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Research Article

AI-based feedback tools in education: A comprehensive bibliometric analysis study

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Abstract: This bibliometric analysis offers a comprehensive examination of AI-based feedback tools in education, utilizing data retrieved from the Web of Science (WoS) database. Encompassing a total of 239 articles from an expansive timeframe, spanning from inception to February 2024, this study provides a thorough overview of the evolution and current state of research in this domain. Through meticulous analysis, it tracks the growth trajectory of publications over time, revealing the increasing scholarly attention towards AI-driven feedback mechanisms in educational contexts. By describing critical thematic areas such as the role of feedback in enhancing learning outcomes, the integration of AI technologies into educational practices, and the efficacy of AI-based feedback tools in facilitating personalized learning experiences, the analysis offers valuable insights into the multifaceted nature of this field. By employing sophisticated bibliometric mapping techniques, including co-citation analysis and keyword co-occurrence analysis, the study uncovers the underlying intellectual structure of the research landscape, identifying prominent themes, influential articles, and emerging trends. Furthermore, it identifies productive authors, institutions, and countries contributing to the discourse, providing a detailed understanding of the collaborative networks and citation patterns within the community. This comprehensive synthesis of the literature serves as a valuable resource for researchers, practitioners, and policymakers alike, offering guidance on harnessing the potential of AI technologies to revolutionize teaching and learning practices in education.

1. INTRODUCTION

In recent years, the integration of Artificial Intelligence (AI) into various aspects of education has revolutionized teaching and learning practices. One significant area of AI application in education is developing and utilizing AI-based feedback tools (Chen, 2023). These tools, leveraging machine learning algorithms and natural language processing capabilities, offer personalized and timely feedback to students, facilitating their learning process and enhancing educational outcomes (Elmaoğlu et al., 2024; Qiao & Zhao, 2023; Su & Yang, 2023). The importance of this topic lies in its potential to reshape traditional feedback mechanisms, making them more adaptive, efficient, and effective in catering to the diverse needs of learners in contemporary educational settings.

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As educational institutions strive to meet the evolving demands of a digital era, exploring AI-based feedback tools has gained considerable momentum in educational research. These tools encompass a wide range of applications, from automated grading systems to intelligent tutoring systems capable of providing detailed performance insights to students (Palocsay & Stevens, 2008; Roldán-Álvarez & Mesa, 2024). Consequently, a rich body of literature has emerged, documenting various aspects of AI-driven feedback tools, including their development, implementation, and impact on learning outcomes.

A review of the existing literature reveals several key themes that have surfaced in research on AI-based feedback tools in education. For instance, scholars have investigated the technical aspects of these tools, examining the algorithms and methodologies underpinning their design and functionality (Lee, 2023; Lee et al., 2023). This technical exploration is crucial for understanding AI-driven feedback systems' capabilities and limitations and optimizing their performance in educational contexts. Moreover, research in this field has also focused on the pedagogical implications of AI-based feedback tools (Conrad & Hall, 2024; Wong et al., 2023). Educators and researchers are keen to explore how these tools can be integrated into instructional practices to provide personalized guidance and support to students (Wu & Tsai, 2022). By tailoring feedback to individual learning needs and preferences, AI-driven systems have the potential to foster student engagement, motivation, and self-regulated learning (Nazari et al., 2021).

AI-based feedback tools leverage machine learning algorithms and natural language processing capabilities to offer personalized and timely feedback. These tools are used in classrooms to assist with various types of student responses, including multiple-choice questions, short answer questions, essays, and other open-ended tasks. For instance, automated writing evaluation systems provide detailed feedback on grammar, style, coherence, and content quality in student essays. Ding and Zou (2024) reviewed studies on automated writing evaluation systems, highlighting their positive impact on students' writing proficiency and the generally favorable attitudes of both learners and educators towards these tools. Besides, Shi and Aryadoust (2024) reviewed studies on automated written feedback, finding that it is predominantly studied in tertiary-level language and writing classes, with a focus on English as the target language. However, they also identified research gaps. AI-based feedback tools face challenges with more complex and open-ended tasks. Providing feedback on creative writing, complex mathematical proofs, or nuanced scientific explanations can be more difficult due to the variability and subjectivity involved in these responses. For example, while an AI tool can effectively grade multiple-choice questions or provide grammar corrections, evaluating the creativity and originality of a story or the logical coherence of a complex argument requires more sophisticated analysis that current AI technologies are still developing.

Furthermore, studies have investigated the impact of AI-based feedback tools on learning outcomes and academic achievement (Hopgood & Hirst, 2007; Téllez et al., 2024). For example, Soofi and Ahmed (2019) also systematically reviewed the studies on Intelligent Tutoring Systems and concluded that learner performance was the major method for these systems. By analyzing student performance data and feedback interactions, researchers seek to assess the effectiveness of these tools in promoting learning gains and enhancing the quality of education delivery. Understanding the causal mechanisms underlying the relationship between AI-driven feedback and learning outcomes is vital for informing evidence-based educational practices and policies (Cowling et al., 2023; Rad et al., 2023).

Despite the growing interest in AI-based feedback tools in education, there remains a need for a comprehensive bibliometric analysis to synthesize the extant literature, identify research trends, and uncover emerging themes in the field. Such an analysis holds several benefits for advancing our understanding of AI-driven feedback tools and their implications for educational practice. Mainly, a bibliometric analysis provides a systematic and objective overview of the

scholarly landscape surrounding AI-based feedback tools in education. By mapping out the volume of publications, citation networks, and collaboration patterns among researchers and institutions, this analysis offers valuable insights into the dissemination and impact of research in the field. Moreover, a bibliometric analysis facilitates the detection of research gaps and emerging trends within AI-based feedback tools in education. By analyzing keyword co-occurrence and clustering techniques, researchers can identify primary research areas and hotspots of innovation, guiding future inquiry and agenda in the field.

Based on this background, the present study aims to conduct a comprehensive bibliometric analysis of AI-based feedback tools, focusing on the domain of education and covering the publications up to February 2024. By addressing the following research questions, this study seeks to elucidate the main themes, trends, and research areas within the field:

1. What are the main themes and trends in AI-based feedback tools research within the field of education across the available literature?
2. Which countries, academic journals, and affiliations have made significant contributions to the literature on AI-driven feedback tools in education?
3. What are the primary research areas and emerging topics identified as hotspots within the field of AI-based feedback tools in education based on a comprehensive bibliometric analysis?

By undertaking this bibliometric analysis, this study tracks the trajectory of publications over time, revealing an increasing scholarly focus on AI-driven feedback mechanisms in education. Critical thematic areas explored include the role of feedback in enhancing learning outcomes, the integration of AI technologies into educational practices, and the efficacy of AI-based tools in facilitating personalized learning experiences. Through sophisticated bibliometric mapping techniques, such as co-citation and keyword co-occurrence analyses, the study uncovers the intellectual structure of the research landscape. Co-citation analysis identifies articles that are frequently cited together, highlighting seminal works and intellectual connections. On the other hand, keyword co-occurrence analysis reveals common themes and topics based on shared keywords, providing insights into prevalent research areas. These methods were chosen for their ability to systematically map the scholarly landscape, uncovering emerging trends and key contributions in the literature.

Furthermore, this study identifies key contributors (authors, institutions, and countries) engaged in advancing research in this domain, illuminating collaborative networks and citation patterns within the scholarly community. This comprehensive synthesis of the literature serves as a valuable resource for researchers, practitioners, and policymakers alike, offering strategic insights into harnessing the potential of AI technologies to revolutionize teaching and learning practices in education.

2. RELATED WORK

Artificial Intelligence (AI) has influenced various domains from revolutionizing processes to practices, and including education. In recent years, the integration of AI into educational settings has garnered significant attention, with researchers and educators exploring its potential to enhance teaching and learning outcomes (Kim & Adlof, 2024; Li et al., 2024). One featured area of AI application in education is the development and utilization of AI-based feedback tools. These tools leverage advanced algorithms and natural language processing capabilities to provide personalized and timely feedback to learners, aiming to improve their performance and engagement in educational activities (Farshad et al., 2023; Fu et al., 2020; Kumar & Boulanger, 2020).

The integration of AI-driven feedback tools into education is motivated by several factors. Firstly, traditional feedback methods, such as manual grading and assessments, are often time-consuming and resource-intensive for educators (Gao et al., 2024). With growing class sizes

and diverse learner needs, there is a pressing need for scalable and efficient feedback mechanisms to accommodate modern education systems' demands. AI-based feedback tools offer a promising solution by automating the feedback process, thereby freeing up educators' time and resources to focus on more value-added tasks (Zhao et al., 2023). For instance, AI-powered grading systems can quickly evaluate and score large volumes of student essays, providing detailed feedback on writing quality, grammar, and coherence, which can be particularly useful in writing-intensive courses (Yavuz et al., 2024).

Moreover, AI-driven feedback tools have the potential to address the challenge of personalized learning in education. Every learner has unique strengths, weaknesses, and learning preferences, necessitating tailored instructional strategies and feedback mechanisms (Kubsch et al., 2022). However, providing individualized feedback to each student in a traditional classroom setting can be challenging due to time constraints and logistical limitations. AI-based feedback tools overcome this challenge by analyzing vast amounts of student data and generating personalized feedback that is tailored to each learner's needs, including those of children with special needs (Ebenbeck & Gebhardt, 2024). For example, adaptive learning platforms can use AI to assess student performance in real-time and provide customized learning paths and resources, ensuring that each student receives the appropriate level of challenge and support (Gligorea et al., 2023).

Furthermore, AI-driven feedback tools hold promise for promoting self-regulated learning and metacognitive skills development among students (Hopfenbeck et al., 2023; Liang et al., 2024). Research has shown that effective feedback is crucial in facilitating students' ability to monitor and regulate their own learning processes (Zheng et al., 2021). By providing timely and actionable feedback, AI-driven tools empower students to reflect on their performance, identify areas for improvement, and take proactive steps to enhance their learning outcomes (Sharma et al., 2019). For instance, AI-based systems can track student progress over time and provide insights into study habits and learning strategies, encouraging students to develop better self-assessment and planning skills (Li & Kim, 2024). Thus, integrating AI-based feedback tools into educational settings has the potential to foster a culture of continuous improvement and self-directed learning among students.

Despite the potential benefits of AI-based feedback tools, their integration into educational practice is not without challenges. One key challenge is ensuring the validity and reliability of the feedback generated by these tools (Kaldaras et al., 2022). As AI algorithms rely on statistical models and machine learning techniques, there is a risk of bias or error in the feedback provided. Educators and researchers must critically evaluate the accuracy and appropriateness of AI-generated feedback to ensure its utility and effectiveness in supporting student learning (Wang et al., 2024). An example of this issue is the need to regularly update and validate the algorithms used in automated essay scoring to avoid perpetuating any biases present in the training data (Bui & Barrot, 2024).

Additionally, the ethical implications of AI-driven feedback tools require careful consideration (Su & Yang, 2023; Wong et al., 2023). These tools often involve the collection and analysis of sensitive student data, raising concerns about privacy, security, and data protection (Chavez et al., 2023; Williams, 2024). Educators and policymakers must navigate these ethical dilemmas and establish robust safeguards to protect students' rights and interests while using AI's potential in education. For example, implementing strict data anonymization protocols and transparency measures can help decrease privacy risks associated with AI-driven systems (Shahriar et al., 2023).

In the field of research, there has been a growing interest in exploring the design, implementation, and impact of AI-based feedback tools in education. Most of the studies have investigated various aspects of these tools, including their technical underpinnings, pedagogical implications, and effects on student learning outcomes. For example, researchers have

developed AI-driven feedback systems for automated grading and assessment, personalized tutoring, and formative feedback provision (Palocsay & Stevens, 2008; Roldán-Álvarez & Mesa, 2024). These studies have yielded valuable insights into AI-driven feedback tools' potential applications and limitations in educational contexts.

Moreover, scholars have examined the factors influencing the adoption and acceptance of AI-based feedback tools among educators and students (Chiu et al., 2022). Understanding their perceptions, attitudes, and experiences is essential for informing the design and implementation of effective feedback systems. Additionally, research has explored the role of AI-driven feedback in promoting equity and inclusivity in education by addressing disparities in access to personalized support and resources among diverse learner populations (Khoo & Kang, 2022). For instance, AI tools can be used to identify and support at-risk students by providing early intervention strategies tailored to their specific needs (Nimy et al., 2023).

Overall, the literature on AI-based feedback tools in education is massive and complicated, reflecting the diverse interests and perspectives of researchers and practitioners. However, despite the wealth of research available, there remains a need for a comprehensive bibliometric analysis to synthesize the existing literature, identify research trends, and uncover emerging themes. Such an analysis would provide valuable insights into the current state of research on AI-driven feedback tools in education and inform future directions for inquiry and innovation in the field.

3. METHODOLOGY

3.1. Inquiry Process

The study started with a bibliometric analysis to summarize prior studies using AI-based feedback tools to enhance learning experiences. A comprehensive exploration of literature concerning the utilization of AI-based feedback tools to improve learning experiences was conducted by searching the widely recognized electronic database, Web of Science (WoS). This inquiry specifically targeted educational research. On February 22, 2024, the literature within WoS was examined by using the following search string: (feedback AND (educa* OR learn* OR teach*) AND (AI OR artificial intelligence OR chatgpt)).

3.2. Selection Process

While selecting relevant papers, the criteria for inclusion and exclusion (as outlined in Table 1) were defined by following the PRISMA guideline for systematic literature reviews, as proposed by Page et al. (2021). Subsequently, a meticulous selection process was carried out in four distinct stages: identification, screening, eligibility assessment, and final inclusion. This systematic approach ensured a comprehensive and rigorous selection of papers that met the research objectives.

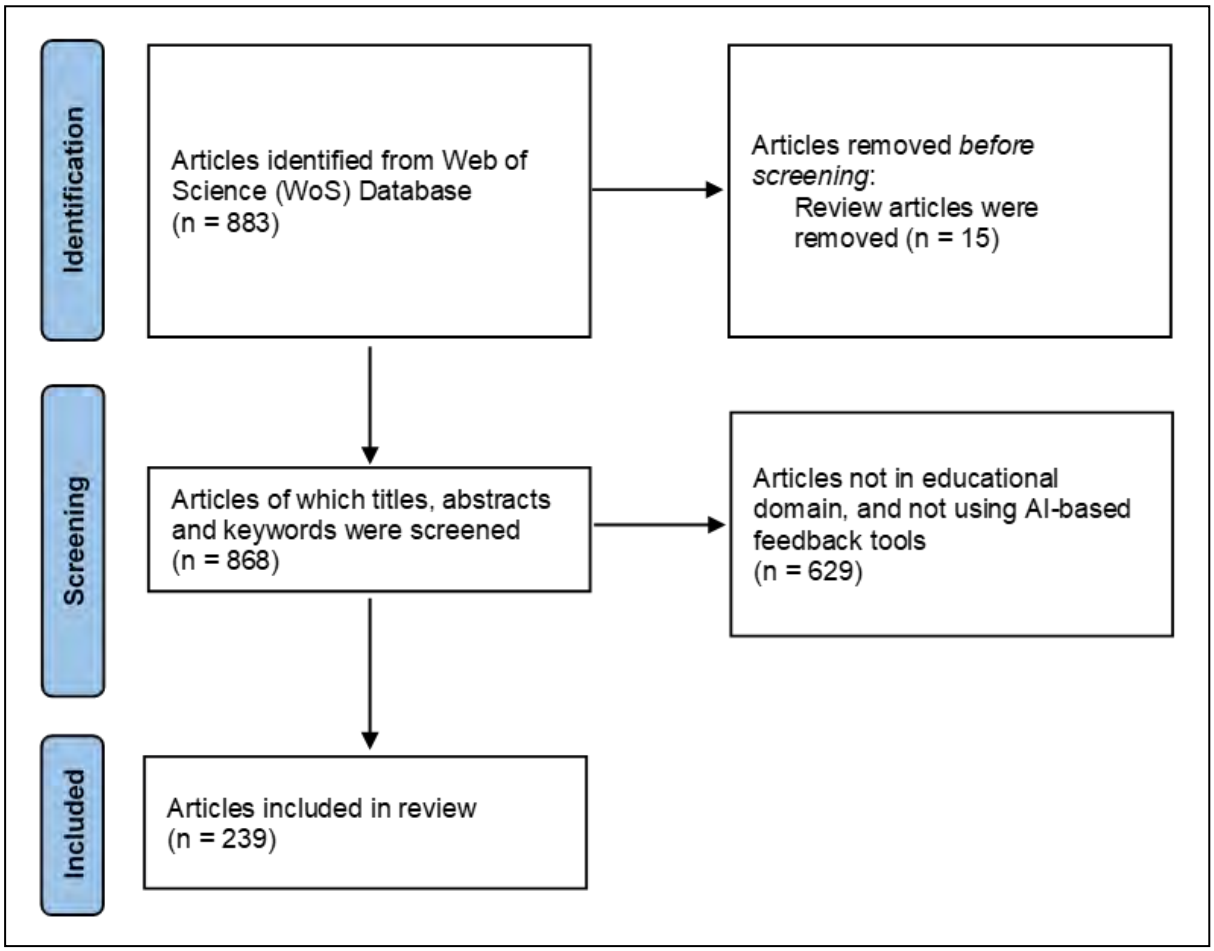
Table 1. *Inclusion and exclusion criteria.*

Inclusion Criteria	Exclusion Criteria
Published in an academic journal	Review, meta-analysis, or conference paper
Written in English	Not written in English
Available in full-text	Not available in full-text
Research paper in the educational domain	Research paper not in the educational domain
Using AI-based feedback tools	Not using AI-based feedback tools

Initially, the review of studies across the WoS database strictly followed predefined inclusion and exclusion criteria, as outlined in Table 1. A total of 883 articles were initially retrieved, from which 15 review articles were identified and removed during the initial screening phase. Following this, the titles, abstracts, and keywords of the remaining 868 articles underwent meticulous inspection to identify those aligning with the inclusion and exclusion criteria.

Consequently, an additional 629 articles not in the educational domain and not using AI-based feedback tools were excluded from consideration in this study. As a result, 239 articles were considered appropriate for inclusion in the current study. A visual representation of the inquiry and selection processes is provided in Figure 1.

Figure 1. *Inquiry and selection process.*



3.3. Data Analysis

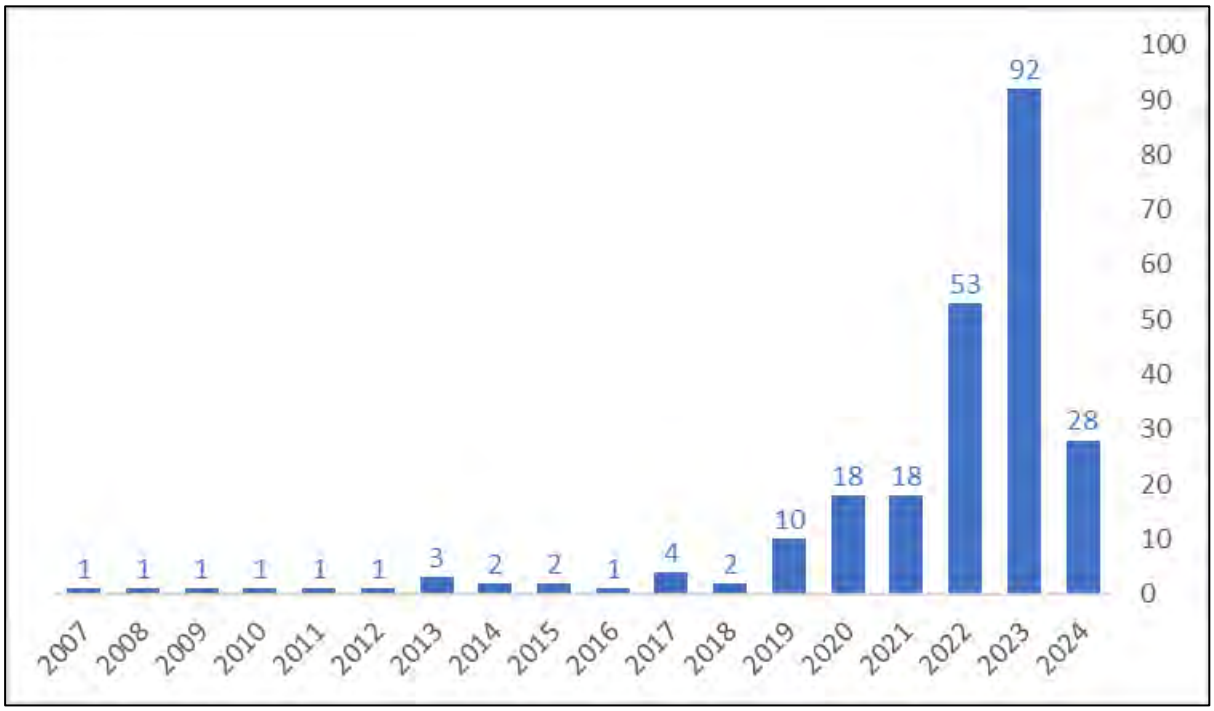
For this study, a comprehensive data analysis was conducted utilizing the WoS database. Initially, a BibTeX file was generated to encompass all pertinent data. Subsequently, the biblioshiny web interface, integrated within RStudio along with the bibliometrix package, facilitated the bibliometric analysis and visualization process (Aria & Cuccurullo, 2017). This approach provided a user-friendly interface, enabling the creation of diverse visual representations, including tables and graphs.

4. RESULTS and DISCUSSION

4.1. Descriptive Analysis

Spanning from 2007 to 2024, the analysis encompassed data extracted from 147 distinct journals among 239 publications. Figure 2 shows a significant increase in the number of publications over the years, particularly from 2019 onwards. The most notable surge occurred between 2022 and 2023, reflecting a growing interest and scholarly attention towards AI-driven feedback mechanisms in educational contexts.

Figure 2. *Number of publications over the years.*



The provided summary table (Table 2) offers a comprehensive overview of the bibliometric analysis conducted on AI-based feedback tools in education. Notably, the annual growth rate of the field stands at an impressive 21.65%, indicative of the increasing interest and scholarly activity surrounding AI-driven feedback mechanisms in educational settings (Kartal & Yeşilyurt, 2024; Song & Wang, 2020).

Table 2. *Summary of bibliometric analysis results on AI-based feedback tools.*

Description	Results
Main Information About Data	
Timespan	2007:2024
Sources (Journals)	147
Documents	239
Annual Growth Rate %	21.65
Document Average Age	2.43
Average citations per doc	7.577
References	10306
Document Contents	
Keywords Plus (ID)	343
Author's Keywords (DE)	829
Authors	
Authors	770
Authors of single-authored docs	28
Authors Collaboration	
Single-authored docs	28
Co-Authors per Doc	3.67
International co-authorships %	25.52

Exploring deeper into the document characteristics, the average age of the included documents is relatively low at 2.43 years, underscoring the currency and relevance of the literature

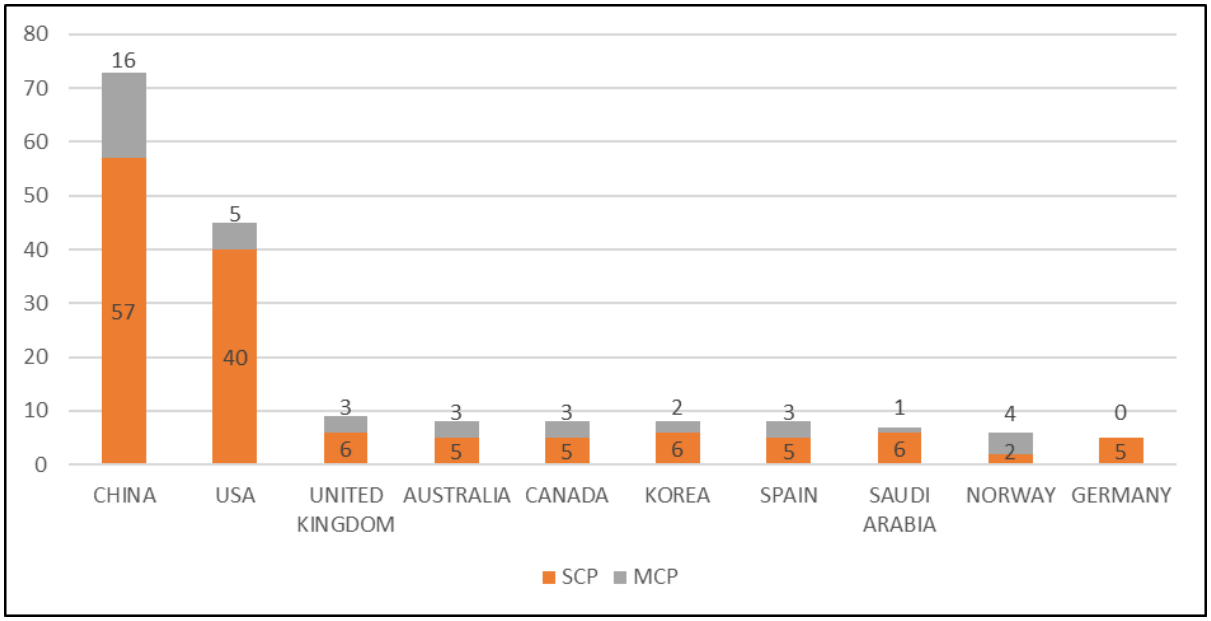
examined. Moreover, each document garners an average of 7.58 citations, indicative of the scholarly impact and influence wielded by research on AI-based feedback tools in education (Bin-Hady et al., 2023). In terms of document contents, a rich tapestry of keywords emerges, with 343 Keywords Plus and 829 author's keywords encapsulating the diverse facets and dimensions explored within the field. This range of keywords reflects the multifaceted nature of research endeavors surrounding AI-based feedback tools, encompassing technical, pedagogical, and evaluative perspectives (Rubio-Manzano et al., 2019). The analysis also sheds light on the collaborative nature of research in this domain, with 770 distinct authors contributing to the body of literature examined. Interestingly, while the majority of documents are co-authored, a notable proportion, 28 documents, are single-authored, indicative of the diverse scholarly contributions within the field. Furthermore, the collaborative landscape extends beyond national borders, with international co-authorships accounting for 25.52% of the total collaborations. This global dimension underscores the transnational collaboration and exchange of ideas characterizing research endeavors in AI-based feedback tools in education (Chen et al., 2023).

In summation, the descriptive analysis of the results provides a nuanced understanding of the breadth, depth, and collaborative dynamics inherent within the scholarly discourse surrounding AI-based feedback tools in education.

4.1.1. *Influential countries*

Figure 3 presents an analysis of the top 10 countries based on the corresponding authors of articles related to AI-based feedback tools in education. The data is segmented into several categories, including the number of articles authored by individuals from each country, the count of single-country publications (SCP), the count of multiple-country publications (MCP), the frequency of each country's appearance, and the ratio of multiple-country publications to total publications.

Figure 3. *Top 10 countries of corresponding authors.*



China emerges as the leading contributor, with 73 articles authored by corresponding authors based in the country. Among these articles, 57 are single-country publications, indicating a significant level of independent research output. However, China also demonstrates substantial collaboration with other countries, as evidenced by 16 multiple-country publications. The United States follows closely behind, with 45 articles attributed to corresponding authors from the country. Of these, 40 are single-country publications showcasing a strong domestic research

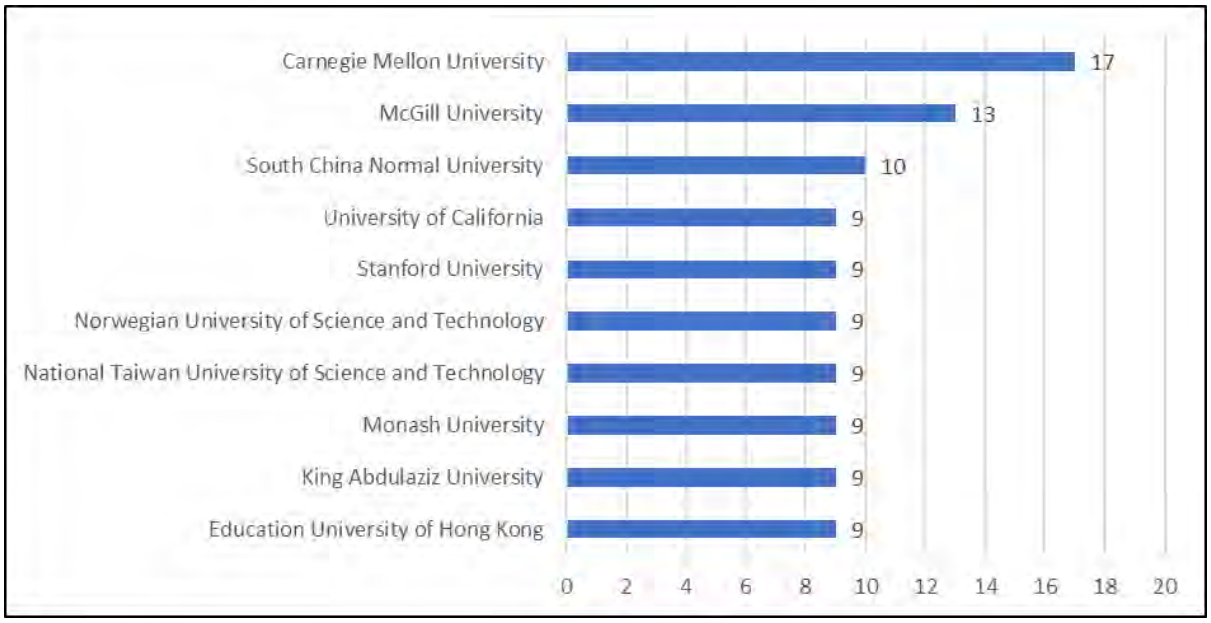
presence. The USA also engages in collaborative efforts with five multiple-country publications. Other notable contributors include the United Kingdom, Australia, Canada, Korea, Spain, Saudi Arabia, Norway, and Germany. Each of these countries has varying levels of research output and collaboration patterns. For instance, Norway stands out with a high MCP Ratio of 0.667, indicating a significant propensity for international collaboration, despite a smaller overall number of articles.

To sum up, this figure underscores the global nature of research on AI-based feedback tools in education, with contributions from diverse geographical locations. It also highlights the prevalence of both independent and collaborative research efforts, providing valuable insights into the international landscape of scholarly inquiry in this field (Zhang et al., 2024).

4.1.2. *Influential affiliations*

Figure 4 presents an analysis of the top 10 affiliations of corresponding authors for articles related to AI-based feedback tools in education. Each affiliation is accompanied by the number of articles attributed to corresponding authors associated with that institution.

Figure 4. *Top 10 affiliations of corresponding authors.*



Carnegie Mellon University emerges as the leading affiliation, with 17 articles authored by corresponding authors affiliated with the institution. It indicates a significant research presence and activity in the field of AI-based feedback tools within the Carnegie Mellon University community. Following closely behind are McGill University and South China Normal University, each with 13 and 10 articles, respectively. These affiliations also demonstrate notable research output and engagement with the topic under investigation. The list of top affiliations also includes institutions such as Education University of Hong Kong, King Abdulaziz University, Monash University, National Taiwan University of Science and Technology, Norwegian University of Science and Technology, Stanford University, and University of California, Irvine. Each of these institutions has contributed a substantial number of articles, showcasing their involvement in research related to AI-based feedback tools in education.

Overall, this figure provides valuable insights into the institutional landscape of scholarly inquiry in this field, highlighting key contributors and hubs of research activity. These affiliations play a crucial role in shaping the discourse and advancement of knowledge in AI-based feedback tools in education.

4.1.3. *Influential journals*

Table 3 provides an overview of the top 10 influential journals within the realm of AI-based feedback tools in education and the number of articles published in each journal.

Table 3. *Top 10 influential journals.*

Journals	# of Articles
International Journal of Artificial Intelligence in Education	14
Education and Information Technologies	9
British Journal of Educational Technology	8
Sustainability	6
Applied Sciences-Basel	5
Frontiers in Education	5
Frontiers in Psychology	5
Interactive Learning Environments	5
Computers & Education	4
IEEE Transactions on Learning Technologies	4

“International Journal of Artificial Intelligence in Education” is at the top of the list with 14 articles. This journal can be seen as a featured platform for scholarly discourse and research dissemination about the intersection of artificial intelligence and education, particularly focusing on feedback mechanisms. Following closely behind is “Education and Information Technologies”, with 9 articles. This journal encompasses a broad spectrum of topics related to educational technology, including the development and application of AI-based feedback tools in educational settings. The “British Journal of Educational Technology” also features prominently on the list, with 8 articles. This journal is renowned for its contributions to the field of educational technology, showcasing research on innovative methodologies and technologies, including AI-driven feedback mechanisms. Other notable journals include “Sustainability” (6 articles), “Applied Sciences-Basel” (5 articles), “Frontiers in Education” (5 articles), “Frontiers in Psychology” (5 articles), “Interactive Learning Environments” (5 articles), “Computers & Education” (4 articles), and “IEEE Transactions on Learning Technologies” (4 articles). Each of these journals plays a significant role in disseminating research findings and fostering scholarly discourse on AI-based feedback tools and their impact on educational outcomes.

Overall, the table provides valuable insights into the scholarly landscape of AI-based feedback tools in education, highlighting key journals that serve as platforms for research dissemination and knowledge exchange in this burgeoning field.

4.1.4. *Influential publications*

Table 4 showcases the top 10 most cited publications related to AI-based feedback tools in education, along with the authors, publication sources, purposes, and the number of citations recorded on the Web of Science (WoS) platform. The publication titled "Automated Writing Assessment in the Classroom" by Warschauer and Grimes (2008) is at the top of the list and published in Pedagogies, which has gathered 105 citations in WoS. This influential work explores the application of an automated essay assessment tool in secondary schools, utilizing interviews, surveys, and classroom observations to assess its effectiveness as a teaching tool and its influence on teachers' instructional practices and students' writing behaviors. Following closely behind is "The Virtual Operative Assistant: An explainable artificial intelligence tool for simulation-based training in surgery and medicine" by Mirchi et al. (2020), published in Plos One, with 92 citations. This study introduces and validates a new framework utilizing explainable artificial intelligence for simulation-based training in surgery, concluding in the development of an automated educational feedback platform, with the aim of enhancing

surgical education by providing participants with immediate, objective feedback based on proficiency benchmarks and expert classification.

Table 4. *Top 10 most cited publications.*

Authors and Year	Source	Purpose	Citations on WoS
Warschauer and Grimes (2008)	Pedagogies	To investigate the implementation and impact of automated essay-scoring software in secondary school classrooms	105
Mirchi et al. (2020)	Plos One	To introduce and validate an automated educational feedback platform designed for simulation-based training in surgery and medicine	92
McLaren et al. (2011)	Computers & Education	To investigate whether employing polite feedback and hints in web-based intelligent tutoring systems impacts student learning outcomes positively	56
Cukurova et al. (2019)	British Journal of Educational Technology	To explore the potential role of artificial intelligence in education as a tool for augmenting human intelligence	51
Chin et al. (2010)	Educational Technology Research and Development	To investigate the effectiveness of Teachable Agents (TA) in K-12 education	51
Rahman and Watanobe (2023)	Applied Sciences-Basel	To investigate the potential impact of ChatGPT on education and research	48
Sharma et al. (2019)	British Journal of Educational Technology	To explore the development of pipelines for educational data leveraging artificial intelligence and multimodal analytics	48
Rose et al. (2019)	British Journal of Educational Technology	To encourage the development of explanatory learner models in education	44
Nazari et al. (2021)	Heliyon	To investigate the effectiveness of an Artificial Intelligence (AI) powered writing tool	37
Bañeres et al. (2020)	Applied Sciences-Basel	To develop and evaluate an accurate predictive model and an early warning system to identify at-risk students	34

Other notable publications include "Polite web-based intelligent tutors: Can they improve learning in classrooms?" by McLaren et al. (2011) in Computers & Education (56 citations), and "Artificial intelligence and multimodal data in the service of human decision-making: A case study in debate tutoring" by Cukurova et al. (2019) in the British Journal of Educational Technology (51 citations). Additionally, "Preparing students for future learning with Teachable Agents" by Chin et al. (2010) in Educational Technology Research and Development (51 citations), and "ChatGPT for Education and Research: Opportunities, Threats, and Strategies" by Rahman and Watanobe (2023) in Applied Sciences-Basel (48 citations), also feature prominently in the list, underscoring their impact on the discourse surrounding AI-driven educational technologies. Furthermore, "Building pipelines for educational data using AI and multimodal analytics: A 'grey-box' approach" by Sharma et al. (2019) in the British Journal of

Educational Technology (48 citations), and "Explanatory learner models: Why machine learning (alone) is not the answer" by Rosé et al. (2019) in the same journal (44 citations), highlight the importance of interpretability and transparency in AI-driven educational systems. Rounding off the list are "Application of Artificial Intelligence powered digital writing assistant in higher education: randomized controlled trial" by Nazari et al. (2021) in Heliyon (37 citations), and "An Early Warning System to Detect At-Risk Students in Online Higher Education" by Bañeres et al. (2020) in Applied Sciences-Basel (34 citations), shedding light on the diverse applications and implications of AI-based feedback tools in educational contexts.

4.2. Keyword Analysis

The word cloud included 50 frequent keywords and was generated from the Keywords Plus data, which highlights the prominent themes and concepts widespread in the literature related to AI-based feedback tools in education (see Figure 5).

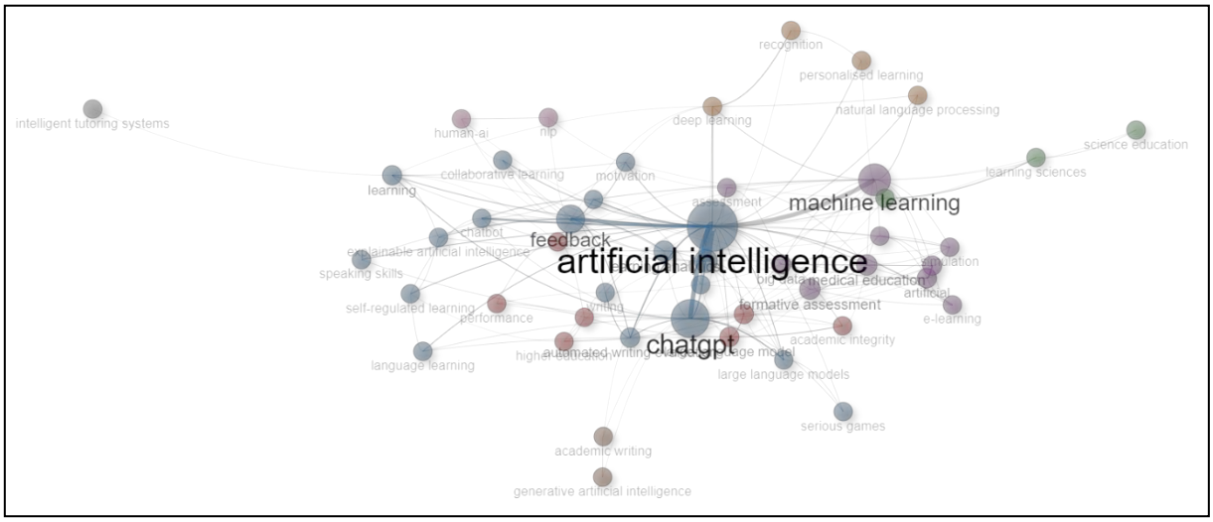
Figure 5. *Most frequent 50 keywords generated from Keywords Plus.*

The most frequently occurring terms, "performance" and "students," underscore the central focus on student outcomes and achievement within educational contexts. These terms suggest a keen interest in assessing and enhancing student performance through the utilization of AI-driven feedback mechanisms (Afzaal et al., 2024). Additionally, the term "feedback", one of the keywords among the search terms of this study, emerges prominently, reflecting the pivotal role of feedback provision in the educational process. This emphasis on feedback aligns with the overarching goal of leveraging AI technology to deliver personalized and timely feedback to students, thereby facilitating their learning and skill development (Heeg & Avraamidou, 2023). Other notable terms include "knowledge," "system," and "education," which highlight the broader context of educational technology and the integration of AI-based systems into educational settings. These terms indicate a multifaceted approach to utilizing AI technology to enhance knowledge acquisition and educational practices (Stojanov, 2023). Furthermore, terms such as "impact" and "quality" suggest a focus on assessing the effectiveness and efficacy of AI-based feedback tools in driving positive educational outcomes. It reflects a critical examination of the impact of technology on teaching and learning processes, with an emphasis on ensuring the quality and integrity of educational interventions (Lee et al., 2024). Finally, the

inclusion of terms like "model" and "English" hints at the diversity of research interests within the field, encompassing topics such as AI modeling techniques and the application of feedback tools in specific educational domains, such as language learning (Kartal & Yeşilyurt, 2024; Shi & Aryadoust, 2024). Overall, the word cloud provides a visually compelling representation of the key themes and concepts underlying research on AI-based feedback tools in education, offering valuable insights into the prevailing trends and interests within the field.

Moreover, the thematic map depicts the author's keywords' distribution, including 50 keywords, in AI-based feedback tools in education, organized into distinct clusters based on their semantic similarities and thematic relevance (see Figure 6).

Figure 6. *Thematic map of author's keywords.*



Cluster 1, labeled "Artificial Intelligence (AI)," encompasses keywords related to artificial intelligence technologies, including "artificial intelligence," "large language model," "higher education," "research," "performance," and "students." These keywords reflect the overarching focus on AI-driven approaches to feedback provision and educational enhancement. For instance, recent studies by Ouyang et al. (2023) and Rad et al. (2023) highlight how AI, particularly large language models, improves feedback quality and student engagement in higher education contexts.

Cluster 2, also under the label "Artificial Intelligence (AI)," predominantly features keywords associated with specific AI applications in education, such as "ChatGPT," "learning analytics," "automated writing evaluation," and "personalized feedback." This cluster highlights the diverse range of AI-based tools and methodologies utilized for educational purposes, including chatbots, analytics platforms, and automated assessment systems (Chang et al., 2023; Ding & Zou, 2024).

Cluster 3, labeled "Educational Technology," encompasses keywords related to educational technology and instructional design, such as "educational technology," "learning sciences," and "science education." These keywords underscore the intersection between AI-driven feedback tools and broader educational technology frameworks, emphasizing the integration of technology into pedagogical practices (Sağın et al., 2023).

Cluster 4, labeled "Machine Learning," comprises keywords related to machine learning algorithms and methodologies, including "machine learning," "assessment," "formative assessment," and "big data." This cluster highlights the increasing adoption of machine-learning techniques for analyzing educational data, providing personalized feedback, and optimizing instructional strategies (Jaleniauskienė et al., 2023).

Cluster 5, labeled "Deep Learning," focuses on keywords associated with deep learning techniques, such as "deep learning," "natural language processing," and "recognition." These

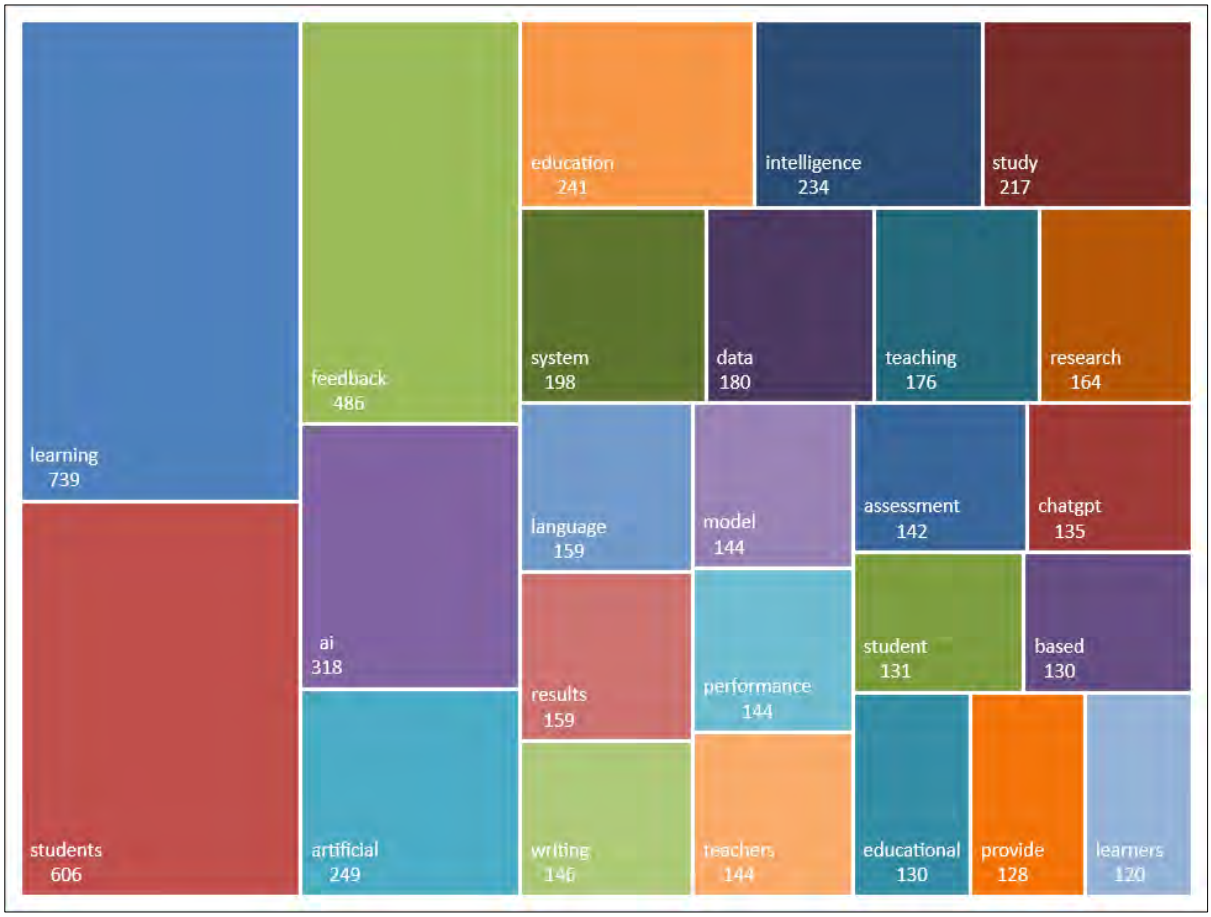
keywords signify the growing interest in deep learning models for processing and analyzing educational data, particularly in the context of natural language understanding and recognition tasks (Li & Mohamad, 2023).

Cluster 6, labeled "Academic Writing," includes keywords related to academic writing and text generation, such as "academic writing" and "generative artificial intelligence." This cluster suggests a specific focus on AI applications in academic writing support and text generation tools (Barrett & Pack, 2023).

Cluster 7, labeled "Human-AI Interaction," encompasses keywords related to the interaction between humans and AI systems, including "human-AI" and "NLP" (Natural Language Processing). This cluster highlights the importance of considering human factors and user experiences in the design and implementation of AI-based feedback tools in education (Wang et al., 2024).

Lastly, Cluster 8, labeled "Intelligent Tutoring Systems," features keywords related to intelligent tutoring systems, such as "intelligent tutoring systems." This cluster focuses on AI-driven tutoring systems that provide students with personalized learning experiences and adaptive feedback. Gu (2024) and Roldán-Álvarez and Mesa (2024) highlight how intelligent tutoring systems leverage AI technologies to tailor educational content and feedback to individual student needs, thereby improving learning outcomes.

Figure 7. *Most frequently used 25 words in abstracts.*



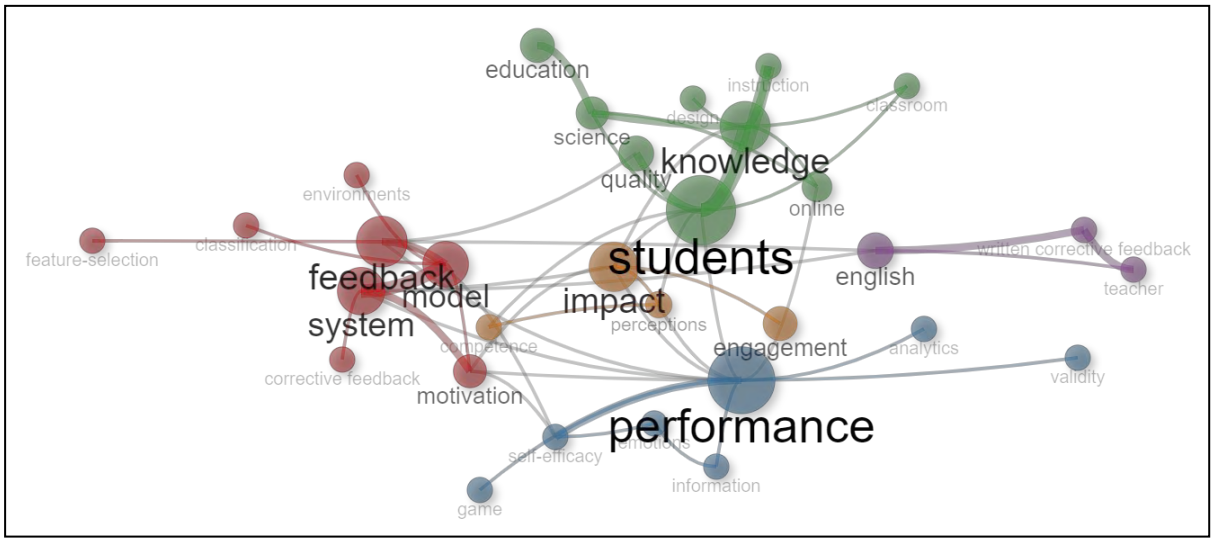
Overall, the thematic map provides a comprehensive overview of the key themes and topics within the field of AI-based feedback tools in education, highlighting the diverse range of AI applications, educational technologies, and pedagogical approaches utilized in research and practice.

Furthermore, Figure 7 presents a visualization of the most frequent 25 words extracted from abstracts of scholarly articles on AI-based feedback tools in education. At the forefront of these words is "learning," indicating a primary focus on educational processes and outcomes within the literature. Subsequently, "students" and "feedback" emerge as prominent themes, underscoring the importance of student engagement and assessment in the context of AI-driven educational interventions. The terms "AI" and "artificial intelligence" reflect the pervasive use of AI technologies in educational settings, particularly in feedback provision and personalized learning experiences. Moreover, key concepts such as "education," "teaching," "research," and "assessment" highlight the multifaceted nature of research endeavors in this field, encompassing pedagogical practices, empirical investigations, and evaluative methodologies. Additionally, the presence of specific terms like "language," "writing," and "ChatGPT" suggests a focus on language learning, writing instruction, and the integration of AI-powered chatbots in educational environments. Overall, the figure provides a brief overview of the prevalent themes and topics addressed in the abstracts of scholarly articles related to AI-based feedback tools in education, offering insights into the scope and depth of research conducted in this domain.

4.3. Conceptual Analysis

The co-occurrence network analysis based on Keywords Plus was utilized to reveal potential research topics along with their relationships and to interpret the knowledge embedded within thematic clusters in the field of AI-based feedback tools in education, providing insights into the relationships between different concepts. The default parameters of the "bibliometrix" package on the web interface "biblioshiny" were employed, including the utilization of the "Walktrap" clustering algorithm with 50 keywords and a minimum of two edges. The obtained five clusters from 31 nodes are depicted in Figure 8.

Figure 8. *Co-occurrence network based on Keywords Plus.*

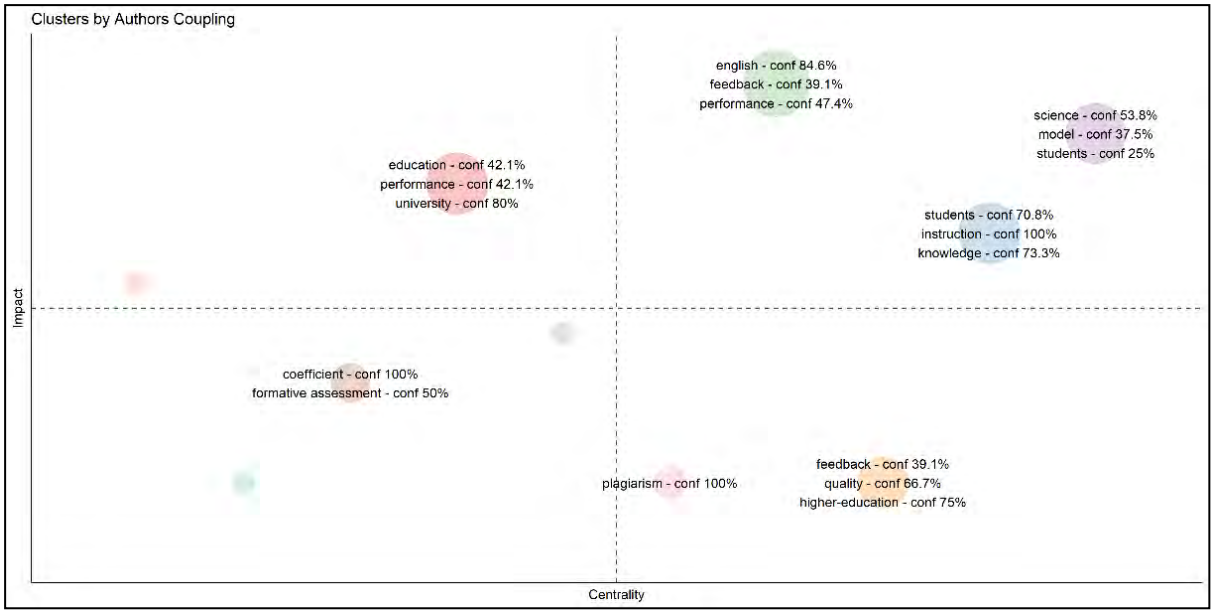


In Cluster 1, terms such as "feedback," "system," "model," and "motivation" emerge as central nodes with high betweenness, closeness, and PageRank centrality scores. These terms represent fundamental components of feedback systems in educational settings, highlighting their significance in research and practice. Cluster 2 focuses on terms related to "performance," "validity," "analytics," and "self-efficacy," indicating a strong emphasis on assessing and optimizing learning outcomes through AI-driven feedback mechanisms. These terms suggest a particular interest in leveraging data analytics and machine learning techniques to enhance performance evaluation and learner motivation. Cluster 3 encompasses terms like "students," "knowledge," "education," and "quality," underscoring the importance of student-centered approaches to education and the pursuit of high-quality learning experiences. These terms

reflect a holistic view of education, emphasizing the acquisition of knowledge and the promotion of educational excellence. In Cluster 4, terms such as "English," "teacher," and "written corrective feedback" suggest a focus on language learning and pedagogical practices in the context of AI-based feedback tools. These terms highlight the role of technology in supporting language instruction and providing personalized feedback to learners. Cluster 5 includes terms like "impact," "engagement," and "perceptions," indicating an interest in understanding the effects of AI-based feedback tools on student engagement and perceptions of learning. These terms suggest a broader consideration of the socio-emotional aspects of education and the implications of technology integration on student outcomes. Overall, the co-occurrence network offers a comprehensive view of the interconnected nature of key concepts in AI-based feedback tools research, illustrating the multidimensional relationships between different aspects of educational practice and technology utilization.

Moreover, Figure 9 illustrates clustering by coupling among the authors measured by Keyword Plus, with cluster labeling also based on Keyword Plus and impact measured by global citation score. The following parameters were utilized: (i) restricting the analysis to 250 words, (ii) setting a minimum cluster frequency of five occurrences, (iii) assigning three labels per cluster, and (iv) employing "walktrap" as the clustering algorithm. Each cluster is represented by a distinct color, and the nodes within each cluster are labeled with keywords associated with the cluster.

Figure 9. *Clustering by coupling among the authors.*



Cluster 1: This cluster is characterized by keywords such as "education," "performance," and "university." These keywords suggest a focus on educational performance within academic institutions, with a significant impact indicated by a high global citation score.

Cluster 2: Keywords in this cluster include "students," "instruction," and "knowledge," indicating a focus on student learning and instructional practices. The high centrality and impact scores suggest that research within this cluster has considerable influence in the field.

Cluster 3: This cluster comprises keywords such as "English," "feedback," and "performance," suggesting a focus on language learning and feedback mechanisms. The high impact score indicates that research within this cluster significantly contributes to advancements in these areas.

Cluster 4: Keywords in this cluster include "science," "model," and "students," indicating a focus on scientific education and modeling approaches. The high centrality and impact scores

suggest that research within this cluster has a substantial influence on educational practices related to science.

Cluster 5: This cluster includes keywords such as "feedback," "quality," and "higher education," suggesting a focus on the quality of feedback mechanisms within higher education settings. The absence of an impact score suggests that research within this cluster may be relatively less cited compared to others.

Cluster 6: Keywords in this cluster include "coefficient" and "formative assessment," suggesting a focus on quantitative assessment methods. The moderate impact score indicates that research within this cluster contributes to advancements in assessment practices.

Cluster 7: This cluster comprises the keyword "plagiarism," indicating a focus on academic integrity and plagiarism detection methods. The absence of an impact score suggests that research within this cluster may be less cited compared to others.

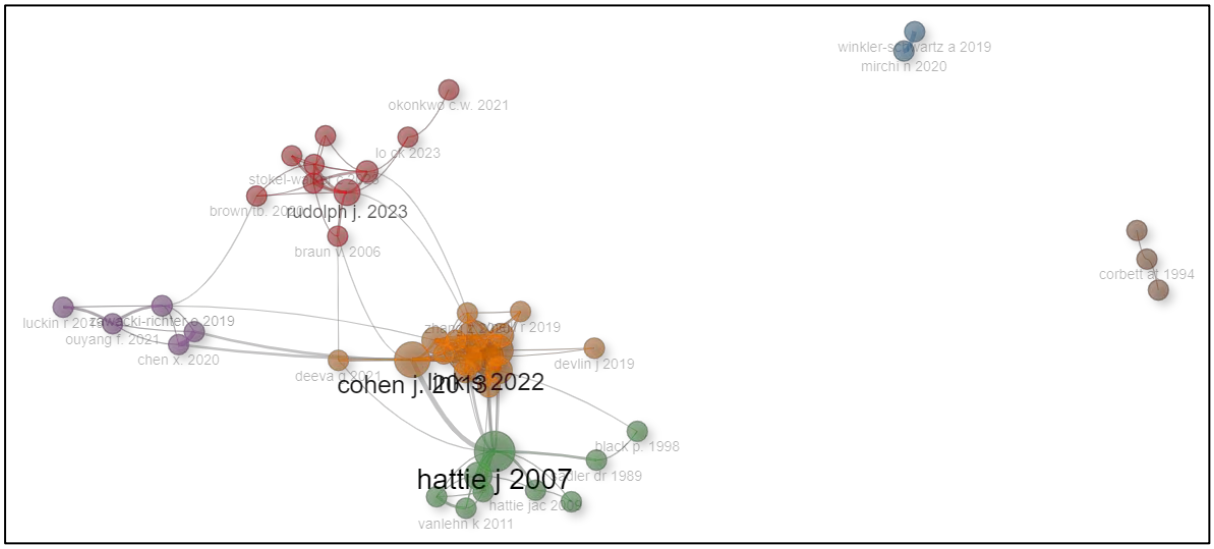
Cluster 8: Keywords in this cluster include "formative assessment," "quality," and "teacher," suggesting a focus on assessment practices and teacher training. The moderate impact score indicates that research within this cluster contributes to advancements in educational assessment.

Cluster 9: This cluster includes the keyword "perceptions," suggesting a focus on understanding learners' perceptions in educational contexts. The absence of an impact score suggests that research within this cluster may be less cited compared to others.

Cluster 10: Keywords in this cluster include "ai" and "curriculum," indicating a focus on integrating artificial intelligence into curriculum development. The moderate impact score suggests that research within this cluster contributes to advancements in AI-based educational technologies.

Furthermore, Figure 10 identifies six clusters with notable works in the field of AI-based feedback tools in education. It reveals distinct clusters of authors based on shared citation patterns, each characterized by unique centrality metrics. The default parameters of the "bibliometrix" package on the web interface "biblioshiny" were employed, including the utilization of the "Walktrap" clustering algorithm.

Figure 10. *Co-citation network analysis based on authors.*



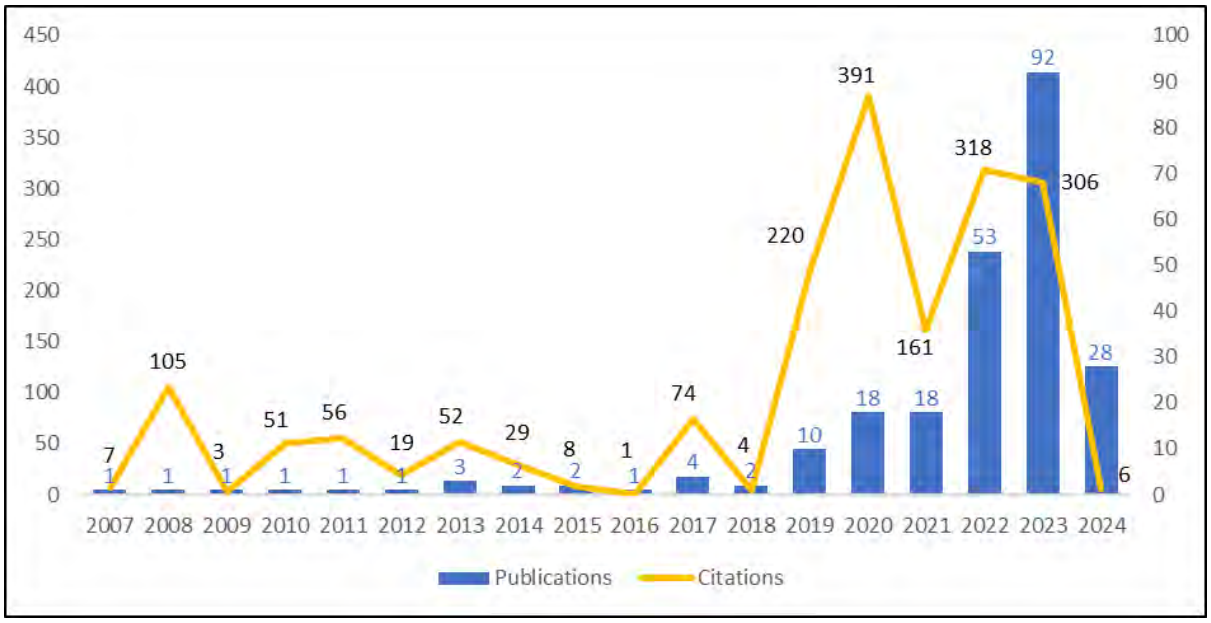
Cluster 1, dominated by recent authors like Rudolph J. and Kasneci E., shows moderate to high betweenness centrality, suggesting their pivotal roles as bridges between other authors. Cluster 2 includes authors such as Mirchi N. and Winkler-Schwartz A., notable for their high closeness centrality, indicating close connectivity within their cluster. Cluster 3, featuring Hattie J. and

Shute VJ, stands out with significant PageRank scores, indicating their substantial citation impact. Clusters 4, 5, and 6 display diverse profiles with authors like Zawacki-Richter O. and Cohen J. demonstrating varying degrees of influence across their respective networks. Overall, these clusters provide insights into the structure and dynamics of scholarly communication within the field, highlighting key authors and their roles in knowledge dissemination and integration.

4.4. Comparative Analysis

The chart below provides a comprehensive overview of the evolution of research output and its corresponding impact in the realm of AI-based feedback tools in education, spanning from 2007 to 2024 (see Figure 11). This analysis is particularly insightful when contextualized alongside significant developments in the field, such as the release of ChatGPT, an advanced chatbot developed by OpenAI, launched on November 30, 2022.

Figure 11. *Comparison of the number of publications and citations.*



Between 2007 and 2018, the number of publications remained relatively modest, with periodic peaks indicating a gradual but steady accumulation of scholarly work in the domain. However, citation rates during this period varied, with notable spikes observed in 2008, 2011, and 2013. These peaks suggest that despite the limited number of publications, certain research findings garnered substantial attention and recognition within the academic community.

The landscape shifted noticeably post-2018, marked by a significant surge in both the number of publications and their corresponding citations. This trend aligns with the growing interest and investment in AI technologies, including chatbots, for educational purposes. It's worth noting that the release of ChatGPT in late 2022 might have acted as a catalyst for this surge in research activity (Su et al., 2023), contributing to the exponential growth observed in publications and citations in 2022 and 2023.

Between 2019 and 2024, there was an unprecedented surge in research output, marking a period of intense scholarly engagement and innovation within the field. The publication count escalated from 10 in 2019 to a peak of 92 in 2023, showcasing a remarkable expansion of research endeavors. It's worth noting that this study included publications up to February 22, 2024. Given the substantial number of articles published in this short timeframe, it's plausible that the total publication counts for 2024 may surpass that of 2023 by year-end. This surge can be attributed to various factors, including advancements in AI technologies, enhanced

accessibility to research resources, and the growing recognition of the potential of AI-based feedback tools to improve learning outcomes (Sallam et al., 2023).

Simultaneously, the citation rates mirrored this growth trajectory, demonstrating a proportional increase in the impact of research findings during the same period. The surge in citations signifies the growing influence of research in shaping scholarly discourse and informing educational practices, driven by the proliferation of innovative AI-based feedback tools like ChatGPT.

In summary, the comparative analysis underscores the dynamic interplay between research output and impact over time in the field of AI-based feedback tools in education. The release of ChatGPT and other advancements in AI technologies have undoubtedly catalyzed a surge in research activity, shaping the trajectory of scholarly inquiry and innovation for enhancing educational practices.

5. CONCLUSION and SUGGESTIONS

The comprehensive analysis conducted on AI-based feedback tools in education provides invaluable insights into the dynamic and evolving landscape of scholarly inquiry within this domain. Through a meticulous examination of publication trends, citation rates, thematic trends, and collaborative dynamics, this study offers a nuanced understanding of the multifaceted nature of research endeavors and the transformative potential of AI technologies in educational settings.

The descriptive analysis serves as a foundational pillar, offering a panoramic view of the scholarly discourse surrounding AI-driven feedback mechanisms. By investigating document characteristics such as publication trends, citation rates, and keyword distributions, this analysis reveals the vitality and relevance of the literature examined. Notably, the exploration of influential countries, affiliations, journals, and publications underscores the global nature of research efforts and the pivotal role of diverse stakeholders in shaping the discourse and advancing knowledge in this field.

Furthermore, the keyword and conceptual analyses provide deeper insights into the prevailing themes and topics within the literature, illuminating the central focus on student performance, feedback provision, and AI technologies in educational contexts. Through co-occurrence networks, the interconnectedness of key concepts and the intricate relationships between different aspects of educational practice and technology utilization are revealed, highlighting the holistic and interdisciplinary nature of research endeavors.

Moreover, the comparative analysis offers a temporal perspective, charting the evolution of research output and impact over time. The exponential growth observed in publications and citations, particularly following significant developments such as the release of ChatGPT, underscores the transformative potential of AI-based feedback tools and the need for continued exploration and innovation in this rapidly evolving field.

Moving forward, it is crucial to address specific gaps in the literature and explore uncharted territories. Future research should focus on investigating the ethical implications of AI-based feedback tools in education, particularly concerning privacy, data security, and potential biases in AI algorithms. Understanding these concerns is essential for developing responsible and equitable deployment strategies.

While AI-based feedback tools offer significant advantages in enhancing educational practices, they also present ethical and social challenges that must be addressed. Concerns around data privacy and security are paramount, as these tools often require the collection and analysis of sensitive student data. Ensuring robust data protection measures and adhering to privacy regulations is crucial to maintain trust and safeguard student information. Additionally, the potential for bias in AI algorithms poses a risk of perpetuating existing inequalities in education. It is essential to critically assess and mitigate biases in AI-driven feedback to ensure fair and

equitable learning opportunities for all students. Addressing these ethical considerations is vital for the responsible deployment of AI technologies in education.

The current study provides a comprehensive bibliometric analysis of AI-based feedback tools in education, revealing significant trends, influential works, and key contributors in the field. While the reliance on the Web of Science database is a limitation, the insights gained are invaluable for understanding the scholarly landscape. Besides, longitudinal studies are imperative to assess the sustained impacts of AI-based feedback tools on student learning outcomes and educational practices over time. By conducting longitudinal research, researchers can better understand how these technologies influence learning trajectories, educational equity, and overall academic achievement.

Additionally, future studies could explore emerging technologies and innovative pedagogical integration strategies to enhance the effectiveness and inclusivity of AI-driven feedback mechanisms. Collaborative efforts across disciplines will be essential in harnessing the full potential of AI technologies to foster positive educational outcomes and address evolving challenges in the field.

Declaration of Conflicting Interests and Ethics

The authors declare no conflict of interest. This research study complies with research publishing ethics. The scientific and legal responsibility for manuscripts published in IJATE belongs to the author.

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