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Global Trends in the Use of Artificial Intelligence in Dental Education: A Bibliometric Analysis

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ABSTRACT

Introduction: The aim of this study was to examine the application of artificial intelligence (AI) and generative AI (GAI) in dental education through a comprehensive bibliometric analysis, with the goal of identifying potential future research areas in this field.

Materials and Methods: Data were obtained from the Web of Science and Scopus databases, with no date restrictions. The inclusion criteria encompassed research articles, reviews and proceedings papers focused on the use of AI in dental education. The Bibliometrix R package was used for data analysis.

Results: A total of 54 documents were analysed, revealing a significant increase in publications from 2021 to 2024. The *Journal of Dental Education* was identified as the most prolific source, with the United States leading in terms of contributions. The findings showed a growing interest in AI's potential to transform dental education, with significant contributions from a diverse set of global authors and institutions. Several key themes were identified, including 'large language models', 'chatbots' and 'clinical decision support systems'. The citation analysis highlighted influential papers, including those by Thurzo et al. (2023) and Yüzbaşıoğlu (2021).

Conclusion: There is a growing interest in the use of AI and GAI in dental education. However, further research, particularly experimental studies, is essential to fully understand their impact on educational outcomes in dentistry. Key areas for exploration include the application of AI for personalised learning, the integration of chatbots as educational tools to support students, and the use of AI for training and assessing practical skills.

1 | Introduction

Artificial Intelligence (AI) has evolved significantly since the original postulates by McCarthy in 1956 [1], resulting in tools that can generate (Generative Artificial Intelligence [GAI]) large amounts of new information. The functioning of GAI is based on pre-existing AI workflows, Big Data algorithmsE and their combinations, with the objective of significantly increasing the ability to produce new content [2]. Recently, GAI has optimised its performance by using a pre-trained model built from a large corpus of data extracted from the Internet, with the aim of generating different material each time [2]. Not only can written material be obtained from GAI tools, but also images or music. Moreover, AI is considered to be able to analyse medical images through deep learning training to identify disease-related patterns [3]. In dentistry, the benefits of incorporating AI into daily practice is being widely recognised [4]. Applications for diagnostic procedures [5],

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treatment planification and different functions focused on patient education and care or preventive dentistry can illustrate the current situation [6, 7].

Education in health sciences has also been impacted by the emergence of accessible GAI-based tools in recent years, and their advantages and disadvantages have been widely discussed [8]. GAI applications in education include tools that students can use autonomously to complete their tasks and those that the professor can use during class as a tool for dynamisation, attracting student's attention and making the teaching-learning process easier and deeper. As a result, dental students' learning outcomes acquisition could benefit from the use of AI in academic environments. Nevertheless, although topics, such as computing sciences and their relationship with healthcare have already been included in current dental curricula, the inclusion of AI and GAI tools and their integration into international educational guidelines and into defined intended learning outcomes have not been fully achieved yet [9].

Conversely, the high potential use of AI in education has raised certain concerns from an ethical point of view, especially those related to transparency in its use, privacy in handling clinical data, biases related to the proper characteristics of the AI functioning, and the devaluation of human work, reasoning and judgement [10]. UNESCO published a consensus document on AI and education, recommending the incorporation of AI into educational policies for students' benefit, in such a way that its advantages outweigh potential drawbacks and risks described above, and positioning AI as a tool to enhance rather than replace educators [11].

Bibliometric analysis involves the systematic exploration of existing literature in a transparent and reproducible manner [12], and provides valuable information about the development, key contributors and thematic trends in a field [13]. This approach is particularly useful for identifying knowledge gaps, mapping research networks and understanding how a topic is being integrated into a field [12]. Thus, the objective of this bibliometric study was to examine the current research landscape in the field of AI in dental education, including GAI, and to identify gaps and potential future directions for research in this area.

2 | Materials and Methods

2.1 | Information Sources and Search Strategy

A systematic search was carried out on June 13, 2024 using the Web of Science (WoS) Core Collection. The following search strategy was used: ('artificial intelligence' OR 'AI' OR chatgpt OR perplexity) AND (education OR teaching OR learning OR assessment OR evaluat* OR exam* OR student* OR professor*) AND (dentistry OR dental OR odontology). The same search was conducted in Scopus, due to its significant differences in coverage, indexing and search functionality compared to WoS. No date filter was applied, and the last query date was made on July 9, 2024.

The articles were selected based on the following criteria.

Inclusion criteria

- Articles focused on the use of AI or GAI specifically for educational purposes in dental education.
- Studies evaluating the role of AI or GAI in supporting teaching, curriculum development or learning for dental students, including both undergraduate and postgraduate populations.
- Research involving dental students (both undergraduate and postgraduate) in the context of formal or informal educational settings.
- Research articles, proceedings papers, reviews and systematic reviews that explicitly address the use of AI or GAI in dental education.
- Papers involving students in other health sciences, as long as they include dental students.

Exclusion criteria

- Studies focused on non-educational applications of AI or GAI, such as diagnostic tools or AI performance evaluation.
- Research conducted in medical or health sciences education without specific relevance to dentistry.
- Papers that only examine the functionality of AI or GAI to evaluate the accuracy or performance of the tool without an educational component.
- Studies that used AI or GAI for education, dental care or diagnosis in patients.

2.2 | Article Selection

Two reviewers (M.I. and J.P.) double-checked the title, abstract and full text (if needed) of each publication based on the inclusion and exclusion criteria. The Cohen kappa was calculated to determine the inter-rater reliability. Disagreements between them were resolved by consensus.

2.3 | Data Analysis

The data analysis was conducted using the R package Bibliometrix [12], version R4.3.0, and the Biblioshiny application, which provides a web interface for Bibliometrix.

Both Scopus and WoS were searched to ensure comprehensive coverage of relevant literature. These platforms may yield different results due to their unique approaches to keyword mapping, journal coverage and metadata indexing [14]. By incorporating both, the study ensures a more thorough retrieval of relevant literature, reducing the likelihood of missing key studies due to platform-specific search biases [15]. However, due to differences in metadata structure between the two databases, the articles identified in Scopus were subsequently searched in WoS and were only incorporated if they were indexed in the latter. WoS

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was used as the reference database due to its enhanced metadata and robust information retrieval capabilities [16]. These attributes ensure optimal integration of the exported data with the Bibliometrix platform. The identified articles were exported in plain text format.

The first step was to perform a descriptive analysis of the bibliographic data frame.

The second step was to determine the impact of the sources and the authors. Bradford's law was used to analyse the sources [17]. A citation analysis was used to identify the most influential authors, considering both the total number of citations and the average number of citations per document. The dominance ranking of sources and authors was calculated using the h, g and m indexes. The h-index is defined as the number of published articles (h) that have been cited at least h times within this collection [18]. The g-index is a modification of the h-index that gives more weight to highly cited articles [19]. The m-index is a modification of the h-index that incorporates the number of years since the first article was published in the journal [20].

In addition, international collaborations and the geographical distribution of authors were analysed to identify the most influential institutions and countries. Social network analysis metrics, such as Betweenness, Closeness and the PageRank index, were applied to evaluate collaborative networks among authors, institutions and countries. These metrics assist in the identification of significant nodes within the network that facilitate communication and information flow [21]. The clustering algorithm utilised was the Walktrap algorithm [22].

The third step involved analysing the documents according to the number of citations and the co-citation network, using the Walktrap algorithm, the most frequent keywords and trending topics. In addition, a general thematic distribution and a distribution by year were performed using the edge betweenness clustering algorithm [23]. In order to facilitate the analysis, synonymous terms were combined as follows: (a) dental education, dental students, education, dental student; (b) artificial intelligence, AI; (c) attitude, attitudes; (d) dental curriculum, curriculum; and (e) chatbots, chatgpt.

3 | Results

3.1 | Overview

The workflow of the study, from search strategy to screening and included records, is shown in Figure 1. After removing duplicates, the agreement between reviewers selecting articles based on title or abstract was 97.7% and $\kappa = 0.765$. Subsequent review of potentially eligible studies had an agreement of 95.5% and $\kappa = 0.837$.

After filtering, a total of 54 documents were included, with contributions from 253 authors (Table S1). Three documents (5.55% of the total) were single-authored publications. The included documents were published between 2021 and 2024, showing a general increasing trend of 50.79% over time (2021, $n = 7$; 2022, $n = 7$; 2023, $n = 16$; 2024, $n = 24$) (Figure 2, Table S2). Due to the relatively recent concentration of literature on this topic, the average number of citations per year is currently low, with papers from 2021 and 2023 representing the highest level of citation activity (Figure 2, Table S2).

3.2 | Source Analysis

The 54 retrieved documents were published in 32 sources (Table S1). The *Journal of Dental Education* had the highest number of publications ($n = 13$) and the highest local impact h-index (h-index = 4). It was followed by the *Cureus Journal of Medical Science* ($n = 4$; h-index = 2) and the *European Journal of Dental Education* ($n = 4$; h-index = 2) (Table S3). According to Bradford's Law, these three journals contained most of the papers, indicating their central importance in the field (Figure S1). In terms of g-index, the *Journal of Dental Education* and the *European Journal of Dental Education* had the highest local impact, with g-indices of 9 and 4, respectively (Table S3). Local impact refers to the number of times that a document/journal is cited by other documents from this collection.

3.3 | Author and Country Analysis

There were 13 authors in the field of AI applied to dental education, with two publications each. The most productive authors in a single year were Professors Kavadella A and Rehman A in 2024, with two publications each [24–27]. Professors Angelov N, Chang J and Glick A had the longest continuous period of publication, with two joint publications, one in 2022 [28] and one in 2024 [29] (Figure 3). Professors Afrashtehfar KI, Strunga M, Surovková J, Thurzo A, Urban R and Yüzbasioglu E had the highest number of total citations. The first five authors received 76 citations for the same document [30], and Yüzbasioglu E received 45 for his paper [31] (Table S4).

The three institutions that made the most significant contributions to this topic were the King Saud bin Abdulaziz University for Health Sciences, the University of London and the University of Texas Health Science Center Houston, which is part of the University of Texas System (Table S5).

According to the corresponding authors, the most relevant country was the United States, with nine published documents (16.7%), nearly twice as many as the second and third countries on the list, Saudi Arabia with 5 (9.3%) and India with four articles (7.4%). However, the level of international collaboration was comparatively lower, with a shared authorship in only 22.2% of the articles, compared to 40% in Saudi Arabia and 25% in India (Table S6). Denmark exhibited the highest level of collaboration, with 100% international authorship from two articles on the topic (Table S6). Regarding citations, however, Slovakia ranked first with 76 citations (an average of 76.0 per article). The United Kingdom, Turkey, the United States and Saudi Arabia received 56 (28.0), 51 (25.50), 49 (5.40) and 48 (9.60) citations, respectively (Table S7).

Collaborations among authors, institutions and countries were analysed using a collaborative network. The results of

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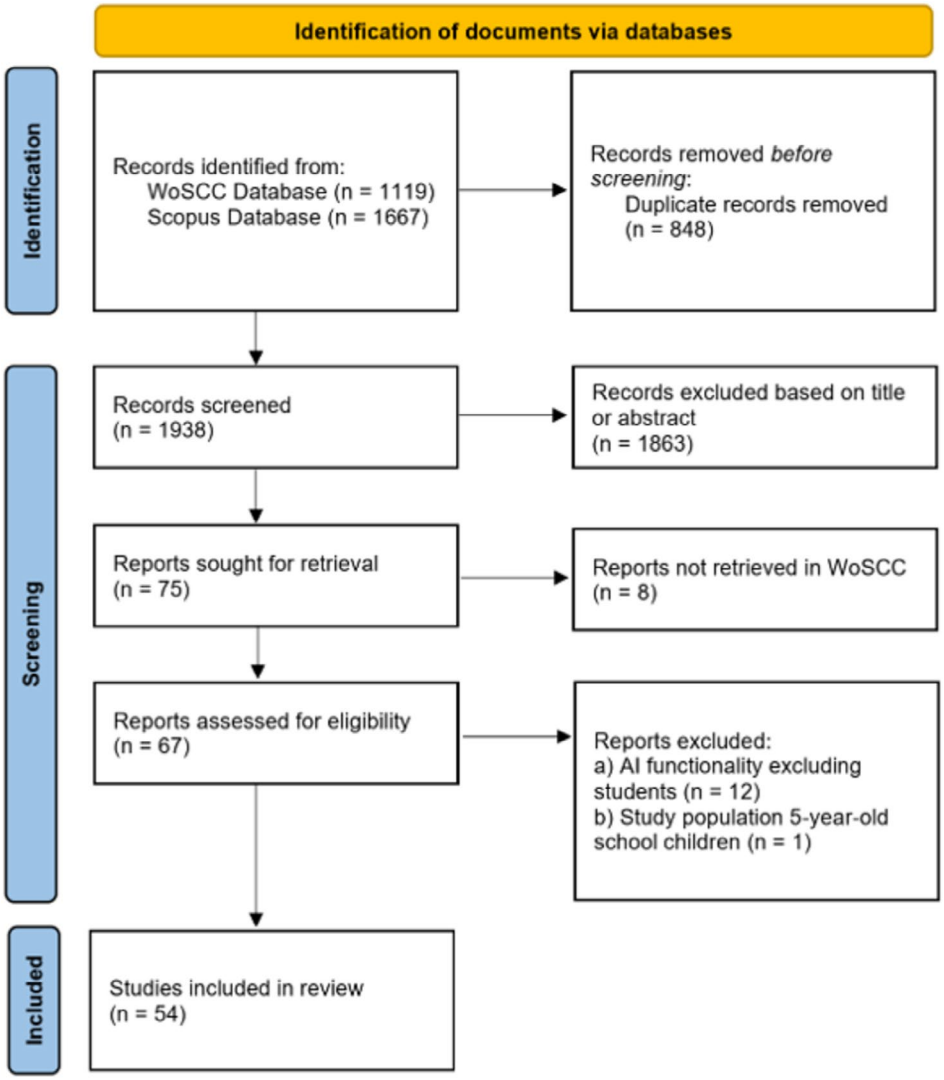

FIGURE 1 | Number of articles retrieved from the databases, criteria and documents selected for the bibliometric analysis.

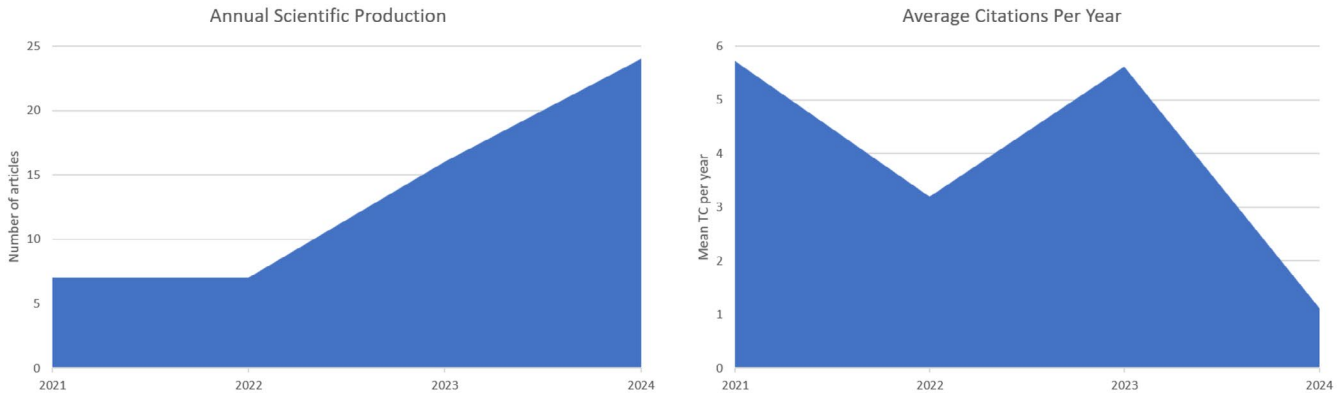

FIGURE 2 | Annual scientific production and average citations per year of the documents included in this bibliometric analysis.

each centrality calculation are presented in Tables S8–S10, respectively. Chaurasia A, Fontana M, Schwendicke F and Uribe SE were identified as the most relevant authors based on the PageRank index (Figure S2) and exhibited the highest Betweenness degree (Table S8), which could be an indicator of their influence on the flow of information.

In terms of institutional relevance, the University of London and the University of Michigan were identified as the most significant institutions (Figure 4). The University of London formed a cluster together with Cardiff University and Egyptian institutions (Egyptian Knowledge Bank), among others, and exhibited the highest degree of Betweenness (Table S9).

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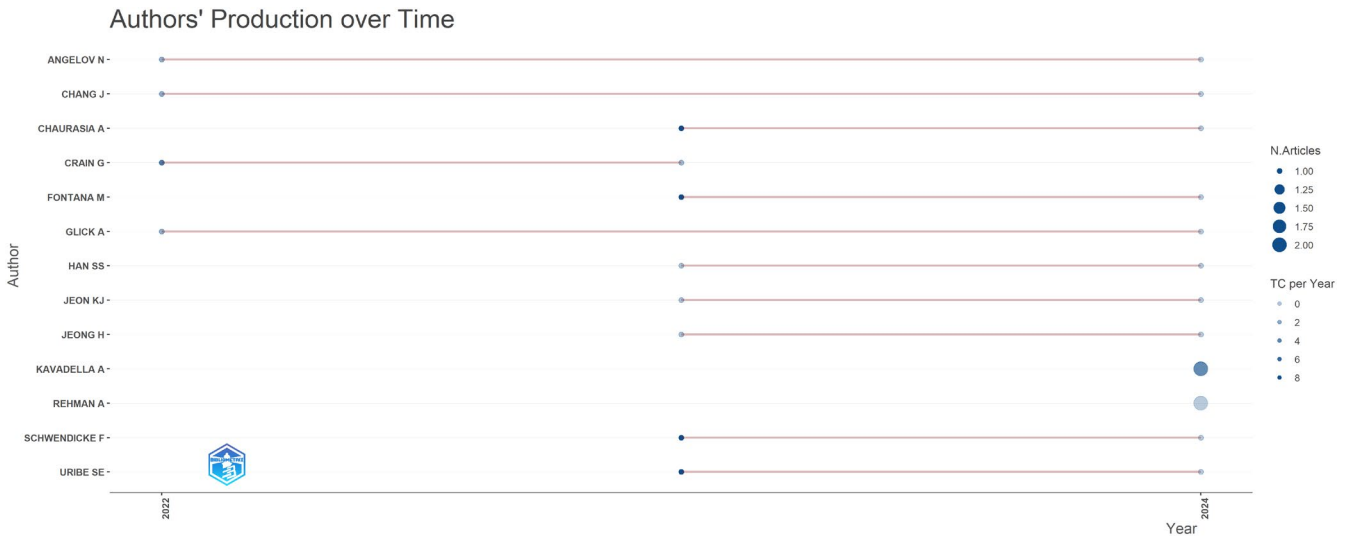

FIGURE 3 | Production of the top 13 authors over time. The graph illustrates the volume of articles published in a given year, represented by a proportional increase in the size of the circle. The effect is measured by the annual citation, shown by the colour of the circle (the darker the colour, the higher the impact of the article).

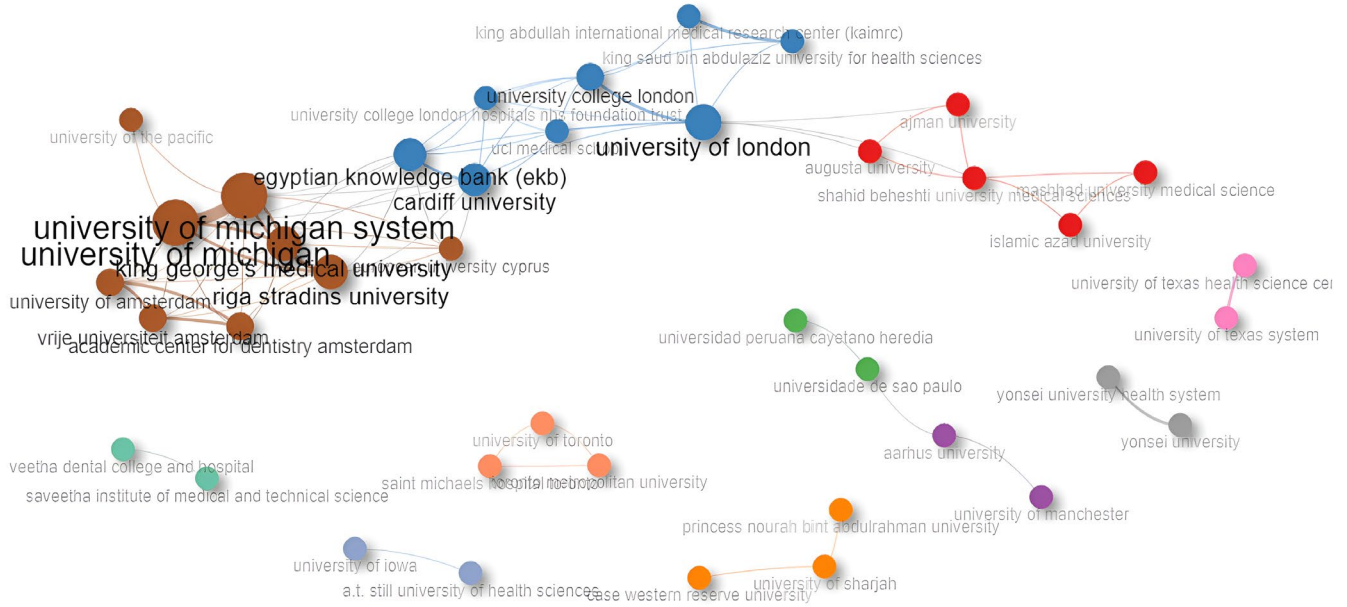

FIGURE 4 | Map of collaboration networks among institutions. The nodes represent institutions and are proportional to the frequency of occurrence of the institution in question. The edges represent the connections between them, with the thickness of the edges indicating the frequency of occurrence between two of them. The relative positions of the nodes indicate the interrelation between them. The colours represent the clusters to which each institution belongs.

The countries with the highest relevance in this field were the United States, the United Kingdom and Germany (Figures S3 and S4), which clustered together. The flow of information was primarily directed through the United Kingdom, the United States and the United Arab Emirates based on their higher degree of Betweenness. These countries, together with Germany, also showed the highest degree of closeness within this collaborative network (Table S10). This would allow these core countries the ability to effectively disseminate information from their position to other countries.

3.4 | Document Analysis

3.4.1 | Main Information

According to the WoS classification, the collection consisted of 41 articles, six early access articles, one proceedings paper and six reviews (Table S1). A manual categorisation of the collection classified 42 documents as research articles, of which 11 included at least two experimental groups, 25 were qualitative studies, two were pilot studies and four systematic reviews (with

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or without meta-analyses). The papers addressed a range of subjects, including the usefulness of GAI versus traditional methods as a source of information, the potential of AI as a learning tool for clinical procedures, the applicability of GAI as an assessment tool and knowledge, awareness and perceptions towards AI. The remaining 12 papers included eight other reviews, two position papers and two perspective papers. Table 1 depicts all studies included in this analysis, and Table S11 provides a summary of the main findings.

3.4.2 | Advanced Information

The most cited document worldwide, according to the WoS database, was a review by Thurzo et al., a professor at Comenius University in Slovakia, on AI in dental education, with 76 citations [30]. The second most cited was a study on the evaluation of dental students' knowledge and attitudes towards AI and its potential applications in dentistry, conducted in Turkey in 2021 and authored by Yüzbaşıoğlu, with 45 citations [31]. The third most influential paper was on the perception of AI by medical and dental students worldwide, authored by Bisdas et al. [60], a professor at University College London, which received 42 citations (Table S12). In terms of the co-citation analysis, the paper by Yüzbaşıoğlu [31] showed the highest Betweenness and PageRank value (Table S13).

TABLE 1 | References of the studies included in the bibliometric analysis.

Type of article	References
Systematic reviews with meta-analysis	[32]
Systematic reviews	[33–35]
Quantitative studies	[24, 28, 29, 36–43]
Pilot studies	[44, 45]
Qualitative studies	[25–27, 31, 46–66]
Scoping reviews	[67, 68]
Narrative reviews	[69]
Review articles	[30, 70–73]
Perspective papers	[74, 75]
Position papers	[9, 76]

The most frequently used author's keywords were 'artificial intelligence' (40 times), 'dental education' (34), 'dentistry' (14), 'machine learning' (14), 'chatbots' (10), and 'attitude' (7) (Figure S5). The trending topics graph shows the terms that appear three or more times per year in the author's keywords (Figure 5). Over the last 3 years, the trending topics have been 'artificial intelligence' and 'attitude', whereas over the last 2 years, 'dental education', 'dentistry' and 'machine learning' have emerged as prominent subjects of interest. The term 'chatbots' appears in 2024.

The thematic distribution map allows the categorisation of the main research topics along two dimensions. The first dimension, related to relevance (degree of centrality), determines the relative importance of each topic in this area. The second dimension, related to development (degree of density), shows the progress and extent of knowledge generated in this area. This analysis resulted in 10 clusters (Figure 6). The basic themes were organised around clusters 1 (artificial intelligence), 3 (chatbots) and 6 (robotics). Cluster 5 (dental) was identified as a motor theme. Clusters 8 (endodontics), 9 (survey) and 10 (teaching methods) showed some degree of development, but their relevance in the area was not high. Cluster 4 (attitude) was the topic with the highest degree of

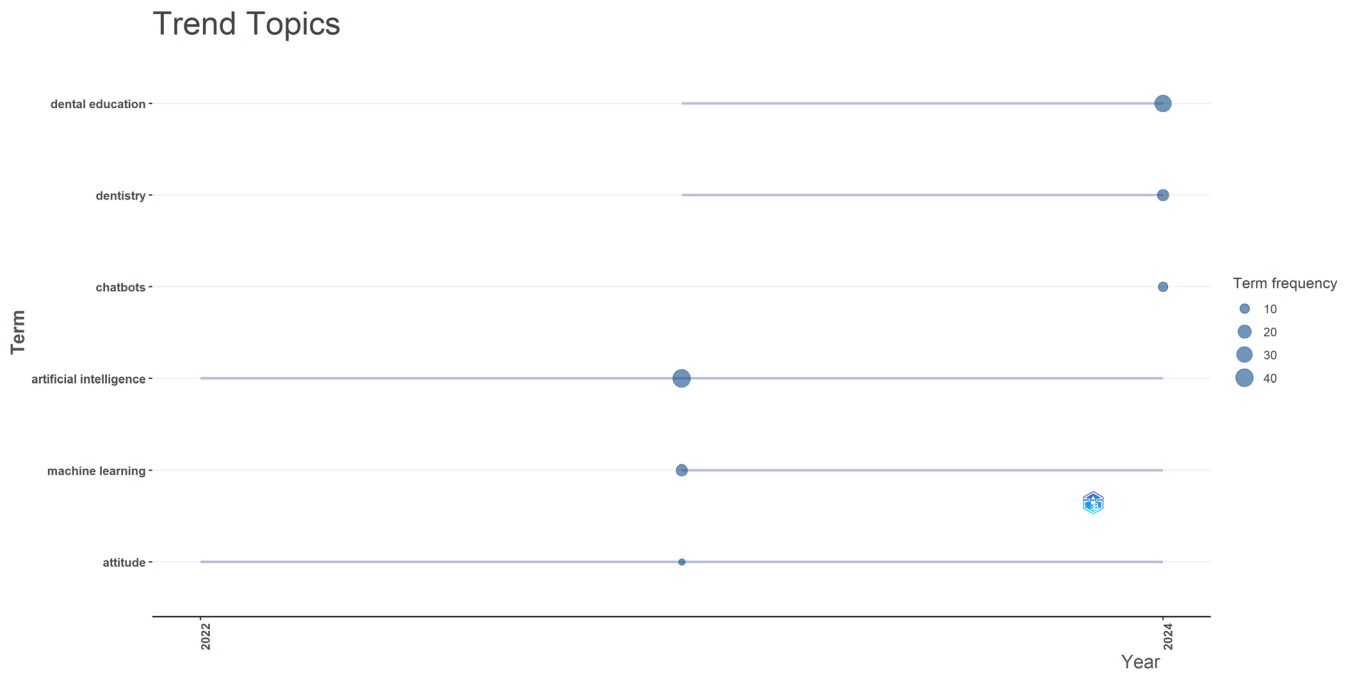

FIGURE 5 | The trending topics are determined based on the author's keywords. The frequency of occurrence of these keywords is represented by a proportional increase in the size of the circle.

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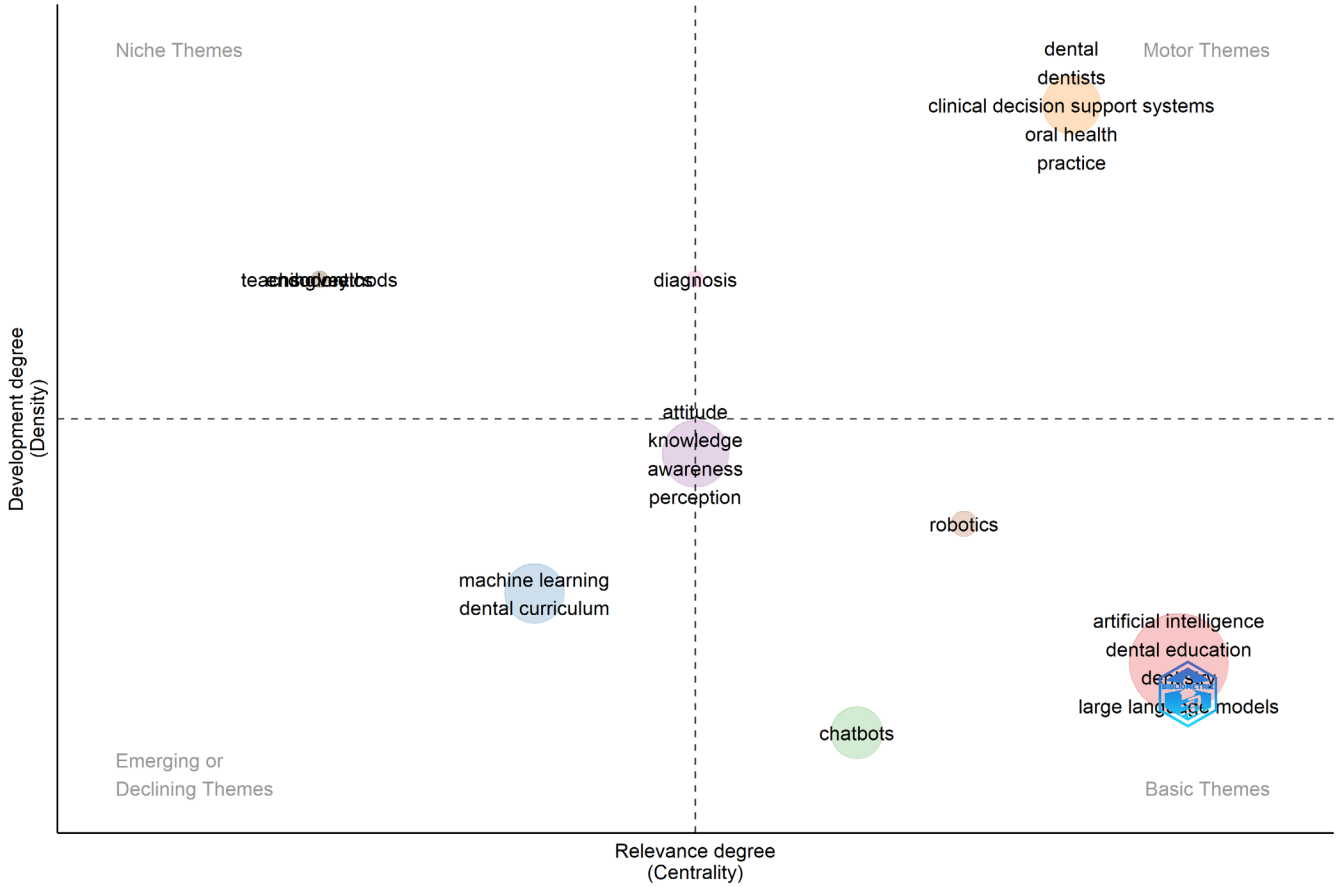

FIGURE 6 | Thematic map based on the authors' key words, organised according to the degree of centrality and density. The circle size is proportional to the word occurrences in the cluster.

relevance and development. Cluster 2 (machine learning) represented either an emerging or a disappearing theme. Cross-cutting clusters were 4 (attitude) and 7 (diagnosis). The different clusters and their related terms are detailed in Table S14.

The evolution of the thematic content was examined on an annual basis. In 2021, the documents were organised into two clusters ('artificial intelligence' and 'dental education'). The former emerged as the relevant theme, while the latter emerged as a niche theme. In 2022, the 'artificial intelligence' cluster continued to be a foundational theme, whereas the focus shifted to 'dental education', indicating a growing interest in this area. By 2023, the documents were organised into four clusters, 'artificial intelligence', 'dental education', 'machine learning' and 'attitude'. The 'dental education' cluster gained prominence in the literature, while 'machine learning' and 'attitude' were identified as niche themes. In 2024, the documents were organised into six clusters. The clusters 'endodontics' and 'robotics' were identified as niche topics, whereas 'machine learning' was positioned as an emerging or declining topic, and 'attitude' emerged as a motor theme. The evolution of the different clusters is shown in Figure S6 and Table S15.

4 | Discussion

This bibliometric analysis aimed to explore the current scientific literature regarding the use of AI and GAI in dental education to identify potential future directions and gaps in this area. The results of this analysis have made it possible to identify the most significant early studies on AI applied to dental education and the evolution of topics that have been the subject of development in recent years, revealing several areas of interest for possible future research.

Our results showed a notable increase in the number of publications and their associated citations over the time. In terms of temporal variation, the number of publications increased significantly, with an annual growth rate of approximately 51% from 2021 to the first half of 2024. These findings are in line with current trends, as there have been significant advances in AI, especially in machine learning and natural language processing [77], so this field is receiving increasing attention for its potential applications in higher education [78].

The most prolific publication sources were the *Journal of Dental Education*, *Cureus Journal of Medical Science* and *European Journal of Dental Education*. However, when considering the number of citations, the *Journal of Dental Education* and the *European Journal for Dental Education* obtained the highest impact. Both are journals belonging to the two most important societies related to dental education: the American Dental Education Association (ADEA) and the Association for Dental Education in Europe (ADEE), respectively. Other authors, such as Bigdeli et al. (2013), also observed that the majority of information regarding a specific topic comes from a limited number of sources, predominantly well established information resources [79].

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The corresponding authors' analysis showed that the United States had a relatively low proportion of international collaborations, despite being the most productive country in this field. This may be attributed to the fact that large countries with a high research output and many research institutions have more opportunities for national collaboration than other countries [80].

In August 2020, Yüzbasioglu published an article in the *Journal of Dental Education*. To the best of our knowledge, he can be considered the first author to address the application of AI in dental education [31]. Consequently, he became the most cited author within this collection and the second most cited author worldwide. The paper by Thurzo et al., published in 2023 as a review on the impact of AI and its implications for the dental education curriculum [30], was more highly cited globally than the aforementioned paper. It is important to consider the distinction between global and local citation rates, as this may indicate the extent to which the latter article is related to other topics or issues beyond AI, such as dental education.

The term 'artificial intelligence' was the most frequently used keyword, highlighting its central role in this topic. Other significant keywords included 'dental education', 'dentistry', 'machine learning' and most recently, 'chatbots', which may reflect the specific technologies and applications that are being adopted at a rapid pace in dental education.

The thematic distribution of the authors' keywords showed that articles related to 'clinical decision support systems' and 'oral health practice' had the highest development and relevance. This can be attributed to the professional profile associated with the Dentistry Degree. Other keywords related to terms, such as 'robotics', 'chatbots' or 'dental education', while demonstrating a high degree of relevance, had a restricted number of publications. The development and relevance of topics such as 'machine learning' or 'dental curriculum' were limited. In this bibliometric analysis, only three articles, focused on proposals for creating an updated core curriculum incorporating AI or GAI [9, 75, 76]. These studies highlight the transformative potential of AI in enhancing education and clinical practice, propose frameworks for adaptive curricula and emphasise the importance of a core curriculum to boost AI literacy among dental professionals. This underscores the need for dental institutions to prioritise actionable frameworks for adoption, fostering innovation while addressing contemporary educational demands.

Furthermore, the keywords 'knowledge', 'awareness', 'perceptions' and 'attitudes' showed a high level of development and relevance during 2024. This finding is consistent with the manual categorisation of the articles, as 23 of the 54 documents included in this collection (42.5% of the total) were related to these keywords. In addition, three systematic reviews specifically addressed this topic, focusing on dental students' knowledge, attitudes and perceptions towards AI [32–34].

On the other hand, well developed topics related to keywords, such as 'teaching methods' or 'diagnosis' have not reached a high level of relevance. Further efforts to develop comparative studies (experimental research) that provide an objective evaluation of the role of AI in the acquisition of learning outcomes could have a beneficial impact on two areas. Firstly, they may facilitate the personalization of the teaching–learning process, aligning it more closely with the students' individual needs [81]. Secondly, they may enhance students' clinical skills, for example, through the implementation of clinical decision support systems [82]. Our analysis revealed that only 12 papers (22.2%) were comparative studies with at least two groups, focusing on teaching different areas of dentistry, including diagnostics, periodontics, cariology, etc. A higher number of experimental studies, evaluating the long-term impact and using a multicentric approach to consider the diverse backgrounds of students, could provide insight into the true effectiveness of AI and GAI in the acquisition of learning outcomes. Future research should also explore technological advances in AI to provide real-time feedback and/or assessment to students.

This bibliometric analysis revealed several methodological limitations and potential biases that must be considered. This study utilised the Bibliometrix R package for data analysis, which, while a powerful tool, has certain limitations. The accuracy of the findings depends on the completeness and quality of the bibliometric data obtained from the database. Three main issues were detected: a case of double counting of an author for the same publication, which was corrected manually; poor retrieval of the keywords plus (41.7% of the keywords plus were not correctly extracted from the metadata), so the analysis was conducted using the author's keywords; and a problem with the classification by WoS of systematic reviews in the category of articles and articles in the category of proceedings papers. This misclassification by WoS has rarely been published before, although it tends to be frequent [83].

Bibliometric analyses, by their nature, also have some inherent limitations. The databases typically focus on indexed and peer-reviewed articles, which exclude grey literature and may limit the completeness of the analysis [84]. Furthermore, the classification of articles into subject areas is to some extent subjective and depends on the categorisation systems used by the database [85]. This subjectivity can lead to misclassification of data, which affects the accurate analysis of specific research topics and their relative importance within the field. In addition, metrics such as citation counts, h-index and publication volume can overemphasise quantity at the expense of quality, often overlooking nuanced contributions that are less frequently cited but still impactful [86]. Finally, bibliometric databases often have a predominance of English-language journals, which may lead to the underrepresentation of research published in other languages [87].

5 | Conclusions

In conclusion, although the current state of AI and GAI in dental education has shown advancement in fundamental areas, more research is needed in emerging technologies and innovative teaching methods to fully maximise the potential of AI in dental education. Future research should prioritise the application of AI for personalised education, the integration of chatbots as educational tools to support students and the exploration of AI for practical skills training and assessment. These areas present opportunities to further integrate AI into specialised aspects of dental education, with the potential to transform traditional teaching methods and curricula.

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Author Contributions

All authors contributed substantially to the conceptualisation and interpretation of the data for the work. M.I. performed the software-based bibliometric analysis. M.I. and J.J.P.-H. contributed to the drafting and critical revision of the manuscript. They gave their final approval of the version to be published and agreed to be accountable for all aspects of the work.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

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