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MAPPING THE INTEGRATION OF ADAPTIVE LEARNING AND LEARNING ANALYTICS IN EDUCATION: A BIBLIOMETRIC STUDY (2004 – 2025)

Pemetaan Integrasi Pembelajaran Adaptif dan Analitik Pembelajaran dalam Pendidikan: Satu Kajian Bibliometrik (2004–2025)

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ABSTRACT

This study presents a bibliometric analysis of research on the integration of adaptive learning and learning analytics in education from 2004 to 2025, based on 1,858 publications. Using publication and citation analysis, collaboration networks, keyword co-occurrence, and thematic evolution analysis, the study examines the development of this research area, its main contributors, research themes, and patterns of growth. The findings show a steady increase in publications and citation impact, reflecting growing interest in data-driven approaches and the increasing use of artificial intelligence in education. However, the high proportion of conference papers and the relatively small number of review studies suggest that this area is still developing, with rapid growth occurring faster than the development of a more structured knowledge base. Citation and authorship analysis indicates that research influence is concentrated among a relatively small group of active authors and institutions, while collaboration patterns highlight the strong role of the United States alongside increasing but uneven international participation. Thematic evolution analysis shows a shift from early research on intelligent tutoring systems and student modelling to more data-focused and learner-centred approaches, including learning analytics, machine learning, and Bayesian modelling, with growing attention in recent studies to multimodal learning analytics and explainable artificial intelligence. Overall, adaptive learning and learning analytics form an increasingly connected and interdisciplinary research area in education, although knowledge production remains concentrated in specific regions and research groups, indicating the need for broader collaboration and further theoretical development.

Keywords: Adaptive learning; Learning analytics; Bibliometric analysis; Education; Integration of adaptive learning and learning analytics.

ABSTRAK

Kajian ini mengutarakan analisis bibliometrik terhadap penyelidikan berkaitan pembelajaran adaptif dan analitik pembelajaran yang diterbitkan antara tahun 2004 hingga 2025 berdasarkan 1,858 penerbitan. Dengan menggunakan analisis penerbitan dan sitasi, rangkaian kolaborasi, kemunculan bersama kata kunci, serta analisis evolusi tema, kajian ini meneliti pertumbuhan bidang tersebut, penyumbang utama, tema penyelidikan, dan corak perkembangannya. Dapatan kajian menunjukkan peningkatan yang ketara dan berterusan dalam jumlah penerbitan serta impak sitasi, sekali gus mencerminkan kepentingan yang semakin meningkat terhadap pendekatan berasaskan data dan penggunaan kecerdasan buatan yang semakin meluas dalam pendidikan. Walau bagaimanapun, peratusan kertas persidangan yang tinggi dan bilangan kajian ulasan yang masih kecil secara relatif menunjukkan bahawa bidang ini masih berada dalam fasa perkembangan, dengan pertumbuhan penyelidikan berlaku lebih pantas berbanding usaha untuk membina asas pengetahuan yang lebih menyeluruh. Analisis sitasi dan penulis menunjukkan bahawa pengaruh penyelidikan tertumpu kepada kumpulan kecil penulis dan institusi yang sangat produktif, manakala corak kolaborasi memperlihatkan peranan dominan Amerika Syarikat di samping peningkatan penyertaan antarabangsa. Analisis evolusi tema pula menunjukkan peralihan daripada penyelidikan awal yang memfokuskan kepada sistem tutor pintar dan pemodelan pelajar kepada topik yang lebih berorientasikan data dan berpusatkan pelajar, termasuk analitik pembelajaran, pembelajaran mesin, dan pemodelan Bayesian, dengan perhatian yang semakin meningkat terhadap analitik pembelajaran multimodal dan kecerdasan buatan yang boleh dijelaskan. Secara keseluruhannya, pembelajaran adaptif dan analitik pembelajaran telah berkembang menjadi bidang penyelidikan yang pesat berkembang dan semakin bersifat antara disiplin. Walaupun bidang ini terus berkembang dan menjadi semakin pelbagai, sumbangan penyelidikannya masih tertumpu kepada sejumlah kecil penulis, institusi, dan negara, yang menunjukkan keperluan untuk pengukuhan pembangunan teori serta kerjasama antarabangsa yang lebih meluas.

Kata kunci: *Pembelajaran adaptif; Analitik pembelajaran; Analisis bibliometrik; Pendidikan; Integrasi Pembelajaran Adaptif dan Analitik Pembelajaran.*

INTRODUCTION

Digital technologies have changed how teaching and learning are designed and delivered, especially in environments supported by online and blended learning systems. As classrooms become more diverse, there is growing interest in approaches that can better support differences in learner needs, pace, and progress(Bernacki et al., 2021; Cheng & Yu, 2026; Gligorea et al., 2023). In traditional instruction, learners often receive the same content and learning activities regardless of their individual differences, which limits the ability to support personalized learning effectively.

Adaptive learning has been developed as one response to this challenge. It refers to systems that adjust learning content, sequence, and feedback based on learner performance and needs(Shemshack & Spector, 2020). By using digital platforms and intelligent technologies, adaptive learning aims to provide more tailored learning pathways that can support student engagement and learning outcomes. It has been widely used in higher education, online learning environments, and training programmes.

The development of adaptive learning has been supported by advances in educational technologies such as artificial intelligence, big data, and systems that collect learner interaction data(Zawacki-Richter et al., 2019). These technologies make it possible to track learner behaviour and adjust instruction based on real-time data, making learning systems more responsive and flexible.

Closely related to this development is learning analytics, which focuses on the collection and analysis of learner data to understand learning processes and support decision-making in education(Shemshack & Spector, 2020). Learning analytics provides insights into learner behaviour, performance patterns, and learning challenges, which can be used to improve teaching strategies and learning support.

Over time, adaptive learning and learning analytics have become closely linked. Adaptive learning systems depend on learner data to adjust instruction, while learning analytics provides the insights needed to understand and improve these adjustments. This connection has led to increasing research that combines both areas, particularly in digital learning environments supported by artificial intelligence and educational data systems. However, these studies are still spread across different disciplines such as education, computer science, and educational technology, which makes it difficult to clearly see how the field has developed as a whole.

Although research in this area has grown rapidly, existing studies often focus on specific tools, models, or applications rather than providing a broad overview of the field. As a result, there is still limited transparency on how research in adaptive learning and learning analytics is structured, how it has developed over time, and how different research themes are connected.

To address this gap, this study uses bibliometric analysis to examine research on adaptive learning and learning analytics in education. Bibliometric analysis is a quantitative method used to analyse academic publications in order to identify research trends, influential authors, collaboration patterns, and thematic structures(Ellegaard & Wallin, 2015). This approach allows a systematic overview of how a research field develops over time.

Therefore, this study aims to map the development of research on adaptive learning and learning analytics, identify key contributors, examine collaboration patterns, and explore major research themes within the field. The study is guided by the following research questions:

RQ1: How has research on adaptive learning and learning analytics evolved over time in terms of publication output and citation trends?
RQ2: Who are the main contributors in this field in terms of authors, institutions, and countries?
RQ3: What are the main collaboration patterns and intellectual structures within this research domain?
RQ4: What are the main research themes in adaptive learning and learning analytics, and how have these themes changed over time?

This study contributes to the literature in four ways. First, it provides a structured overview of the research landscape on adaptive learning and learning analytics, offering a consolidated view of how the field has developed over time (2004-2025). Second, it identifies key contributors, including authors, institutions, and countries, that have shaped the development of this research area. Third, it examines collaboration patterns and knowledge structures to show how research in this field is connected across different levels. Finally, it highlights major research themes and their evolution, providing a clearer understanding of how this interdisciplinary field has developed and where future research may be directed.

METHODOLOGY

Research Design

This study employed a bibliometric analysis approach to examine the development of research on adaptive learning and learning analytics in education. Bibliometric analysis is a quantitative method used to map and evaluate scientific literature based on publication metadata such as authors, affiliations, citations, keywords, and references(Ellegaard & Wallin, 2015). This approach enables the identification of research trends, influential contributors, collaboration patterns, and thematic structures within a specific field.

Data Source

The data were retrieved from the Scopus database, which is widely recognized as one of the most comprehensive sources of peer-reviewed literature across multiple disciplines. Scopus provides extensive coverage of journals and conference proceedings in education, computer science, and related fields, along with detailed citation and bibliographic information suitable for bibliometric analysis(Baas

et al., 2020). Data collection was conducted in April 2026, and all records were retrieved on the same date to ensure consistency and replicability.

Search Strategy

The search strategy was developed to capture studies located at the intersection of adaptive learning and learning analytics within educational contexts. The search was performed using the Title, Abstract, and Keywords fields in Scopus.

The search query was as follows: [TITLE-ABS-KEY(("adaptive learning" OR "adaptive instruction" OR "personalized learning" OR "intelligent tutoring system*" OR "adaptive educational system*") AND ("learning analytics" OR "educational data mining" OR "student modeling" OR "knowledge tracing") AND (education OR "higher education" OR university OR college OR classroom OR teaching OR learning)) AND NOT TITLE-ABS-KEY(robotics OR antenna OR wireless OR manufacturing OR mechanical OR IoT OR "signal processing" OR "control system*" OR cybersecurity) AND PUBYEAR > 2003 AND PUBYEAR < 2026].

The search was limited to publications from 2004 to 2025. The starting year was selected to capture the early development of research in adaptive and data-driven educational technologies. To ensure relevance to education, terms such as education, higher education, university, college, classroom, teaching, and learning were included. Non-educational domains such as robotics, manufacturing, wireless communication, signal processing, cybersecurity, and Internet of Things applications were excluded to reduce noise in the dataset.

Screening and Data Cleaning

The initial search resulted in 1,989 records. A screening process was conducted to ensure relevance to the research objectives. First, duplicate records were removed. Second, titles, abstracts, and metadata were reviewed to exclude studies not related to educational contexts. Third, inconsistencies in author names, institutions, and keywords were standardized to improve data quality. After screening and cleaning, a final dataset of 1,858 publications was retained for analysis.

Data Analysis Procedure

The analysis was conducted using BiblioSpy®(Ahmi, 2026) to perform the bibliometric analysis of the dataset. The application was used to generate an overall bibliometric profile, summarize the characteristics of the dataset, examine document type distribution, analyze publication and citation trends, evaluate author productivity and impact, assess author productivity patterns based on Lotka's Law, and explore the conceptual structure of the field through keyword trends, thematic mapping, and thematic evolution analysis.

In addition, VOSviewer was employed to construct and visualize network analyses, including author collaboration networks, keyword co-occurrence networks, and country collaboration networks. The findings from both software applications were interpreted using bibliometric indicators and contextual analysis to provide a comprehensive understanding of the development, knowledge structure, and thematic evolution of research on adaptive learning and learning analytics. These analyses were selected to address the four research questions concerning publication trends, key contributors, knowledge structure, and thematic development within the field.

Limitations of the Study

This study has several limitations that should be acknowledged when interpreting the findings. First, the analysis is based solely on data retrieved from the Scopus database. Although Scopus is widely recognized for its broad coverage of peer-reviewed literature, it does not include all relevant publications indexed in other databases such as Web of Science or Google Scholar. As a result, some relevant studies may not be captured in the dataset, which may influence the completeness of the analysis.

Second, the search strategy was designed to focus on studies related to adaptive learning and learning analytics in educational contexts. While carefully constructed inclusion and exclusion criteria were applied to improve relevance, the use of specific keywords may still have led to the omission of studies that address similar concepts using different terminology. This is a common limitation in bibliometric studies that rely on keyword-based retrieval methods.
Third, the study relies on metadata extracted from bibliographic records, including titles, abstracts, keywords, and citation information. Any inconsistencies or errors in the original database records, such as variations in author names or institutional affiliations, may affect the accuracy of network and performance analyses despite data cleaning procedures.

Fourth, bibliometric analysis focuses primarily on quantitative indicators such as publication trends, citations, and network structures. While these indicators provide valuable insights into the structure and development of a research field, they do not capture the full depth of theoretical, methodological, or contextual contributions within individual studies. Therefore, the interpretation of thematic patterns should be understood as descriptive rather than evaluative.

Finally, the study covers publications from 2004 to 2025. Although this period captures the major development phases of the field, research published outside this timeframe may provide additional historical or emerging perspectives that are not reflected in the current analysis. Despite these limitations, the study provides a systematic and reproducible overview of research trends, contributors, and thematic developments in adaptive learning and learning analytics, offering a useful foundation for future research in this area.

RESULT

Evolution of Research on Adaptive Learning and Learning Analytics (RQ1)

This section presents the development of research on adaptive learning and learning analytics between 2004 and 2025. The analysis focuses on publication characteristics, document types, citation patterns, and the overall evolution of the field.

General Characteristics of the Literature

Table 1: Bibliometric Summary

Indicator	Value
Timespan	2004:2025
Total Publications (TP)	1858
Citable Year Span	22 years
Annual Growth Rate	28.1%
Document Average Age	5.62 years
Total Citations (TC)	36895
Average Citations per Document	19.86
Number of Cited Papers (NCP)	1410
Average Citations per Cited Paper	26.17
Average Citations per Year	1677.05
Total Contributing Authors	6611
Total Unique Authors	4456
Single-Authored Documents	168
Average Authors per Paper	3.56

International Co-authorship Rate	43.76%
Unique Author Keywords	3324
Total References	192980
h-index	87
g-index	152
m-index	3.955
Citation Sum within h-Core	18520

Source: Generated by the author(s) using BiblioSpy® (Ahmi, 2026).

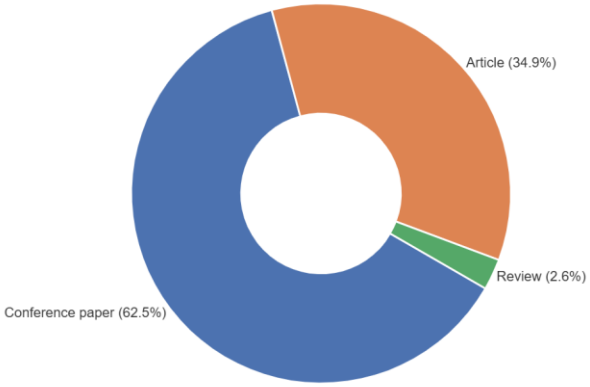
Table 1 presents a bibliometric summary of adaptive learning and learning analytics research from 2004 to 2025. The dataset includes 1,858 publications over a 22-year period, showing a substantial and continuously growing body of literature. The annual growth rate of 28.1% indicates a steady increase in research activity over time. The average document age of 5.62 years suggests that a large proportion of the literature has been published in recent years, highlighting the relatively recent expansion of this research area.

In terms of impact, the field has accumulated 36,895 citations, with an average of 19.86 citations per document and 26.17 citations per cited paper. The h-index of 87 and g-index of 152 indicate that a number of publications have received sustained academic attention. The average of 1,677 citations per year further reflects continuous scholarly engagement with this topic over time.

The dataset includes 6,611 authors, of which 4,456 are unique contributors. The average of 3.56 authors per document indicates that research in this area is generally collaborative, involving contributions from multiple researchers. The international co-authorship rate of 43.76% suggests a moderate to strong level of cross-country collaboration. At the same time, the relatively small number of single-authored publications (168) indicates that individual authorship is less common in this field.

A total of 3,324 author keywords were identified, reflecting a wide range of research topics and perspectives. The dataset also contains 192,980 references, indicating a broad and expanding knowledge base that supports ongoing research development in this area.

Document Type Distribution



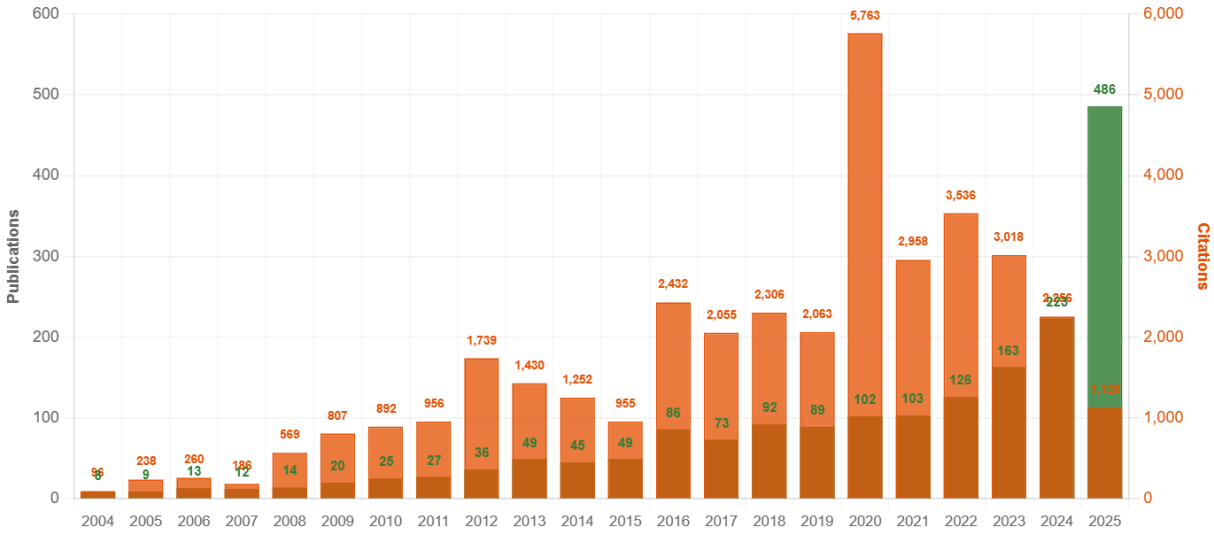
Source: Generated by the author(s) using BiblioSpy® (Ahmi, 2026).

Figure 1: Document Type Distribution

The document type distribution shows that conference papers account for 62.5% of the publications, indicating a strong emphasis on rapid dissemination of new ideas and technical developments. This pattern is commonly observed in interdisciplinary fields influenced by computer science and educational technology. Review articles represent a small proportion (2.6%), suggesting that fewer studies have focused on synthesizing and integrating existing research findings. Given the rapid growth of the field, additional review studies may be useful for providing clearer synthesis and direction for future research.

Annual Publication and Citation Trends

The publication trend (Figure 2) shows a gradual increase in research output from 2004 to 2025. In the early period (2004–2008), annual publications remained below 20, indicating limited research activity. From 2009 onwards, output increased steadily, reaching around 25–50 publications per year in the early 2010s and approximately 80–90 by 2019. After 2016, growth became more consistent, with annual publications exceeding 70 and surpassing 100 by 2020. In the most recent years, publication output increased more rapidly, rising from 163 in 2023 to 225 in 2024 and 486 in 2025. This pattern suggests a clear expansion of research activity, particularly in the later period.



Source: Generated by the author(s) using BiblioSpy® (Ahmi, 2026).

Figure 2: Annual Publication Output and Citation Trends

The citation trend generally follows a similar upward pattern, increasing from relatively low levels in the early years to higher values after 2010. Citations rise from below 500 annually in the mid-2000s to over 800 in 2009, and exceed 950 starting from 2012. A peak is observed around 2020, with 5,763 citations, likely reflecting accumulated citations to earlier influential studies. In the following years, citation counts fluctuate and decrease to 2,958 after 2021 and approximately 1,128 in 2025. However, this decrease should be interpreted cautiously as recent publications typically require time to accumulate citations.

Overall, the relationship between publication output and citation patterns suggests a general alignment between research activity and academic attention. However, differences across time periods indicate that citations accumulate unevenly, with earlier publications having more time to gain visibility. This highlights the importance of considering the delay in time when interpreting citation trends..

Developmental Phases of the Field

Based on publication and citation patterns (Figure 2), the development of the field can be broadly divided into three phases: Foundational Emergence (2004–2010), Structured Expansion (2011–2018), and Rapid Growth (2019–2025).

During the Foundational Emergence phase, research activity was relatively low, with fewer than 25 publications per year. Despite the limited output, citation counts increased steadily over time, suggesting that early studies contributed foundational concepts and attracted academic attention.

In the Structured Expansion phase (2011–2018), publication output increased steadily from around 36 to more than 90 publications per year. Citation levels remained relatively stable, indicating continued academic engagement with work produced during this period. This phase reflects a gradual broadening of the research community and a more consistent development of the field.

In the Rapid Growth phase (2019–2025), publication output increased significantly, rising from around 89 publications in 2019 to 486 in 2025. This suggests broader participation from the research community and increased attention to the topic across disciplines. The range of research topics also appears to have expanded during this period, indicating diversification of research directions and applications.

Overall, the findings show that research on adaptive learning and learning analytics has developed steadily over time, moving from an emerging research area to a rapidly expanding field. The progression of publication and citation patterns suggests increasing academic interest and broader participation across time, with noticeable shifts in research intensity across different periods.

Key Contributers of Research on Adaptive Learning and Learning Analytics (RQ2)

This section addresses RQ2 by examining the main contributors to adaptive learning and learning analytics research. The analysis is based on author productivity and citation indicators, including total publications (TP), total citations (TC), citation efficiency (C/P and C/CP), and author-level impact measures such as the h-index, g-index, m-index, and e-index. Table 2 presents the leading authors, their institutional affiliations, and countries.

Table 2: Author Statistics

Author	Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g	m	e
Baker, Ryan S. J. D.	University of Illinois Urbana-champaign	United States	43	38	2,011	46.77	52.92	19	43	1.06	38.64
Heffernan, Neil T.	Independent	United States	35	31	1,884	53.83	60.77	15	35	0.83	39.26
Aleven, Vincent	Carnegie Mellon University	United States	23	21	1,082	47.04	51.52	12	23	0.67	29.77
Kinshuk, K.	Athabasca University	Canada	21	20	554	26.38	27.70	11	21	0.61	19.97
Pardos, Zachary A.	University of California	United States	18	18	982	54.56	54.56	10	18	0.63	29.17
Virvou, Maria	University of Piraeus	Greece	17	17	619	36.41	36.41	11	17	0.61	21.77
Koedinger, Kenneth R.	Carnegie Mellon University	United States	17	14	1,461	85.94	104.36	11	17	0.58	36.32
Liu, Qi	Anhui University	China	14	14	563	40.21	40.21	10	14	1.00	21.02
Gowda, Sujith M.	Alpha Data Labs, Inc.	United States	13	13	377	29.00	29.00	9	13	1.00	16.76

Gašević, Dragan	University of Hong Kong	China	12	11	507	42.25	46.09	8	12	0.57	20.78

Note: *TP = Total Publications; NCP = Number of Cited Publications; TC = Total Citations; C/P = Citations per Publication; C/CP = Citations per Cited Publication; h = h-index; g = g-index; m = m-Quotient; e = e-index*

Source: Generated by the author(s) using BiblioSpy® (Ahmi, 2026).

Leading Authors by Productivity and Scholarly Impact

The results show that a relatively small group of authors accounts for a substantial share of both publications and citations in the field. Baker, Ryan S. J. D. from the University of Illinois Urbana-Champaign ranks first with 43 publications and 2,011 citations, indicating a sustained contribution to the literature. Heffernan, Neil T. follows with 35 publications and 1,884 citations, demonstrating strong publication output and citation impact. Other prominent contributors include Aleven, Vincent (23 publications, 1,082 citations), Pardos, Zachary A. (18 publications, 982 citations), and Koedinger, Kenneth R. (17 publications, 1,461 citations). Together, these authors represent some of the most visible contributors in the field and are frequently associated with research related to adaptive learning systems, intelligent tutoring systems, and learning analytics applications.

Citation Impact and Research Influence Distribution

Citation indicators suggest that research influence is unevenly distributed across authors. While many researchers contribute to the field, a smaller group accounts for a large proportion of total citations. For example, Koedinger, Kenneth R. records a high citations-per-publication ratio (C/P = 85.94), indicating substantial citation impact relative to publication output. Baker, Ryan S. J. D. and Heffernan, Neil T. also maintain high citation counts across multiple publications, reflecting continued visibility within the literature. The h-index and g-index values further indicate that a number of authors have produced work that continues to receive sustained academic attention.

Institutional Concentration of Research Output

At the institutional level, research output is concentrated within a relatively small number of universities, particularly in the United States. Institutions such as the University of Illinois Urbana-Champaign, Carnegie Mellon University, and the University of California are associated with several of the leading authors identified in the analysis. This pattern suggests that these institutions contribute substantially to publication output and citation activity within the field. More broadly, the findings indicate that research activity is concentrated in a limited number of universities with established research programmes related to educational technology, learning sciences, and data-driven education.

Geographical Distribution of Contributors

From a country perspective, the United States records the highest levels of publication output and citation impact among the leading contributors identified in the dataset. The top five authors are affiliated with institutions located in the United States, indicating a strong concentration of highly cited and highly productive researchers within the country. Contributions are also observed from other regions, including Canada, Greece, and China. Examples include Kinshuk (Athabasca University, Canada), Virvou, Maria (University of Piraeus, Greece), Liu, Qi (Anhui University, China), and Gašević, Dragan (University of Hong Kong, China). These findings suggest that research contributions originate from multiple regions, although publication output and citation activity remain concentrated in a limited number of countries.

Highly-Cited Publications

Table 3: Highly-Cited Papers

No.	Authors	Title	Source	TC	C/Y	NTC
1	Chen et al. (2020)	Application and Theory Gaps During the Rise of Artificial Intelligence in Education	Computers and Education: Artificial Intelligence	814	116.29	14.41

2	Ghosh et al. (2020)	Context-aware Attentive Knowledge Tracing	Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining	618	88.29	10.94
3	Papamitsiou & Economides (2014)	Learning Analytics and Educational Data Mining in Practice: a Systemic Literature Review of Empirical Evidence	Educational Technology and Society	609	46.85	21.89
4	Chen et al. (2022)	Two Decades of Artificial Intelligence in Education: Contributors, Collaborations, Research Topics, Challenges, and Future Directions	Educational Technology and Society	584	116.8	20.81
5	Yudelson et al. (2013)	Individualized Bayesian Knowledge Tracing Models	Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	475	33.93	16.28
6	Guan et al. (2020)	Artificial Intelligence Innovation in Education: a Twenty-year Data-driven Historical Analysis	International Journal of Innovation Studies	472	67.43	8.35
7	Pavlik P.i. et al. (2009)	Performance Factors Analysis - a New Alternative to Knowledge Tracing	Frontiers in Artificial Intelligence and Applications	434	24.11	10.76
8	Shemshack & Spector (2020)	A Systematic Literature Review of Personalized Learning Terms	Smart Learning Environments	407	58.14	7.2
9	Baker et al. (2008)	More Accurate Student Modeling Through Contextual Estimation of Slip and Guess Probabilities in Bayesian Knowledge Tracing	Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	378	19.89	9.3
10	Desmarais & Baker (2012)	A Review of Recent Advances in Learner and Skill Modeling in Intelligent Learning Environments	User Modelling and User-adapted Interaction	373	24.87	7.72

Note: *TC = Total Citations; C/Y = Citations per Year; NTC = Normalised Total Citations*
Source: Generated by the author(s) using BiblioSpy® (Ahmi, 2026).

Table 3 presents the ten most highly cited publications in adaptive learning and learning analytics research. These studies represent some of the most influential contributions within the field and provide insight into the topics that have attracted substantial scholarly attention.

The most highly cited publication is Application and Theory Gaps During the Rise of Artificial Intelligence in Education(Chen et al., 2020) with 814 total citations. This is followed by Context-aware Attentive Knowledge Tracing(Ghosh et al., 2020) which has received 618 citations, and Learning

Analytics and Educational Data Mining in Practice: A Systematic Literature Review of Empirical Evidence(Papamitsiou & Economides, 2014) with 609 citations. Several highly cited studies focus on learner modelling and knowledge tracing such as Individualized Bayesian Knowledge Tracing Models (Yudelson et al., 2013), Performance Factors Analysis - a New Alternative to Knowledge Tracing (Pavlik Jr. et al., 2009) and More Accurate Student Modeling Through Contextual Estimation of Slip and Guess Probabilities in Bayesian Knowledge Tracing(Baker et al., 2008) which indicated the importance of these topics in the development of the field.

The list also includes review and bibliometric studies, such as Chen et al. (2022) and Shemshack and Spector (2020), indicating strong scholarly interest in synthesizing existing knowledge and examining broader research trends. More broadly, the highly cited publications span themes related to artificial intelligence in education, learning analytics, educational data mining, personalised learning, and Bayesian knowledge tracing. This distribution suggests that both methodological developments and educational applications have influence the growth of the field.

Overall, the highly cited publications provide a useful overview of the intellectual foundations of adaptive learning and learning analytics. The prominence of studies on artificial intelligence, learner modelling, and learning analytics is consistent with the thematic patterns identified elsewhere in the analysis, indicating their continued importance within the research landscape.

Patterns of Research Contribution

The findings collectively indicate that research activity and scholarly influence in adaptive learning and learning analytics are concentrated among a relatively small group of authors, institutions, and publications. The leading authors identified in Table 2 explains for a substantial share of both publication output and citation impact, while the highly cited papers presented in Table 3 have received considerable attention within the academic community. Similarly, research contributions are strongly associated with a limited number of institutions, particularly those with established expertise in educational technology, learning analytics, and artificial intelligence. This pattern suggests that knowledge production within the field is not evenly distributed, but is concentrated among a core group of contributors who play an important role in advancing research and attracting scholarly attention. At the same time, the wider community of researchers continues to contribute to the growth and diversification of the field through a broad range of publications and collaborative activities.

Author Productivity Distribution and Lotka's Law

Table 4: Author Productivity Distribution

Documents (x)	No. of Authors (y)	Proportion (%)	Fitted Lotka C/xn (%)	Classic Lotka 60/x² (%)
1	4,061	82.64%	72.94%	60.00%
2	549	11.17%	13.63%	15.00%
3	151	3.07%	5.11%	6.67%
4	61	1.24%	2.55%	3.75%
5	23	0.47%	1.48%	2.40%
6	24	0.49%	0.95%	1.67%
7	11	0.22%	0.66%	1.22%
8	12	0.24%	0.48%	0.94%

9	3	0.06%	0.36%	0.74%
10	6	0.12%	0.28%	0.60%

The author productivity distribution presented in Table 4 shows a highly skewed pattern. A large majority of authors (82.64%) contributed only one publication, while progressively fewer authors produced multiple publications. This pattern reflects a long-tail distribution of scientific productivity within adaptive learning and learning analytics research.

When compared with theoretical expectations, the observed distribution generally aligns with Lotka's Law, particularly within the lower publication ranges (x = 1 to 3), where most authors are concentrated. The fitted Lotka model (C/x^n) provides a closer approximation to the observed values than the classical $60/x^2$ formulation, although some deviations are evident at higher publication frequencies. Such deviations are common in empirical bibliometric datasets. Overall, the findings suggest that research productivity is unevenly distributed, with a relatively small group of authors contributing repeatedly while most authors publish only once.

Summary of Key Contributors

Overall, adaptive learning and learning analytics research is characterized by a relatively small group of highly productive and highly cited authors, alongside a concentration of research activity within a limited number of universities, particularly in the United States. Contributions from other countries are also evident, reflecting the increasingly international nature of the field. The observed productivity patterns are consistent with a core–periphery structure and with the distribution predicted by Lotka's Law, where a small proportion of contributors account for a large share of research output. Together, these findings indicate that knowledge production in the field remains concentrated among a limited number of authors and institutions, although participation from a broader international research community continues to expand.

Knowledge Structure in Terms of Collaboration Networks and Intellectual Relationships (RQ 3)

The knowledge structure of adaptive learning and learning analytics was examined through three complementary network analyses: a co-authorship network, a three-field plot (authors–keywords–countries), and a country collaboration network. Together, these analyses provide insights into collaboration patterns, thematic connections, and international research relationships within the field.

Co-authorship Network Structure

The co-authorship network (Figure 3) shows a structured pattern of collaboration centred around a group of highly connected researchers, including Baker, Ryan S. J. D., Aleven, Vincent, Heffernan, Neil T., and Koedinger, Kenneth R. These authors occupy central positions within the network and maintain collaborative links with multiple researchers. Dense connections are particularly visible among authors such as Heffernan, Koedinger, and Pardos, Zachary A., indicating frequent collaboration within this group.

Surrounding the central network are several smaller clusters and individual researchers with fewer collaborative links. Authors such as Gašević, Dragan and Mitrović, Antonija appear in more peripheral positions, reflecting participation in smaller collaboration groups. The network also includes several authors who connect otherwise separate clusters. For example, authors such as Gowda, Sujith M. appear to occupy intermediary positions between groups, contributing to the overall connectivity of the network. Overall, the co-authorship structure suggests that collaboration in the field is concentrated within several established research groups while remaining connected through a smaller number of bridging contributors.

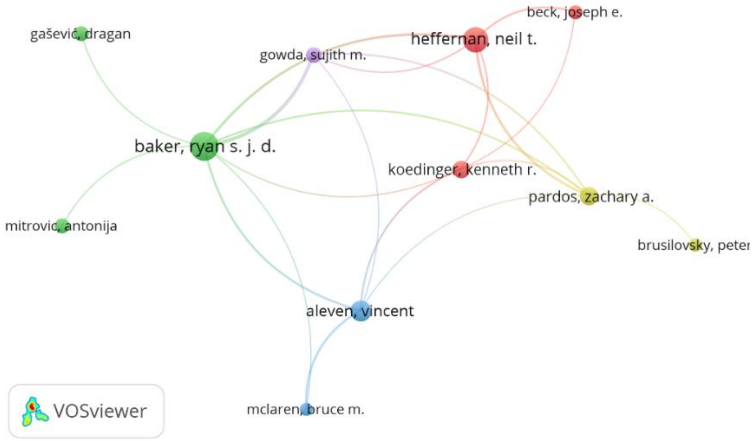


Figure 3: Author Collaboration Network

Keyword Co-occurrence Network Structure

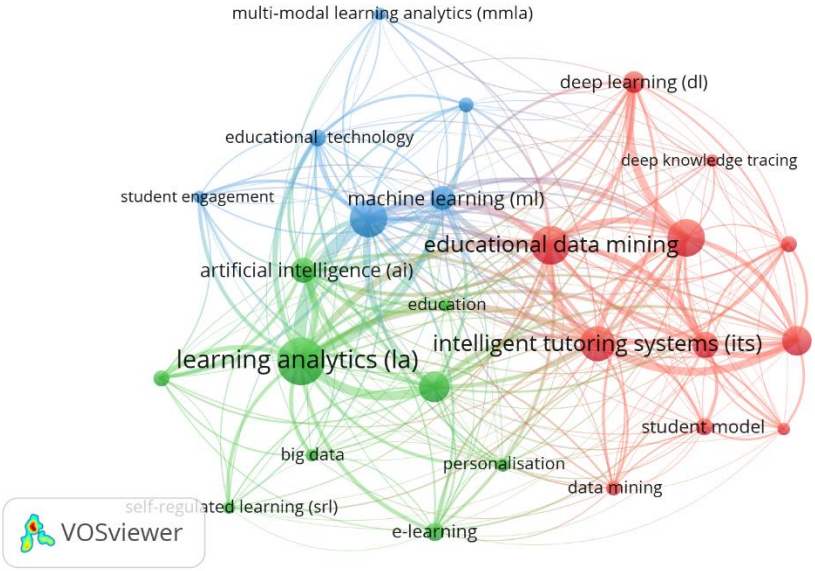


Figure 4: Keyword Co-occurrence Network

The keyword co-occurrence network reveals three interconnected thematic clusters representing different areas of adaptive learning and learning analytics research. The first cluster is centred on educational data mining, intelligent tutoring systems, student modelling, and deep learning, reflecting research related to computational techniques and adaptive learning systems. The second cluster includes learning analytics, artificial intelligence, education, e-learning, and self-regulated learning, indicating a focus on data-informed approaches within educational settings. The third cluster contains machine learning, educational technology, student engagement, and multimodal learning analytics, linking methodological developments with educational applications.

Although each cluster demonstrates a distinct thematic emphasis, numerous connections are visible across clusters through shared concepts such as artificial intelligence, machine learning, learning analytics, educational data mining, and education. These links suggest that the field is organized around related research themes rather than isolated areas of study. In addition, concepts such as multimodal learning analytics and some deep learning-related topics appear closer to the periphery of the network

and have fewer connections than more established concepts, which may indicate areas that are still developing within the broader research landscape.

Country Collaboration Network Structure

The country collaboration network displays a clustered pattern of international research partnerships. The United States occupies a central position within the network and maintains collaborative links with multiple countries. One major cluster includes the United States, China, Canada, Taiwan, France, and Japan, indicating substantial collaboration across North America, East Asia, and parts of Europe.

A second cluster is composed primarily of European countries, including the United Kingdom, Germany, Spain, Italy, and Greece, together with links to Brazil. A third cluster includes countries such as India, Malaysia, Indonesia, Saudi Arabia, and South Korea, representing collaboration networks across Asia and the Middle East. Australia and the Netherlands appear in a smaller cluster that connects with multiple regional groups. Overall, the network suggests that international collaboration occurs through both regional partnerships and broader cross-regional connections, with a limited number of countries occupying more central positions within the global collaboration structure.

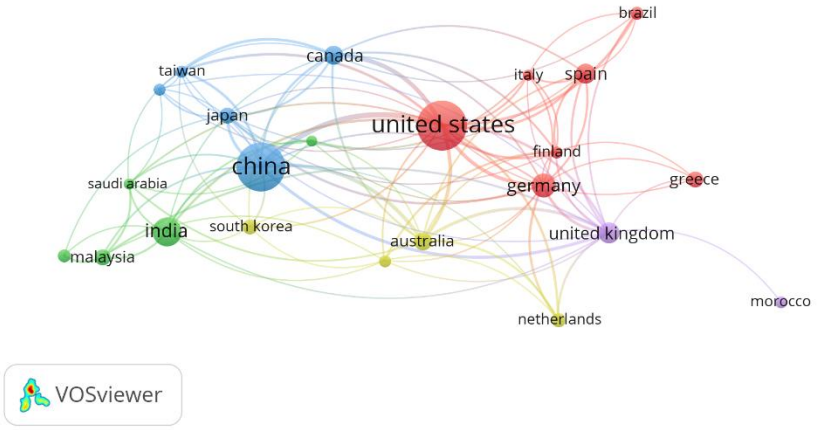


Figure 5: Country Collaboration Network

Integrated Knowledge Structure

When the co-authorship, keyword co-occurrence, and country collaboration networks are considered together, a consistent pattern can be observed across the collaborative, conceptual, and geographical dimensions of the field. The co-authorship network reflects that research collaboration tends to occur within identifiable groups of researchers rather than being evenly distributed across all contributors. The keyword network reveals several interconnected thematic areas that link computational approaches, learning systems, and educational applications. Similarly, the country collaboration network shows that international research partnerships are organised into regional clusters while maintaining connections across geographical boundaries.

Taken together, these findings suggest that adaptive learning and learning analytics research is characterised by interconnected but differentiated structures. Collaboration patterns, research themes, and international partnerships are linked through multiple overlapping networks rather than through a single unified structure.

Main Research Themes and Themes Evolution (RQ4)

Main Research Themes

Table 5: Thematic Map by Words

Occurrences	Word	Cluster	Cluster Label	Btw.Cent.	Clos.Cent.	PageRank
472	learning analytic	2	learning analytic	0.2098	0.7563	0.02181
400	intelligent tutoring system (its)	7	intelligent tutoring system (its)	0.1603	0.7062	0.01898
320	educational data mining	5	educational data mining	0.1661	0.7376	0.01695
290	personalised learning	8	personalised learning	0.1607	0.7233	0.01933
286	knowledge tracing (kt)	4	knowledge tracing (kt)	0.0782	0.6260	0.01716
200	adaptive learning (al)	6	adaptive learning (al)	0.0771	0.6622	0.01471
177	student modeling	7	intelligent tutoring system (its)	0.0389	0.5936	0.01404
126	artificial intelligence (ai)	6	adaptive learning (al)	0.0328	0.6032	0.01247
120	machine learning (ml)	1	machine learning (ml)	0.0262	0.5984	0.01183
95	deep learning (dl)	9	deep learning (dl)	0.0210	0.5665	0.00918
69	e-learning	3	e-learning	0.0059	0.5399	0.00923
65	student models	3	e-learning	0.0065	0.5341	0.01437
61	educational technology	1	machine learning (ml)	0.0056	0.5581	0.00818
52	bayesian knowledge tracing (bkt)	3	e-learning	0.0052	0.5341	0.01007
51	higher education	1	machine learning (ml)	0.0022	0.5284	0.00735
47	adaptive learning system	1	machine learning (ml)	0.0011	0.5284	0.00478
46	data mining	9	deep learning (dl)	0.0097	0.5321	0.01008
39	personalisation	1	machine learning (ml)	0.0022	0.5246	0.00976
35	bayesian network	4	knowledge tracing (kt)	0.0016	0.5103	0.00868
35	education	6	adaptive learning (al)	0.0009	0.5228	0.00472

Table 5 presents the thematic structure of adaptive learning and learning analytics research based on keyword occurrence and network centrality measures. The results indicate that the field is organized around several highly connected themes that link educational applications with computational methods.

Among all themes, learning analytics records the highest values across multiple centrality indicators, including betweenness centrality, closeness centrality, and PageRank. This suggests that learning analytics occupies one of the most connected positions within the thematic network and is closely linked to a wide range of research topics in the field.

Among all themes, learning analytics is the most frequently occurring topic, appearing 472 times. It also records the highest betweenness centrality (0.2098), closeness centrality (0.7563), and one of the highest PageRank values (0.02181). Taken together, these indicators suggest that learning analytics occupies one of the most connected positions within the thematic network and is closely associated with multiple research areas across the field.

Intelligent tutoring systems (ITS) represent another major theme, with 400 occurrences and strong network connectivity across all centrality measures. Similarly, educational data mining (320 occurrences) and personalised learning (290 occurrences) demonstrate high levels of occurrence and connectivity, indicating that they are closely associated with a wide range of studies within the field. Together, these themes form some of the most prominent areas of research and reflect the close relationship between learner support, data analysis, and adaptive educational systems.

Research related to knowledge tracing (286 occurrences) and adaptive learning (200 occurrences) also occupies important positions within the network. Although these themes record lower centrality values than learning analytics and educational data mining, their relatively high occurrence frequencies indicate their continued relevance in the literature. Closely related topics such as student modelling (177 occurrences), artificial intelligence (126 occurrences), and machine learning (120 occurrences) further highlight the role of learner modelling and computational techniques in supporting adaptive educational environments.

Several additional themes appear with lower frequencies but remain connected to the broader thematic structure. These include deep learning (95 occurrences), e-learning (69 occurrences), student models (65 occurrences), educational technology (61 occurrences), and Bayesian knowledge tracing (52 occurrences). Their presence suggests continuing interest in specialized methodological approaches and educational applications. Other themes, including higher education, adaptive learning systems, personalisation, Bayesian networks, and data mining, appear less frequently but contribute to the overall diversity of the research landscape.

Overall, the thematic structure suggests that adaptive learning and learning analytics research is organized around a set of interconnected themes that combine educational applications, learner modelling, data-driven approaches, and artificial intelligence techniques. Learning analytics, intelligent tutoring systems, educational data mining, personalised learning, and knowledge tracing emerge as particularly prominent themes, reflecting their central positions within the broader knowledge structure of the field.

Thematic Evolution

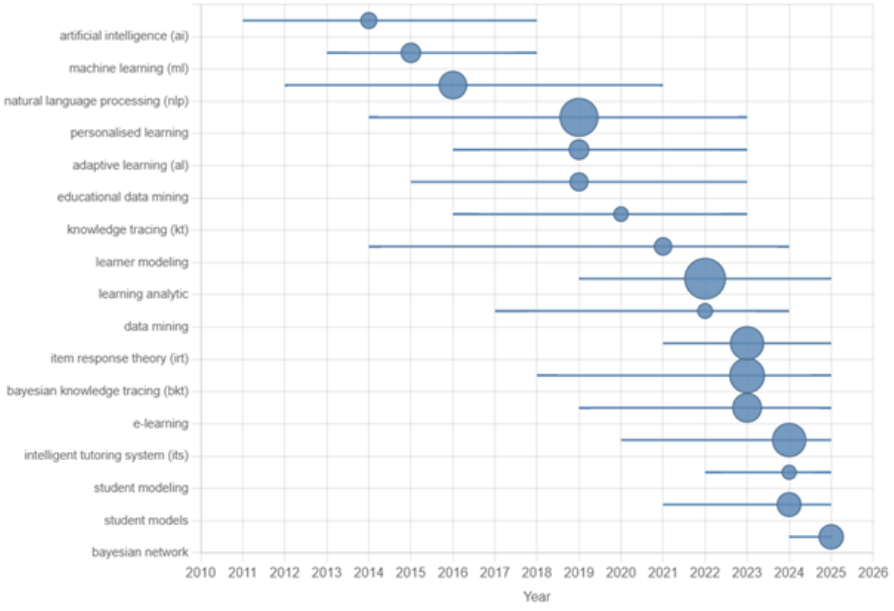


Figure 6: Keyword Trend Topics

The trend topics analysis reveals changes in research emphasis within adaptive learning and learning analytics between 2011 and 2025. Earlier research activity was characterized by topics such as artificial intelligence and machine learning, which appeared consistently during the initial years of the study period. These themes formed part of the computational foundation of the field and remained visible throughout subsequent periods.

From approximately 2014 onwards, research attention expanded to include educationally oriented themes such as personalised learning, adaptive learning, and educational data mining. This shift suggests increasing interest in applying computational techniques to support teaching and learning processes.

Beginning around 2019, learning analytics became one of the most visible topics in the trend analysis, alongside learner modelling and knowledge tracing. The growing presence of these themes indicates increased attention to the use of learner data for understanding learning processes and supporting adaptive educational systems.

More recent years show the appearance of specialised topics such as Bayesian knowledge tracing, item response theory, student models, and Bayesian networks. These themes suggest continuing development of approaches related to learner modelling, assessment, and predictive analytics within educational environments.

Overall, the thematic evolution pattern indicates a gradual broadening of research topics over time. While computational methods remain important, later periods show increasing attention to educational applications, learning analytics, learner modelling, and data-informed approaches to personalised learning.

Summary of Research Themes and Their Evolution

Taken together, the thematic map and trend topics analysis suggest that adaptive learning and learning analytics research is organized around interconnected educational and computational themes. Intelligent tutoring systems, student modelling, knowledge tracing, learning analytics, educational data mining, adaptive learning, and personalised learning represent some of the most prominent themes within the field. Artificial intelligence, machine learning, and related computational approaches remain closely connected to these educational topics throughout the study period.

The temporal patterns further suggest that research themes have expanded rather than shifted completely from one area to another. Newer topics appear alongside established themes, indicating the continued coexistence of adaptive systems, learner modelling, learning analytics, and emerging artificial intelligence applications. This pattern reflects the increasing breadth of the field and the growing interaction between technological developments and educational applications.

DISCUSSIONS

Thematic Evolution and Emerging Directions

The thematic structure of adaptive learning and learning analytics shows a combination of established research themes and emerging areas of development. Well-established topics such as intelligent tutoring systems, student modelling, and knowledge tracing form the core of the field. These themes reflect the early development of research focused on learner modelling and the application of artificial intelligence in education, and they continue to act as key reference points in the literature.

At the same time, artificial intelligence, machine learning, and educational data mining dominate highly connected positions within the thematic structure. Rather than functioning as isolated topics, these areas are closely linked to multiple research themes and support a wide range of applications in adaptive learning and learning analytics. Their central position suggests that computational methods play an important role in connecting different components of research within the field.

In addition to these core themes, several emerging topics such as multimodal learning analytics, reinforcement learning, and explainable artificial intelligence appear in more peripheral positions. These themes are less connected to the main structure but indicate areas of ongoing development and growing research interest. Their presence suggests that the field is gradually expanding into more specialised and advanced methodological directions.

The thematic evolution over time shows changes in research emphasis across the study period. Earlier studies were mainly focused on artificial intelligence and machine learning as general computational approaches. Over time, research attention shifted toward learning analytics, personalised learning, and educational data mining, reflecting increased interest in the application of data-driven approaches in educational settings. More recent studies show greater attention to learner modelling and predictive techniques such as knowledge tracing.

The increasing use of Bayesian methods and probabilistic modelling in recent years suggests a growing focus on more structured approaches to representing and predicting learner behaviour. These methods allow for more detailed modelling of learning processes based on available educational data and support more refined adaptive learning systems.

Importantly, the prominence of these thematic areas is also reflected in the highly cited literature. Many of the most cited publications focus on artificial intelligence in education, learning analytics, educational data mining, personalised learning, and knowledge tracing. This alignment suggests that the most influential studies in the field are closely connected to the core themes identified in the thematic analysis, reinforcing their central role in shaping research attention.

Overall, the thematic evolution suggests that adaptive learning and learning analytics research involves both continuity and gradual change. Established educational technologies remain important within the field, while new computational and analytical approaches are increasingly integrated into existing research directions. This pattern indicates a steadily expanding and increasingly interdisciplinary research area, where educational concepts and data-driven methods continue to develop in parallel.

Implications of the Study

Theoretical Implications

This study contributes to the understanding of adaptive learning and learning analytics as an interdisciplinary research domain shaped by education, artificial intelligence, and data science. The results suggest that the development of the field is not linear but instead reflects changes in publication growth, collaboration patterns, and thematic emphasis over time.

First, the strong increase in publication output and citation impact indicates that the field is rapidly expanding. However, the relatively high proportion of conference proceedings and the small number of review studies suggest that the literature is still in a developing stage, where empirical and technical studies are more common than conceptual synthesis. This pattern indicates that the field is growing faster than it is being systematically established.

Second, the concentration of productivity and citation impact among a small group of authors and institutions is consistent with proven bibliometric patterns such as Lotka's Law and the Matthew Effect. This suggests that research influence is unevenly distributed with a limited number of contributors accounting for a large share of scientific output. In this context, knowledge production appears to be driven by a core group of highly active researchers and institutions.

Third, the co-authorship and country collaboration patterns indicate that research activity is organized through a combination of central collaborative groups and more distributed peripheral participation. This core–periphery structure suggests that while some research clusters are highly connected, broader participation is still developing across regions and institutions.

Fourth, the thematic evolution shows a gradual shift from system-oriented approaches such as intelligent tutoring systems and student modelling toward more data-driven approaches such as learning analytics, machine learning, and Bayesian modelling. Rather than a complete transformation, this pattern suggests that newer computational approaches are being added to existing research directions, resulting in a more diverse thematic structure over time.

Practical Implications

From a practical perspective, the findings offer several implications for researchers, institutions, and policymakers in educational technology.

First, the concentration of influential research in a small number of countries and institutions suggests the need to strengthen research capacity in under represented regions. This may include investing in research infrastructure, training, and international collaboration opportunities to support more balanced global participation.

Second, the prominence of artificial intelligence, machine learning, and learning analytics highlights the increasing technical demands of the field. This suggests a need for interdisciplinary skills that combine educational knowledge with computational methods. Collaboration between education specialists and computer scientists is likely to remain important for future development.

Third, the relatively small number of review and synthesis studies indicates a gap in knowledge integration. This suggests a need for more systematic reviews and meta-analyses to help organize the rapidly expanding literature and support clearer understanding of the field.

Fourth, emerging topics such as multimodal learning analytics, reinforcement learning, and explainable artificial intelligence suggest new directions for educational technology development. In practice, these areas highlight the importance of not only improving prediction accuracy but also ensuring transparency and usability in educational settings.

Finally, the observed regional clustering in international collaboration suggests that research partnerships are still unevenly distributed. Encouraging broader international collaboration may help improve knowledge sharing and support more inclusive development of adaptive learning technologies. Overall, the findings suggest that adaptive learning and learning analytics is a growing and increasingly interdisciplinary field, but one that still shows concentration in terms of research output and collaboration networks.

Future Research Directions

The findings suggest several directions for future research that address current gaps in the field.

First, there is a need for more synthesis-oriented studies, including systematic reviews and meta-analyses. The rapid growth of primary studies compared to review papers suggests that knowledge integration remains limited. Future research could focus on combining findings across intelligent tutoring systems, learning analytics, and adaptive learning systems to develop clearer conceptual structures.

Second, future studies should explore adaptive learning applications in under represented regions. The current concentration of research in a limited number of countries suggests that more comparative and cross-cultural studies are needed to understand how adaptive learning systems perform in different educational contexts.

Third, emerging artificial intelligence methods such as multimodal learning analytics, reinforcement learning, and explainable AI should be further explored in practical educational settings. Future work should examine how these methods can be integrated into real learning environments while maintaining usability and interpretability.

Fourth, there is a need for stronger integration across research areas that currently appear in separate clusters. Future research could focus on combining learner modelling, predictive analytics, and instructional design to reduce fragmentation across subfields.

Fifth, more longitudinal studies are needed to evaluate the long-term effectiveness of adaptive learning systems in real classrooms. Much of the current literature appears to focus on system development and short-term evaluation, so longer-term evidence would strengthen the field.

Finally, future research should continue to address ethical and human-centered aspects of artificial intelligence in education, including fairness, transparency, and interpretability. These considerations are increasingly important as adaptive learning systems become more data-driven.

Integrated Future Research Agenda

Overall, future research should focus on improving integration across methodological, thematic, and geographical dimensions. Rather than focusing only on technological development, the field would benefit from approaches that combine artificial intelligence, learning analytics, and educational theory in a more coordinated way. This may support the development of adaptive learning systems that are both technically advanced and educationally meaningful.

CONCLUSION

This study provides a bibliometric overview of research on adaptive learning and learning analytics published between 2004 and 2025. Based on 1,858 publications indexed in Scopus, the analysis examined publication trends, key contributors, collaboration patterns, and thematic development to better understand the evolution of the field.

The findings show a substantial increase in both publication output and citation activity over the study period, indicating growing research interest in adaptive learning and learning analytics. However, the large proportion of conference papers and the relatively small number of review studies suggest that the field is still developing with research growth occurring more rapidly than efforts to synthesize existing knowledge.

The analysis also shows that research output and citation impact are concentrated among a relatively small group of authors, institutions, and countries, particularly those based in the United States. Collaboration networks reveal several well-connected research groups and international partnerships, although participation remains uneven across regions. These patterns suggest that while the field has become increasingly collaborative and international, research activity continues to be concentrated within a limited number of influential contributors.

The thematic analysis identifies learning analytics, intelligent tutoring systems, educational data mining, personalised learning, adaptive learning, and knowledge tracing as some of the most prominent research themes. Thematic evolution further indicates that research has expanded from early work on adaptive systems and learner modelling to include learning analytics, machine learning, Bayesian modelling, and other data-driven approaches. Rather than replacing earlier research directions, these newer themes appear alongside established topics, contributing to a broader and more diverse research landscape.

Overall, the findings suggest that adaptive learning and learning analytics has become an increasingly active and interdisciplinary area of research. The field continues to expand through the interaction of educational applications, learner modelling, learning analytics, and artificial intelligence. At the same time, opportunities remain for stronger knowledge synthesis, broader international participation, and further integration across research areas. By providing a structured overview of the field, this study offers a useful reference for researchers seeking to understand its development, major contributors, and emerging directions.

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