation Z, and millennials, as well as terms like psychology, nursing, and baby boomer. Their placement suggests that these topics are either emerging areas gaining scholarly attention or established themes undergoing conceptual transition. In particular, the positioning of generational cohort terms

indicates that research on generational differences is still developing and has not yet reached a high level of conceptual maturity within the broader field.

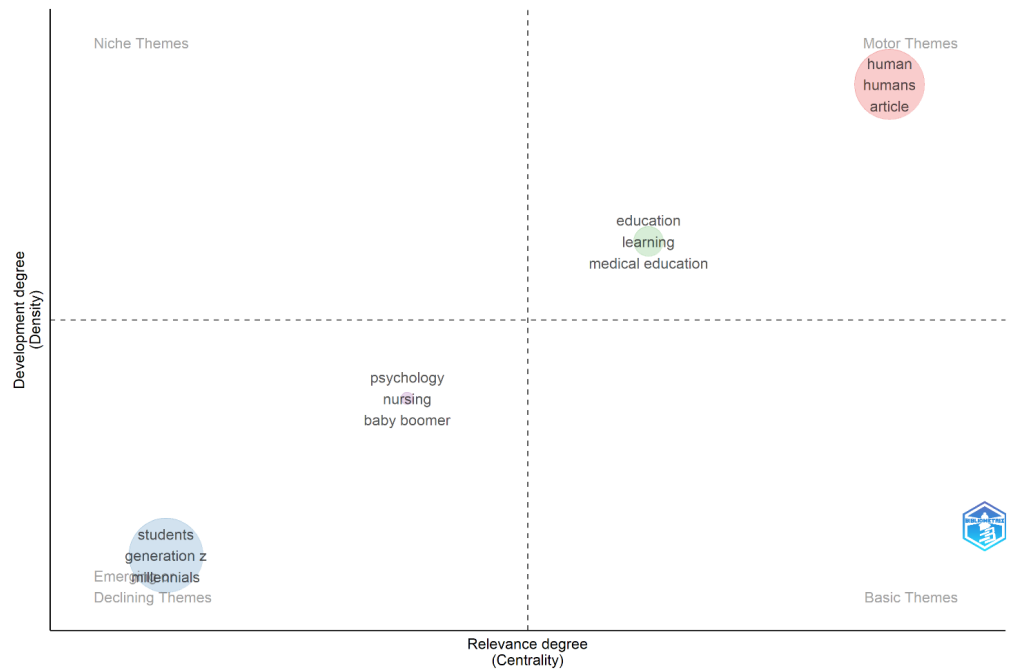


Figure 8. Thematic map

Notably, both the Basic Themes and Niche Themes quadrants are unpopulated. The absence of basic themes suggests a lack of broadly connected but underdeveloped transversal topics, while the absence of niche themes indicates that the field has not yet developed highly specialized or isolated subdomains. This pattern implies that research on generational learning performance remains concentrated around a set of dominant core themes and emerging areas, reflecting a field that is still consolidating rather than diversifying into distinct thematic branches.

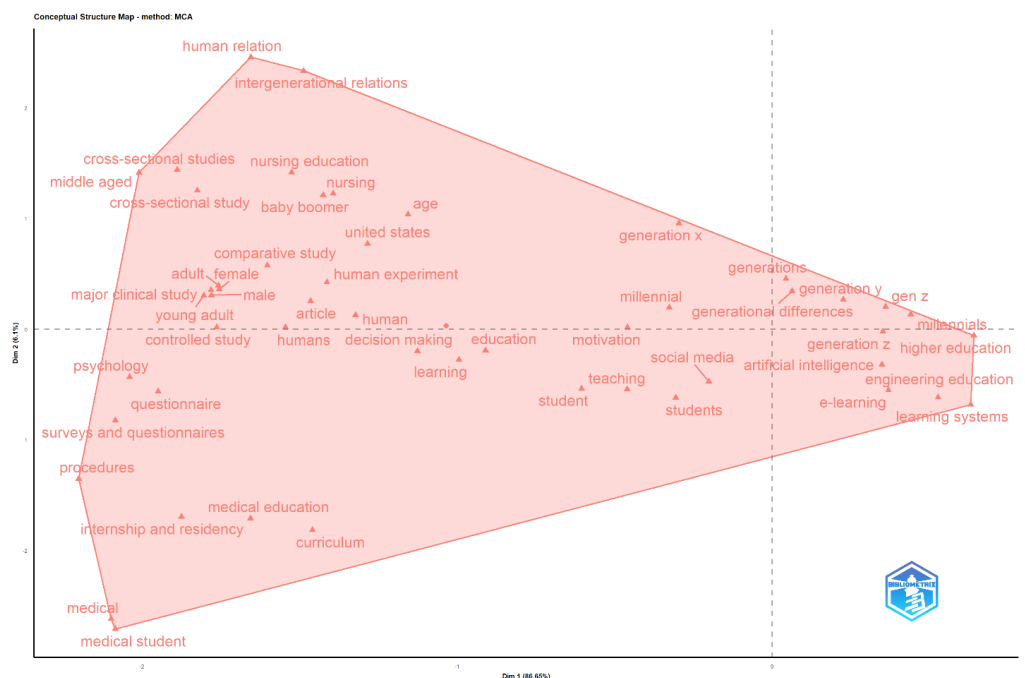


Figure 9. Factorial analysis map

The Multiple Correspondence Analysis (MCA) map in **Figure 9** illustrates the conceptual relationships among keywords in research on generational differences in learning performance. The map reveals a continuous conceptual structure rather than distinct clusters, suggesting that the research field is highly interconnected.

On the right side of the map, keywords such as Generation Z, millennials, generational differences, and higher education are closely positioned alongside terms related to digital and technology-enhanced learning, including e-learning, learning systems, artificial intelligence, and engineering education. This spatial proximity suggests a strong association between generational cohort research and technology-mediated learning environments.

In the central region, general educational and pedagogical terms such as education, learning, student, teaching, and motivation are located, indicating that these concepts serve as a conceptual bridge linking different areas of the field. These terms reflect the foundational role of educational theory and practice within generational learning research.

On the left side of the map, a distinct grouping of keywords relates to health, professional education, and research methodologies. This includes terms such as nursing, nursing education, medical education, medical student, internship and residency, as well as methodological and demographic descriptors such as cross-sectional study, surveys and questionnaires, human, male, female, and age. This pattern indicates that a substantial portion of the literature is grounded in applied and empirical research, particularly in health and clinical education settings. The MCA structure suggests that research on generational learning performance is organized along a conceptual continuum, linking methodological and discipline-specific research on the left with generational and technology-enhanced learning studies on the right, with core educational concepts occupying a central integrative role.

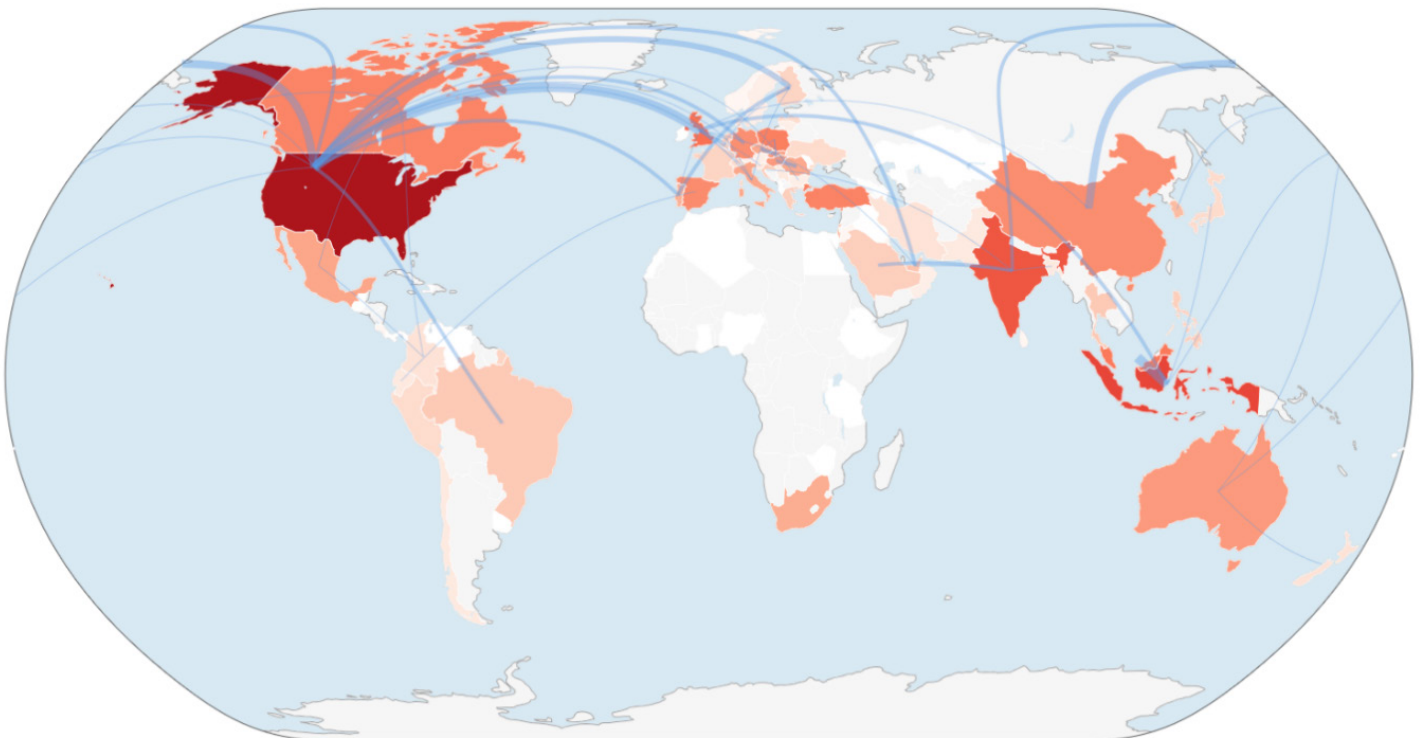


Figure 10. Countries collaboration map

Figure 11 shows the co-occurrence network of keywords, which provides insight into the conceptual architecture of research on generational differences in learning performance. Co-occurrence analysis identifies clusters of keywords that frequently co-occur in the literature, revealing the dominant thematic domains shaping the field. The network structure indicates that generational learning research is organized around several interconnected knowledge areas linking educational practices, generational cohort analysis, and technology-enhanced learning environments. The network also illustrates the increasing integration of technological themes within generational learning research. Keywords related to digital learning environments, artificial intelligence, and data-driven educational systems appear in proximity to generational cohort terms, suggesting that researchers are increasingly examining how emerging technologies influence learning behaviors across different generations. This pattern indicates a gradual conceptual shift in the field from traditional generational comparisons toward technology-mediated learning environments that may eventually evolve into immersive or metaverse-based educational ecosystems.

4. Discussion

The findings of this study provide a comprehensive overview of the development and structure of research on generational differences in learning performance within digital and technology-enhanced educational environments. The results indicate that this field has experienced substantial growth over the past decade, reflecting increasing scholarly interest in how generational characteristics influence learning outcomes in contemporary education systems.

The strong upward trend in publication output, particularly after 2018, suggests that research on generational learning performance is closely linked to broader transformations in education. The rapid expansion of online learning, the increasing integration of digital technologies, and the growing presence of Generation Z in higher education have intensified research activity in this domain. The acceleration observed around 2020 further reflects the global shift toward remote and hybrid learning environments, prompting greater attention to how different generational cohorts adapt to technology-mediated education [39,40].

Another key finding is the highly interdisciplinary nature of the research field. While Social Sciences remain the dominant disciplinary foundation, substantial contributions from Computer Science, Business, Engineering, Medicine, and Psychology indicate that generational learning differences are examined across diverse academic contexts. This interdisciplinary pattern reflects the complexity of modern education systems, where learning outcomes are shaped not only by pedagogical factors but also by technological infrastructures, organizational settings, and behavioral characteristics [41,42]. In particular, the presence of health and professional education fields suggests that generational learning differences are increasingly relevant in applied and practice-oriented educational environments.

The thematic and conceptual analyses reveal that research on generational learning performance is increasingly connected to digital and technology-mediated learning environments. Keywords such as Generation Z, e-learning, digital devices, machine learning, and artificial intelligence indicate that scholars are increasingly examining how digital technologies influence generational learning experiences. Millennials and Generation Z are often described as digitally immersed or technology-savvy learners who interact with information, communication technologies, and social media in ways that differ from those of earlier generations [43,44]. Consequently,

educational researchers are increasingly exploring how digital learning environments, online collaboration tools, and intelligent learning systems affect student engagement, motivation, and academic performance. The emergence of artificial intelligence-related keywords also suggests that future research may increasingly integrate learning analytics, adaptive learning systems, and AI-driven educational technologies to better understand generational differences in learning behavior.

The Multiple Correspondence Analysis (MCA) results reinforce this interpretation by showing a continuous conceptual structure linking different areas of the field. On the one hand, research on generational cohorts is closely associated with digital and technology-enhanced learning environments, including e-learning systems and AI-supported education. In the central area, foundational pedagogical concepts such as teaching, learning, and student engagement act as integrative elements. On the other side, a substantial portion of the literature is situated within health, nursing, and professional education contexts, often characterized by empirical and methodological approaches. This structure highlights the interconnected and evolving nature of generational learning research across disciplinary and applied contexts [45,46]

The collaboration analysis indicates that, although research activity is globally distributed, international collaboration remains relatively limited. Most publications are produced within single-country networks, suggesting that generational learning research is often shaped by local educational systems, cultural contexts, and institutional practices. However, the increasing contributions from multiple regions indicate growing global interest in this topic. Strengthening international collaboration may enhance comparative insights and support a more comprehensive understanding of generational learning across diverse educational settings [47,48].

Overall, the findings suggest that research on generational differences in learning performance is transitioning from an emerging field to a more structured, interdisciplinary one. The integration of digital technologies, artificial intelligence, and data-driven learning environments has become a defining feature of this research domain. While the study does not directly analyze immersive or metaverse-based education, the observed trends toward increasingly technology-mediated learning environments suggest potential future directions for research into more advanced, immersive educational systems.

4.1 Implications for educational practice and policy

The findings of this bibliometric analysis provide several implications for educational practice and policy, particularly in the context of rapidly evolving learning environments and generational shifts in student populations.

First, the growing body of research on generational learning performance underscores the importance of recognizing generational diversity in educational design and instructional strategies. Millennials, Generation Z, and emerging Generation Alpha learners exhibit distinct technological familiarity, communication styles, and learning preferences. Educators and curriculum developers should therefore consider integrating flexible, technology-enhanced pedagogical approaches, such as blended learning, interactive digital platforms, and adaptive learning systems, to better accommodate diverse generational learning behaviors.

Second, the interdisciplinary nature of the research field suggests that effective educational strategies should incorporate insights from multiple domains, including educational psychology, technology-enhanced learning, and organizational learning. Educational institutions may benefit from collaborative approaches that combine expertise from different disciplines when designing curricula and learning

environments. For example, integrating data analytics and artificial intelligence tools may support more personalized, responsive learning experiences for different generational cohorts [49].

Third, the geographic distribution of research activity indicates that generational learning issues are increasingly relevant in global and multicultural educational contexts. Policymakers and institutions should therefore promote international collaboration and cross-cultural research to better understand how generational learning differences manifest across diverse educational systems. Strengthening global academic partnerships may help develop more inclusive and adaptable educational policies [50].

Finally, the continued expansion of research on digital and technology-enhanced learning environments highlights the importance of investing in digital infrastructure, teacher training, and effective technology integration in education systems. As digital transformation continues to reshape educational practices, understanding how different generations interact with technology-based learning environments will be essential for improving student engagement, learning outcomes, and overall educational effectiveness [51,52].

While this study does not directly examine immersive or metaverse-based education, the observed trends toward increasingly advanced and interactive digital learning environments suggest potential directions for future exploration. Further research may investigate how emerging technologies, including virtual and extended reality systems, influence generational learning behaviors and educational outcomes. Such developments may contribute to the design of more adaptive, inclusive, and future-oriented education systems.

4.2 Limitations and Future Research Directions

Despite offering a comprehensive overview of research trends on generational differences in learning performance, this study has several limitations that should be acknowledged. First, the analysis is based exclusively on publications indexed in the Scopus database. Although Scopus provides extensive coverage of high-quality, peer-reviewed literature, it may not include all relevant studies, particularly those published in regional journals, books, or conference proceedings indexed in other databases. As a result, the dataset may not fully capture the entire scope of global research in this field. Future studies could address this limitation by incorporating additional databases, such as Web of Science and Google Scholar, to achieve a more comprehensive and inclusive representation of the literature.

Second, bibliometric analysis focuses on quantitative patterns in publication output, citation relationships, and keyword structures rather than the in-depth examination of theoretical frameworks or methodological rigor of individual studies. Consequently, the findings reflect the field's structural and conceptual development but do not provide detailed insights into the quality or effectiveness of specific research approaches. To complement these findings, future research could employ systematic literature reviews or meta-analyses to critically evaluate theoretical perspectives, methodologies, and empirical evidence within the domain of generational learning.

Third, while this study identifies major thematic areas and conceptual relationships, it does not directly examine how generational differences influence actual learning outcomes, instructional practices, or student experiences in real educational settings. Further empirical research is needed to investigate these relationships in greater depth, particularly through studies that explore how

generational characteristics interact with digital technologies, learning environments, and institutional contexts.

In addition, the findings highlight important gaps in the current literature, particularly the relatively limited level of international collaboration and the predominance of cross-sectional research designs. Strengthening cross-national research partnerships would enable more robust comparative analyses across diverse cultural and educational contexts, thereby enhancing the generalizability of findings and supporting the development of globally relevant educational strategies. At the same time, there is a clear need for longitudinal research following generational cohorts to better understand the evolution of learning behaviors, technological adaptation, and educational outcomes. Such approaches would provide deeper insights into causal relationships and developmental trends that cannot be captured through single-point observations.

Finally, the increasing prominence of digital learning environments and artificial intelligence suggests important directions for future inquiry. Further research should examine how advanced technologies, such as learning analytics, adaptive learning systems, AI-driven platforms, and immersive virtual environments, shape generational learning processes and outcomes. Investigating these developments will be essential to understanding how emerging digital ecosystems continue to transform education across generations. Addressing these limitations and research gaps will contribute to a more nuanced, rigorous, and globally informed understanding of generational differences in learning performance, ultimately supporting the development of more adaptive and inclusive educational systems.

5. Conclusion

This study provides a comprehensive bibliometric analysis of research on generational differences in learning performance within digital and technology-enhanced educational environments. The findings demonstrate that this field has evolved into a dynamic and rapidly expanding area of research, characterized by strong publication growth, interdisciplinary contributions, and increasing global participation. The results indicate that research on generational learning performance is anchored in foundational educational concepts while increasingly integrating perspectives from technology-related disciplines such as computer science and engineering. Generational cohorts, particularly Generation Z and Millennials, are emerging as important areas of investigation, although the thematic analysis suggests that these topics are still developing and have not yet reached full conceptual maturity within the broader research landscape. The study also highlights the interconnected nature of the field, where generational research, educational practices, and technology-enhanced learning environments are closely linked. The presence of applied research contexts, particularly in health and professional education, further demonstrates the practical relevance of understanding generational learning differences across diverse educational settings. At the same time, the relatively limited level of international collaboration suggests opportunities for future research to adopt more global and comparative perspectives. The findings contribute to a deeper understanding of how generational differences shape learning performance in contemporary education systems. As digital transformation continues to influence educational practices, future research may further examine how emerging and advanced technologies influence generational learning behaviors and outcomes. Such investigations may help inform the development of more adaptive and inclusive education systems that respond to the evolving needs of diverse learner populations.

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