Mapping Adaptive Learning Research and Its Contribution to SDG 4

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Abstract

This study conducts a decade-long bibliometric analysis to critically map the intellectual structure, thematic evolution, and collaboration patterns within adaptive learning research. The study addresses a key gap in prior literature, where existing reviews remain predominantly narrative and fragmented, limiting systematic understanding of how adaptive learning has evolved conceptually and methodologically. Using the Scopus database, 14,009 records were initially identified, of which 141 articles met rigorous inclusion criteria. Bibliometric analysis was performed using Bibliometrix and Biblioshiny, incorporating co-authorship analysis, co-citation mapping, keyword co-occurrence, and thematic evolution techniques to ensure analytical depth and methodological robustness. The findings reveal three dominant knowledge clusters: technology-driven personalization, data-informed learning optimization, and pedagogical integration of adaptive systems. Influential authors, leading journals, and emerging research fronts highlight a shift from system development toward learning effectiveness and equity-oriented implementation. Collaboration networks indicate increasing internationalization but uneven scholarly connectivity across regions. This study contributes by providing a consolidated intellectual map, identifying emerging trajectories, and clarifying theoretical and methodological directions for future research. The findings offer practical implications for designing evidence-based adaptive learning strategies and inform policy and research agendas in data-driven education.

How to Cite:

Rosyidah, S. D., Wida, W., & Purwa, P. H. (2026). Mapping Adaptive Learning Research and Its Contribution to SDG 4. *Economic Education Analysis Journal*, 15 (1), 112-127.

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INTRODUCTION

The rapid expansion of digitalization has fundamentally reshaped contemporary educational systems, intensifying demands for learning environments that are simultaneously personalized, efficient, and scalable. Traditional instructional models, historically grounded in standardized delivery and uniform pacing, increasingly struggle to accommodate heterogeneous learner needs in technologically mediated contexts (Mukul & Büyüközkan, 2023). This structural tension has stimulated the search for pedagogical and technological innovations capable of reconciling mass education with individualized learning trajectories. Within this evolving landscape, immersive and data-driven learning technologies have emerged as transformative forces, enabling new forms of knowledge construction, learner interaction, and performance monitoring. In continuing and higher education contexts, where interdisciplinary complexity and lifelong learning imperatives are becoming dominant, adaptive and responsive instructional approaches are no longer optional but necessary to sustain educational relevance and effectiveness (Choi et al., 2025).

Among these innovations, adaptive learning has gained increasing scholarly and practical attention as a system capable of dynamically aligning instructional content, pacing, and delivery modes with learners' cognitive profiles, preferences, and performance patterns. Unlike conventional digital learning platforms that merely digitize static content, adaptive learning environments continuously interpret learner data and adjust instructional pathways in real time, thereby fostering a more responsive and individualized learning experience (Kumar et al., 2020). Such systems do not merely enhance engagement but also enable continuous monitoring, formative feedback, and iterative learning optimization, which collectively contribute to improved knowledge acquisition and retention. Despite these promising characteristics, the rapid expansion of adaptive learning research has generated a fragmented intellectual landscape, characterized by diverse technological paradigms, inconsistent methodological approaches, and uneven theoretical integration.

From a technological perspective, adaptive learning systems are closely associated with advances in artificial intelligence (AI), machine learning, and data analytics, which enable the identification of learner needs and the delivery of tailored instructional interventions at precise moments in the learning process (Xie et al., 2019a). The conceptual roots of adaptive learning can be traced to the development of Intelligent Tutoring Systems (ITS), which emphasize algorithm-driven feedback and personalized instructional guidance to enhance knowledge retention and cognitive mastery (VanLehn, 2011). Contemporary adaptive platforms extend these principles by leveraging large-scale educational data and predictive algorithms, including deep learning and reinforcement learning, to anticipate learner difficulties and dynamically optimize learning pathways (Hansen & Smith, 2018). Empirical evidence suggests that such systems can improve learning effectiveness, strengthen retention, and increase learner engagement (El-Sabagh, 2021). However, the expansion of technological sophistication has not always been matched by conceptual coherence, resulting in a research domain that is rich in innovation but uneven in theoretical consolidation.

Beyond education, adaptive learning principles have also been applied in economics and financial modeling, particularly in the context of adaptive expectation formation and data-driven behavioral prediction (García-Peñalvo et al., 2020). These cross-disciplinary applications highlight adaptive learning as a broader epistemic paradigm concerned with dynamic adaptation, feedback-driven optimization, and predictive modeling in complex systems. In the era of big data and AI, such adaptive frameworks enable more realistic representations of human learning and decision-making processes across domains, including education, economics, and finance (Taşkın, 2025a). Nevertheless, despite its

interdisciplinary relevance, the core focus of adaptive learning research remains centered on educational transformation, where its potential to improve personalized learning quality and system responsiveness is most directly observable. Importantly, technological limitations, infrastructural disparities, and resource constraints continue to pose significant challenges to the equitable implementation of adaptive learning systems, particularly in resource-constrained educational environments (du Plooy et al., 2024).

While the adaptive learning literature has grown substantially, its intellectual structure remains insufficiently synthesized. Existing studies often emphasize technological innovation, algorithmic performance, or localized pedagogical outcomes without systematically mapping the broader knowledge architecture of the field. This fragmentation is further compounded by the coexistence of multiple theoretical streams—including ITS, AI-driven personalization, data analytics, and adaptive behavioral modeling—that are frequently discussed in isolation rather than integrated into a coherent conceptual framework. Consequently, scholars and practitioners face difficulties in identifying dominant research trajectories, emerging thematic clusters, and evolving methodological orientations within adaptive learning scholarship. Addressing this limitation requires a systematic and data-driven approach capable of revealing the hidden intellectual organization and developmental dynamics of the field.

Bibliometric analysis provides an appropriate epistemic tool for this purpose. Unlike narrative reviews, which are inherently selective and interpretive, bibliometric methods enable large-scale, systematic mapping of scientific production, intellectual influence, and collaboration patterns within a research domain. By analyzing citation structures, keyword co-occurrence, and authorship networks, bibliometric approaches can uncover latent thematic configurations, identify influential contributors, and trace the evolution of research fronts over time. In the context of adaptive learning, such analysis is particularly valuable

for clarifying how technological, pedagogical, and interdisciplinary perspectives converge and diverge within the literature. Moreover, bibliometric mapping can reveal geographical and institutional asymmetries in knowledge production, thereby highlighting areas where scholarly collaboration and conceptual integration remain limited.

Although several bibliometric studies indexed by Scopus have examined technology-related educational research, their focus on adaptive learning remains partial and contextually constrained. For instance, Ma and Wang (2025) explored technological applications in music education using bibliometric techniques, while Alasmari (2025) examined artificial intelligence in education within Arab contexts and identified regional knowledge disparities. These studies demonstrate the usefulness of bibliometric approaches but do not provide a comprehensive mapping of adaptive learning as a global and interdisciplinary research domain. Furthermore, many existing bibliometric analyses rely primarily on visualization tools such as VOSviewer without integrating deeper analytical indicators such as thematic evolution, co-citation structures, or intellectual clustering. Consequently, the current literature lacks a consolidated and methodologically robust bibliometric synthesis capable of capturing the full complexity of adaptive learning research across time, geography, and disciplinary boundaries.

The research gap addressed in this study, therefore, does not lie in the absence of adaptive learning research but in the lack of systematic, integrative, and longitudinal mapping of its intellectual development. Specifically, prior studies have not sufficiently examined (1) the structural configuration of adaptive learning scholarship, (2) the evolution of dominant and emerging themes, (3) the distribution and dynamics of scholarly collaboration networks, and (4) the methodological patterns shaping knowledge production in this field. These limitations hinder the ability of researchers to identify conceptual convergence, methodological biases, and emerging research

opportunities. Addressing these gaps is essential for advancing adaptive learning from a technologically driven innovation toward a theoretically grounded and methodologically coherent research domain.

The novelty of this study lies not merely in its temporal scope but in its integrative analytical design. By examining adaptive learning research over the period 2015–2025, this study captures a decade marked by rapid technological acceleration, the rise of AI-driven educational systems, and the increasing institutionalization of data-driven pedagogy. More importantly, the study employs a comprehensive set of bibliometric techniques—including co-authorship analysis, co-citation mapping, keyword co-occurrence, and thematic evolution—to provide a multidimensional understanding of the field. This approach enables the identification of dominant knowledge clusters, intellectual turning points, and emerging research trajectories, thereby offering insights that extend beyond descriptive trend analysis. Through this integrative mapping, the study contributes to clarifying how adaptive learning research has evolved conceptually, technologically, and institutionally in the context of digital education transformation.

In addition to its methodological contribution, this study offers theoretical and empirical implications for adaptive learning scholarship. By revealing the intellectual structure and thematic dynamics of the field, the study contributes to the consolidation of adaptive learning as an interdisciplinary research domain integrating technological innovation, pedagogical theory, and data-driven decision-making. The findings also provide empirical evidence on collaboration patterns, highlighting the extent of internationalization and the presence of regional asymmetries in knowledge production. Such insights are critical for understanding how global research networks shape the diffusion and development of adaptive learning innovations.

From a practical perspective, the study generates evidence-based insights relevant to educators, researchers, and policymakers. For educators, bibliometric mapping helps identify validated instructional strategies and emerging pedagogical approaches within adaptive learning. For researchers, it reveals underexplored themes and methodological opportunities, thereby guiding future research agendas. For policymakers, understanding global research trends and collaboration dynamics supports the formulation of informed and forward-looking educational policies aligned with technological and pedagogical developments. Importantly, these contributions move beyond generic claims of usefulness by providing systematic, data-driven evidence on the evolution and structure of adaptive learning research.

To achieve these objectives, this study conducts a comprehensive bibliometric analysis using the Scopus database as the primary source of literature metadata. The study aims to (1) map the intellectual and thematic structure of adaptive learning research, (2) analyze the evolution of dominant and emerging research themes, (3) examine collaboration networks among researchers and institutions, and (4) identify methodological and conceptual trends shaping the field. Through this approach, the study seeks to provide a consolidated and analytically robust overview of adaptive learning scholarship, thereby advancing theoretical understanding, informing educational practice, and guiding future research in the era of data-driven and personalized education.

METHOD

Research Design

This study adopts a quantitative bibliometric research design integrating performance analysis and science mapping techniques to systematically examine the intellectual structure and developmental trajectories of adaptive learning research. Bibliometric analysis is methodologically appropriate for this study because the research objectives are not limited to summarizing prior findings but aim to uncover structural patterns, collaboration dynamics, and thematic evolution within a rapidly expanding and technologically

driven field. As emphasized by Guleria and Kaur (2021a), bibliometric approaches enable the identification of knowledge clusters, influential actors, and relational structures across scientific publications. In the context of adaptive learning—where technological, pedagogical, and interdisciplinary streams converge—such an approach facilitates a macro-level synthesis that cannot be achieved through traditional narrative review methods. Therefore, bibliometric mapping is employed as an epistemic tool to reveal patterns of intellectual convergence, thematic fragmentation, and global research distribution within adaptive learning scholarship.

Data Source and Collecting

The Scopus database was selected as the primary data source due to its extensive coverage of peer-reviewed journals, conference proceedings, and scholarly books indexed according to international quality standards (Yıldız & Karakuş Yılmaz, 2024). The database is widely recognized for its metadata consistency and suitability for large-scale bibliometric research. Data retrieval was conducted on March 23, 2025.

To ensure conceptual specificity while maintaining dataset relevance, the search query was formulated using the string: TITLE ("adaptive learning"). The decision to restrict the query to the title field was guided by the intention to capture publications in which adaptive learning constitutes a central conceptual focus rather than a peripheral reference. While broader search strategies using TITLE-ABS-KEY fields may increase coverage, they risk introducing conceptual noise by retrieving studies where adaptive learning is only tangentially mentioned. The selected strategy prioritizes precision over maximal recall, thereby strengthening thematic coherence within the dataset.

The initial search yielded 14,099 documents. The publication period was limited to 2015–2025 to capture contemporary developments associated with the acceleration of artificial intelligence and data-driven educational technologies. After applying this temporal filter, 9,207 documents remained. To enhance disciplinary relevance, the dataset was further refined using the "Subject Area" filter to focus on education-related and technology-enhanced learning domains, resulting in 541 documents. Subsequently, the document type was restricted to peer-reviewed research articles to ensure methodological rigor and comparability, reducing the dataset to 373 documents. Conference papers, reviews, and book chapters were excluded to maintain analytical consistency in citation structures.

The dataset was then limited to publications in English to ensure terminological uniformity in keyword co-occurrence and thematic mapping analyses, yielding 369 articles. Finally, an Open Access filter was applied, resulting in 141 documents. The decision to include only open-access articles was based on data accessibility and transparency considerations, enabling full-text verification and reproducibility of keyword and citation analyses. However, this criterion may introduce representational bias by excluding subscription-based high-impact journals. This limitation is acknowledged and considered in the interpretation of findings. The entire selection process is illustrated in Figure 1 and reported consistently to ensure methodological transparency.
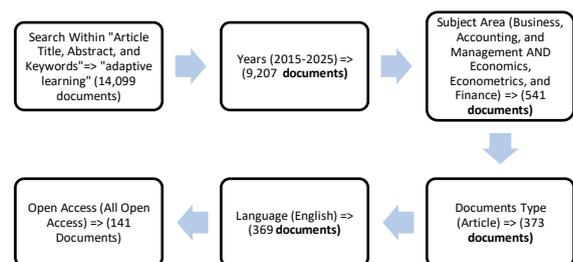

Figure 1. Article selection process and methods

The final dataset of 141 articles was exported in Comma-Separated Values (.csv) format, including bibliographic metadata such as authors, affiliations, titles, abstracts, keywords, countries, sources, citations, and references. Data cleaning procedures were conducted to standardize author names, merge synonymous keywords, and correct

inconsistencies in institutional affiliations. Such preprocessing steps are essential in bibliometric research to avoid fragmentation in network analyses and ensure accurate relational mapping (Guleria & Kaur, 2021b).

The cleaned dataset was subsequently imported into the Bibliometrix package in R and operationalized through the Biblioshiny interface. The version of Bibliometrix used in this study corresponds to the most recent stable release available at the time of data extraction (2025 version). Default normalization procedures were applied for network construction, including association strength normalization for co-occurrence networks. Minimum threshold parameters were set to exclude isolated nodes and reduce noise in visualization outputs, thereby enhancing interpretability.

Data Analysis

The analytical framework integrates performance analysis and science mapping to address distinct but complementary research objectives. Performance analysis was conducted to assess publication productivity, citation impact, most influential journals, leading countries, and institutional affiliations. These indicators provide descriptive evidence of knowledge production patterns and scholarly influence within adaptive learning research.

Science mapping techniques were employed to uncover relational and structural dimensions of the field. Co-authorship analysis was performed to identify collaboration networks among authors, institutions, and countries, thereby revealing patterns of internationalization and scholarly connectivity. Network density and cluster formation were examined to assess the extent of collaborative cohesion.

Co-citation analysis was conducted to identify foundational works and intellectual groupings that shape adaptive learning scholarship. By analyzing how frequently pairs of documents are cited together, this technique reveals underlying theoretical streams and epistemic communities within the field.

Keyword co-occurrence analysis was used

to map conceptual structures and identify dominant and emerging research themes. Author keywords were analyzed using a minimum frequency threshold to construct conceptual networks, enabling the identification of thematic clusters such as AI-driven personalization, learning analytics, and adaptive assessment systems. Thematic mapping and thematic evolution analyses were further conducted to trace the developmental trajectory of adaptive learning research across the 2015–2025 period. These techniques distinguish between motor themes, emerging themes, niche themes, and declining topics, thereby providing dynamic insight into the field's intellectual transformation.

To examine the contribution of adaptive learning research to broader societal agendas, keyword co-occurrence and thematic clustering results were interpreted in relation to the Sustainable Development Goals, particularly SDG 4 (Quality Education). Keywords associated with inclusive education, equity, accessibility, and digital transformation were analyzed to determine the extent to which adaptive learning scholarship aligns with global educational sustainability priorities. This interpretive layer enables the study to move beyond descriptive bibliometrics and situate findings within broader policy and developmental discourses.

Through this integrated methodological design, each analytical component contributes to addressing the core research objectives: performance analysis clarifies productivity and impact patterns; co-authorship mapping reveals collaboration structures; co-citation analysis uncovers intellectual foundations; and keyword co-occurrence combined with thematic evolution identifies conceptual trajectories. Collectively, these procedures ensure analytical rigor, reproducibility, and theoretical relevance in mapping the global development of adaptive learning research.

RESULTS AND DISCUSSION

Table 1 presents the core bibliometric profile of adaptive learning research over the

2015–2025 period and provides an initial structural indication of the field's developmental trajectory. Consistent with bibliometric scholarship, this approach complements but differs from meta-analysis and traditional literature review in that it emphasizes the structural and relational organization of scientific knowledge rather than aggregating empirical effect sizes or synthesizing narrative findings (Donthu et al., 2021). While meta-analysis focuses on statistical generalization and literature reviews prioritize interpretive synthesis, bibliometric analysis reveals publication dynamics, knowledge diffusion, and intellectual consolidation within a research domain.

Table 1. Main information of bibliometric

Description	Result
Timespan	2015:2025
Sources (Journals, Books, etc)	88
Documents	140
Annual Growth Rate %	3.63
Document Average Age	4.48

Source: Processed Primary Data

The dataset comprises 140 documents distributed across 88 sources, including peer-reviewed journals and scholarly books. This dispersion across a relatively large number of publication outlets suggests that adaptive learning research remains moderately fragmented rather than concentrated within a small set of dominant journals. Such fragmentation is characteristic of interdisciplinary and technologically evolving domains, where contributions emerge from education, computer science, and learning analytics rather than a single consolidated disciplinary core. Consequently, the distribution of sources reflects the hybrid epistemic nature of adaptive learning as both a pedagogical and technological research field.

The annual growth rate of 3.63% indicates a steady, though not exponential, expansion of scholarly production. Rather than signaling a dramatic surge, this moderate growth suggests a

field transitioning from early rapid emergence toward gradual consolidation. In comparison with fast-expanding domains such as learning analytics or artificial intelligence in education, where growth rates often exceed double digits during peak expansion periods, the observed rate reflects sustained but stabilizing scholarly attention. This pattern implies that adaptive learning has moved beyond its initial innovation phase and is entering a stage characterized by conceptual refinement, methodological diversification, and broader institutional adoption.

The average document age of 4.48 years provides additional insight into the temporal dynamics of the field. A relatively young citation age typically indicates an actively evolving knowledge base in which recent publications continue to shape ongoing discourse. This temporal proximity suggests that adaptive learning research remains technologically and conceptually dynamic, influenced by rapid developments in artificial intelligence, data analytics, and personalized education systems. However, the interpretation of citation averages must be approached cautiously due to citation lag effects, whereby recently published works may not yet have accumulated their full citation impact. Therefore, while the observed average citation rate per document reflects active scholarly engagement, it does not necessarily indicate long-term intellectual dominance or canonical status.

Taken together, the indicators presented in Table 1 reveal several important characteristics of adaptive learning scholarship. First, the field demonstrates moderate publication growth combined with a relatively young knowledge base, suggesting ongoing conceptual and technological evolution. Second, the dispersion of publications across numerous sources reflects interdisciplinary expansion rather than disciplinary consolidation. Third, citation patterns indicate active but still maturing intellectual influence, consistent with a research domain shaped by rapid technological change and continuous methodological experimentation. These findings provide an empirical foundation for interpreting

subsequent analyses of thematic structures, collaboration networks, and intellectual clustering, thereby situating adaptive learning research within a broader trajectory of emerging yet progressively stabilizing educational technology scholarship (Lim & Kumar, 2024).

Figure 2 illustrates the longitudinal distribution of publications on adaptive learning between 2015 and 2025 and reflects the temporal dynamics of scholarly attention within this research domain. The dataset indicates a gradual increase in publication output, rising from 7 documents in 2015 to a peak of 24 documents in 2024. Rather than indicating abrupt expansion, this pattern suggests a sustained and progressive accumulation of research interest over time, with intermittent fluctuations that are typical in evolving interdisciplinary fields (Najjar et al., 2025). Such fluctuations should not be interpreted as structural decline but as normal variation in annual scholarly production influenced by publication cycles, funding patterns, and shifting research priorities. The steady growth trajectory aligns with the broader expansion of adaptive learning as a data-driven pedagogical paradigm that enables the alignment of instructional content with learner characteristics and performance (Peng et al., 2019).
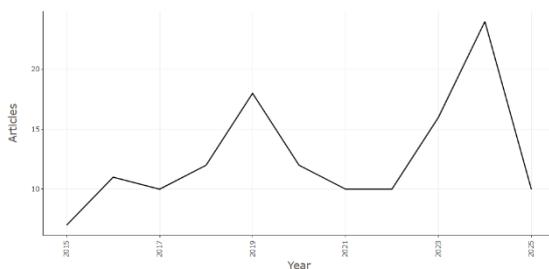

Figure 2. Annual Scientific Production of Adaptive Learning

Although publication output increased during the observed period, attributing this trend to a single external factor would be analytically reductionist. The literature suggests that multiple structural drivers—including digital transformation in education, increased institutional investment in learning technologies, and the maturation of AI-based instructional systems—collectively contributed to sustained research production (Sudrajat et al., 2024). Similarly, Strielkowski et al. (2025) highlight the role of technological change in shaping adaptive learning scholarship, particularly through the broader digital transformation of education. However, bibliometric indicators alone cannot establish causal relationships; rather, they reflect patterns of scholarly activity that must be interpreted cautiously. Technological developments such as the integration of smart devices and algorithmic personalization have expanded the research landscape, but their influence is better understood as part of a gradual structural evolution rather than a singular turning point (Xie et al., 2019b).

Figure 3 presents the average citation rate per year and provides insight into the temporal distribution of scholarly impact within adaptive learning research. The observed variation across years should be interpreted in light of citation-lag effects, whereby recently published articles have had less time to accumulate citations compared with earlier cohorts. Consequently, lower citation averages in more recent years do not necessarily indicate declining scholarly relevance but reflect the normal temporal dynamics of citation accumulation. Similarly, fluctuations in earlier years should not be interpreted as instability in the field but rather as the natural outcome of uneven citation diffusion across publication cohorts.
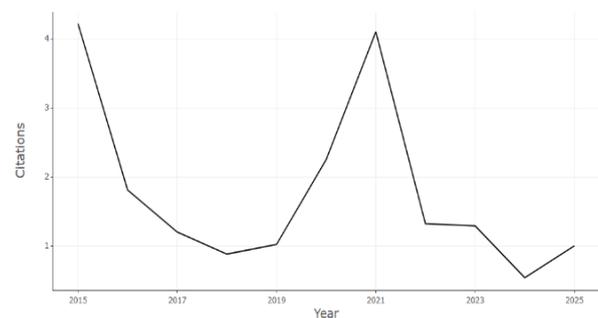

Figure 3. Average Citations Per Year

During the 2015–2019 period, variation in average citations reflects differences in cohort maturity rather than substantive shifts in research importance. Older publications typically accumulate citations over a longer

period, which explains higher citation averages in certain earlier years. Interpretations linking citation variation directly to technological readiness or institutional adoption must therefore be approached cautiously, as bibliometric indicators alone do not provide direct evidence of implementation conditions (Agustina et al., 2025).

Between 2019 and 2021, citation patterns show moderate increases, which may correspond to the consolidation of adaptive learning within broader personalized and technology-enhanced learning research streams. As noted by Younes (2021), scholarly attention to personalized learning intensified during this period, but bibliometric evidence should be interpreted as reflecting broader knowledge diffusion rather than immediate pedagogical transformation. Importantly, citation-based indicators are influenced by publication-year normalization and cohort effects, meaning that comparisons across time must account for differences in citation windows.

In the most recent period, citation averages appear relatively lower, which is consistent with the short exposure time of newer publications rather than a substantive decline in research influence. Bibliometric evidence does not support strong claims of thematic saturation or reduced relevance; instead, the data suggest a field that continues to evolve, with recent contributions still in the process of accumulating scholarly recognition. Overall, the combined interpretation of publication growth and citation dynamics indicates a research domain characterized by steady expansion, ongoing intellectual diffusion, and temporally conditioned citation impact. These patterns provide an empirical basis for subsequent analyses of thematic structures and collaboration networks, situating adaptive learning within a trajectory of gradual maturation rather than episodic fluctuation.

The conceptual structure map presented in the figure was generated through keyword co-occurrence analysis using correspondence analysis to position terms based on their relational proximity within the dataset (Zhu et al., 2015). Keywords were included after applying a minimum frequency threshold to ensure analytical relevance, and association strength normalization was used to reduce bias caused by highly frequent generic terms. Clustering was conducted algorithmically to detect groups of keywords that systematically co-occur within the same documents. Consequently, each color-coded cluster represents not merely a visual grouping of terms but an underlying intellectual stream within adaptive learning scholarship.

Figure 4. Co-occurence Network

The green cluster occupies the central position in the map, indicating its structural prominence within the co-occurrence network. However, closer examination reveals that this cluster combines two conceptually distinct traditions: pedagogical adaptive learning and macroeconomic adaptive expectations. Keywords such as macroeconomic, inflation, expectations, and dynamic models reflect a stream rooted in economic modeling, where agents iteratively update expectations based on observed outcomes. This approach serves as an alternative to rational expectations frameworks and is frequently applied in analyzing policy responsiveness (Dizioli & Wang, 2023). In contrast, terms such as e-learning, system, effectiveness, environments, deep, networks, and experiment represent the educational technology strand, emphasizing AI-driven personalization and adaptive instructional systems (Contrino et al., 2024; Sayed et al., 2023). The coexistence of these keywords within the same cluster does not imply conceptual equivalence; rather, it demonstrates that the term "adaptive learning" functions as a polysemic construct across disciplines. This epistemic divergence underscores the

importance of distinguishing between adaptive learning as a pedagogical system and adaptive learning as an economic expectation mechanism.

The red cluster, located in the lower-right region of the map, concentrates on monetary and fiscal policy themes. The co-occurrence structure indicates a coherent macroeconomic subfield concerned with gradual expectation adjustment and policy effectiveness. Instead of suggesting direct cross-sectoral application, this cluster more accurately reflects a parallel research trajectory where adaptive learning operates as a theoretical modeling framework in economics rather than as an instructional technology. Thus, its presence signals interdisciplinary breadth rather than functional integration.

The pink cluster, situated in the lower-left area, includes evaluation, evidence, theory, and methods. This configuration represents the methodological and conceptual consolidation of adaptive learning research. The co-occurrence of these terms suggests increasing attention to empirical validation, theoretical grounding, and methodological rigor. Rather than indicating general scientific maturity, this cluster highlights a shift toward evidence-based assessment and conceptual refinement within both educational and economic strands.

The yellow and brown clusters positioned in the upper section of the map center on education, artificial intelligence, personalized, modelling, and dynamic. These terms form a cohesive thematic stream focused on AI-enhanced personalization and intelligent instructional design (Taşkın, 2025b). Their proximity indicates strong conceptual alignment between adaptive modeling techniques and educational implementation. Unlike the macroeconomic cluster, this grouping reflects the core pedagogical orientation of adaptive learning research, emphasizing responsive system design and learner-centered optimization.

The blue, purple, and grey clusters encompass system, educational management, financial market, and evolving. These clusters appear less dense, suggesting emerging or

specialized intersections between adaptive systems and organizational or market-level applications (Sajja et al., n.d.). However, the co-occurrence structure does not substantiate strong claims about systemic efficiency gains or cross-sectoral integration. Instead, it indicates exploratory research at the boundary between adaptive modeling and institutional management contexts.

Overall, the conceptual map demonstrates that adaptive learning scholarship is structurally bifurcated between pedagogical technology and macroeconomic modeling traditions. The co-occurrence network does not show complete conceptual convergence but rather reveals parallel intellectual streams sharing a common terminological anchor. This finding refines the understanding of adaptive learning as an interdisciplinary yet conceptually heterogeneous field. Rather than evidencing seamless cross-sectoral synergy, the clusters highlight thematic segmentation, methodological consolidation, and emerging intersections. Such structural differentiation provides critical insight into the intellectual organization of adaptive learning research and informs subsequent analysis of its developmental trajectory.

The thematic map presented in the figure classifies adaptive learning research into four quadrants—Motor Themes, Basic Themes, Niche Themes, and Emerging or Declining Themes—based on two structural indicators: centrality and density. Centrality reflects the degree of interaction between a theme and other themes in the overall knowledge network, indicating its relevance and influence within the field. Density, in contrast, measures the internal cohesion of a theme, reflecting the degree of conceptual development and specialization. Together, these metrics provide insight into the maturity, structural importance, and developmental trajectory of thematic areas within adaptive learning research.
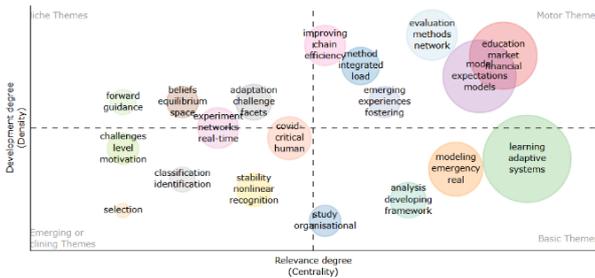
Figure 5. Co-occurence Network

Motor Themes occupy the quadrant characterized by both high centrality and high density, indicating that they are simultaneously well-developed and strongly connected to the broader knowledge structure. In this map, themes associated with integrated modeling approaches, evaluation frameworks, adaptive systems performance, and expectation-based modeling form the structural core of the field. Their position suggests that these themes function as organizing axes rather than merely popular topics. High centrality indicates that they bridge multiple research streams—technological, methodological, and application-oriented—while high density reflects conceptual consolidation and methodological refinement. Consequently, these themes are interpreted not simply as drivers of "innovation" in a generic sense, but as stabilizing and structuring forces that shape the direction of adaptive learning scholarship.

Basic Themes are located in the quadrant characterized by high centrality but lower density, indicating broad relevance but relatively lower internal specialization. Keywords related to adaptive learning systems, modeling frameworks, and organizational or implementation contexts appear within this category. Their structural position suggests that these themes constitute foundational knowledge domains upon which more specialized research builds. Rather than representing fully developed conceptual clusters, Basic Themes reflect widely shared conceptual anchors that connect diverse strands of research. Their high centrality confirms their importance to the field, while their lower density indicates ongoing conceptual expansion rather than complete theoretical consolidation.

Niche Themes appear in the quadrant defined by high density but low centrality, signifying internally cohesive yet relatively isolated research areas. Themes related to expectation formation, experimental modeling, and specialized adaptive procedures fall within this category. The strong internal cohesion suggests a high degree of methodological or conceptual specialization, while their limited centrality indicates weaker integration with the broader adaptive learning knowledge network. This structural configuration does not imply marginality in terms of intellectual value; rather, it reflects specialized subfields that contribute depth and methodological diversity without occupying a central integrative role within the field.

Emerging or Declining Themes occupy the quadrant characterized by both low centrality and low density, indicating limited integration and relatively low conceptual consolidation. In thematic mapping, this category requires cautious interpretation because low density may indicate either early-stage development or progressive decline. Without longitudinal comparison across multiple time slices, it is not possible to definitively classify themes as emerging or diminishing. However, the presence of keywords related to learner motivation, behavioral adaptation, and system responsiveness suggests areas where conceptual consolidation remains incomplete but where potential for future development exists. Their peripheral position indicates that these themes have not yet become structurally influential within the broader knowledge network.

Across the four quadrants, the thematic structure reveals a field characterized by partial interdisciplinarity combined with conceptual segmentation. Educational technology, methodological modeling, and expectation-based analytical traditions coexist within the same knowledge space but do not fully converge into a single unified paradigm. This configuration reflects the hybrid and evolving nature of adaptive learning research, where pedagogical, computational, and analytical perspectives interact unevenly. The thematic map therefore does not merely categorize topics

but provides insight into the intellectual organization of the field, distinguishing between structurally dominant themes, foundational conceptual bases, specialized research niches, and developing areas of inquiry.

The analytical contribution of this thematic structure lies in clarifying how adaptive learning scholarship is organized and how different thematic domains contribute to its evolution. By identifying structurally central themes and distinguishing them from specialized or emerging areas, the map provides a framework for understanding the maturity and direction of the field. For future research, the results suggest the need for greater conceptual integration between methodological modeling and pedagogical implementation, as well as further consolidation of emerging themes related to learner-centered adaptation. Thus, the thematic map advances adaptive learning scholarship by transforming descriptive topic identification into a structured interpretation of intellectual development and research trajectory.

Figure 6 presents the international collaboration network in adaptive learning research based on co-authorship linkages between countries. In bibliometric analysis, cross-national collaboration reflects the relational structure of knowledge production rather than merely the geographic distribution of publications. Such collaboration networks provide insight into how intellectual exchange, resource sharing, and joint authorship contribute to the diffusion and consolidation of scientific knowledge across regions (Radha & Arumugam, 2021). Therefore, the figure should be interpreted not only as evidence of collaboration presence but as an indicator of structural connectivity within the global adaptive learning research system.
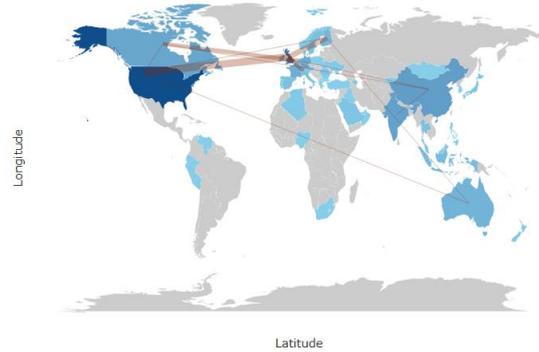

Figure 6. Countries Collaboration Map

The network visualization, represented by interconnecting lines between countries, reveals differentiated levels of collaboration intensity rather than uniform global integration. Several countries—including Australia, Canada, Austria, and Algeria—display visible cross-national linkages, indicating participation in multi-country co-authorship networks. However, the analytical significance lies in the structural position of these countries within the network. Countries that maintain multiple international connections typically occupy more central positions, functioning as hubs that facilitate knowledge exchange and intellectual coordination. In contrast, countries with fewer or isolated linkages tend to occupy peripheral positions, reflecting limited integration into the global collaboration structure.

The collaboration pattern does not indicate a fully interconnected global network but instead suggests a partial core–periphery configuration. Countries such as Australia and Canada appear more structurally connected through multiple co-authorship ties, which implies a higher degree of integration within international adaptive learning scholarship. Austria also demonstrates cross-regional linkages, suggesting participation in transnational research clusters. Algeria is connected within the network but does not exhibit the same density of ties, indicating a more limited but still visible role in cross-national collaboration. These variations in connectivity highlight uneven participation in global knowledge production rather than homogeneous collaboration across countries.

The structure of the network further

indicates that collaboration tends to occur through selective partnerships rather than broad multilateral integration. Instead of forming dense, globally distributed clusters, the network reflects localized collaborative bridges linking specific countries. Such patterns are common in emerging interdisciplinary fields, where collaboration is often shaped by institutional partnerships, shared research agendas, or regional academic linkages rather than fully globalized cooperation.

Within Southeast Asia, the presence of Indonesia and Malaysia indicates regional participation in adaptive learning research, although their position appears relatively peripheral compared with more globally connected countries. Peripheral positioning does not imply marginal scholarly value but suggests lower integration into the dominant international collaboration network. This may reflect differences in research infrastructure, publication visibility, or institutional connectivity rather than differences in research relevance. Importantly, the existence of regional collaboration between Indonesia and Malaysia indicates emerging intra-regional knowledge exchange, which may contribute to strengthening research capacity and thematic development within the region.

Overall, Figure 6 reveals that adaptive learning research is supported by an international but unevenly distributed collaboration structure. The network exhibits characteristics of partial centralization, with a limited number of countries acting as connectivity hubs while others remain less integrated. This configuration suggests that global adaptive learning scholarship is shaped by selective cross-national partnerships rather than fully symmetrical collaboration. Understanding these structural dynamics provides insight into how knowledge flows, how research communities are formed, and how collaboration patterns influence the evolution of adaptive learning research at the global level.

CONCLUSION

This study provides a systematic bibliometric examination of adaptive learning research over the 2015–2025 period and reveals several structural characteristics of the field. First, publication output demonstrates steady but moderate growth, indicating sustained scholarly attention rather than abrupt expansion. Second, the intellectual structure of the field is shaped by recurrent core themes—particularly adaptive learning systems, modeling approaches, and data-driven learning frameworks—which occupy central positions in the conceptual network. These themes function as organizing anchors that connect technological, methodological, and pedagogical strands of research. Third, the collaboration analysis indicates an internationally distributed yet uneven research network, with a limited number of structurally central countries and a broader set of peripheral participants. Together, these findings suggest that adaptive learning research is evolving toward conceptual consolidation while remaining interdisciplinary and globally dispersed.

The interpretation of publication growth should be approached cautiously. While bibliometric indicators show increasing scholarly production, such trends reflect cumulative research activity rather than single causal drivers. Similarly, the prominence of certain countries within the dataset indicates structural visibility in knowledge production but does not imply exclusive intellectual dominance. Instead, the field appears characterized by distributed contributions and ongoing global expansion.

From a theoretical perspective, this study contributes by clarifying the intellectual organization and thematic evolution of adaptive learning scholarship. The bibliometric mapping demonstrates how adaptive learning integrates technological innovation, data-driven modeling, and pedagogical personalization within a partially consolidated but still evolving research domain. By identifying structurally central and emerging themes, the study advances understanding of how adaptive learning knowledge develops, interacts, and diffuses across disciplinary boundaries.

In practical terms, the findings offer

implications for educational research and policy, particularly in relation to Sustainable Development Goal 4 (Quality Education). The prominence of themes related to personalized learning, adaptive systems, and learner-centered modeling indicates a growing emphasis on improving accessibility, responsiveness, and effectiveness in education. Bibliometric evidence suggests that adaptive learning research increasingly aligns with the goal of enhancing inclusive and data-informed educational systems. These insights provide an empirical basis for educators and policymakers to design strategies grounded in evidence rather than generalized technological optimism.

This study also acknowledges several limitations. The dataset is restricted to a single bibliographic source, which may influence representativeness and citation coverage. Additionally, bibliometric indicators capture structural and relational patterns but cannot fully explain causal mechanisms underlying research development. Future studies may extend this work by integrating multiple databases, employing longitudinal thematic comparisons, and incorporating complementary qualitative or systematic review approaches to deepen interpretive insight.

Overall, this study provides a structured and empirically grounded synthesis of adaptive learning research, clarifying its intellectual architecture, thematic dynamics, and collaboration patterns. By transforming dispersed bibliographic data into an integrated knowledge map, the study offers a foundation for guiding future research trajectories and supporting evidence-based development of adaptive, data-driven educational systems.

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