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Emerging Trends in ChatGPT Research: A Quantitative Literature Review and Clustering Analysis

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ABSTRACT

This study presents a quantitative literature review of ChatGPT research using a clustering approach to analyse knowledge flow through Main Path Analysis (MPA) and Global Main Path (GMP). We constructed a citation network from 1,147 articles published between 2015 and 2023, sourced from the Web of Science. The analysis employed edge-betweenness clustering to identify eight rapidly growing research topics: five clusters focus on ChatGPT in healthcare, two clusters on ChatGPT performance and one on ChatGPT in education. One of the most significant clusters is the impact and ethics of ChatGPT across various sectors, including healthcare, hospitality and cybersecurity, with AGR (0.47) and RGR (0.96) showing very high growth. Meanwhile, other clusters, such as AI chatbots in healthcare and trust and personalization in chatbots, demonstrate more moderate growth rates, with AGR 0.29 and 0.14 and RGR 0.59 and 0.29, respectively. Despite these varying growth rates, key challenges related to ethics, trust and personalization remain critical issues that must be addressed to ensure the successful and effective deployment of ChatGPT across diverse sectors.

1. Introduction

Artificial Intelligence (AI) represents an important part of computer science dedicated to creating machines that can understand and perform tasks that normally require human intelligence [1]. Within AI, several major branches have emerged, including Machine Learning (ML), Natural Language Processing (NLP) and Deep Learning (DL). ML focuses on developing algorithms that enable computers to learn and make data-based decisions. DL, a more advanced subset of ML, uses artificial neural networks to model and understand complex data patterns [2]. NLP, on the other hand, relates to the ability of computers to process, analyse and generate human language in both written and spoken forms [3]. These technologies collectively enhance the ability of AI systems to interact and

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interpret the world in ways that closely resemble human cognition and communication. One of the AI products with NLP that is currently often discussed is ChatGPT.

The rapid and widespread emergence of ChatGPT literature is a phenomenon that requires careful observation and analysis. Recently, ChatGPT has continued to impact various fields significantly and the growth of related literature shows no signs of slowing. This impact is visible in studies such as those conducted by Lee [4], which explore the potential of ChatGPT in medical education. Several interesting questions emerged during this early stage of ChatGPT research. From a bibliometric perspective, what important academic platforms are accelerating knowledge exchange during this period of rapid research output? What are the important issues in this path of knowledge development and where do they come from? Is there a driving force leading the development of knowledge pathways at this early stage of ChatGPT? These questions are particularly relevant considering the ethical and social implications of ChatGPT, as Fanni *et al.,* [5] discusses in his research on the impact of AI on human agency.

This study aims to examine and analyse the current patterns and developments in research about ChatGPT. Emerging themes, distinct from established ones, have recently attracted the attention of researchers. While these new areas have yet to be extensively examined, a small but coherent body of literature has begun to accumulate due to newly released works. For instance, Makokha [3] have investigated the potential of ChatGPT in enhancing human-AI collaboration in creative tasks, while Coello *et al.,* [6] have explored its applications in code generation and software engineering. These studies highlight the diverse and rapidly evolving landscape of ChatGPT research, underscoring the need for a comprehensive analysis of current trends and future directions.

Many review articles on contemporary topics often rely heavily on subjective interpretations, drawing primarily from the author's expertise and qualitative research content analysis. In contrast, this study adopts a more rigorous, systematic and quantitative approach to uncover recent themes in ChatGPT research. Our methodology centres on a citation-based bibliometric analysis to address our primary research question: What are the most current and significant themes in ChatGPT research? Specifically, we construct and partition a citation network into subnetworks using well-established clustering methods, such as edge betweenness or modularity optimization [7,8]. These techniques allow us to identify clusters of densely interconnected nodes, representing articles with strong thematic relationships. This approach ensures that most articles within each subnetwork pertain to a cohesive research topic, thereby enabling a more objective and comprehensive analysis of emerging trends in the rapidly evolving field of ChatGPT research.

To further enhance the robustness of our analysis, we utilize citation information provided by Web of Science (WoS) to trace knowledge flows and identify key influencers within the field. This method allows us to map the intellectual structure of ChatGPT research and highlight pivotal works that have shaped the discourse. By combining network analysis with traditional bibliometric indicators, we aim to provide a multi-faceted view of the research landscape. The final section of this study synthesizes our findings to offer evidence-based recommendations for future research directions. These suggestions guide researchers, policymakers and practitioners toward promising avenues of inquiry, potential applications and critical areas requiring further investigation. By doing so, we hope to contribute to the strategic development of ChatGPT research, fostering innovation and addressing crucial gaps in our understanding of this transformative technology.

2. Methodology

2.1 Data Sources

This study collected citation data and publications from the Thomson Reuters WoS in two stages. Figure 1 depicted the process to generate data source. Initially, a broad query was performed, including phrases related to ChatGPT, [9-12], such as "ChatGPT", "Chat Generative Pre-training Transformer", "large language models", "LLM", "generative AI" and specific versions like "GPT-3", "GPT-3.5" and "GPT-4". The search targeted articles indexed in the Science Citation Index (SCI) and Social Sciences Citation Index (SSCI) databases, yielding an initial dataset of 1,519 articles published from 2000 to 2024. After refining the dataset by removing irrelevant or uncited articles, a focused dataset of 1,147 publications was formed, which served as the basis for subsequent analysis.

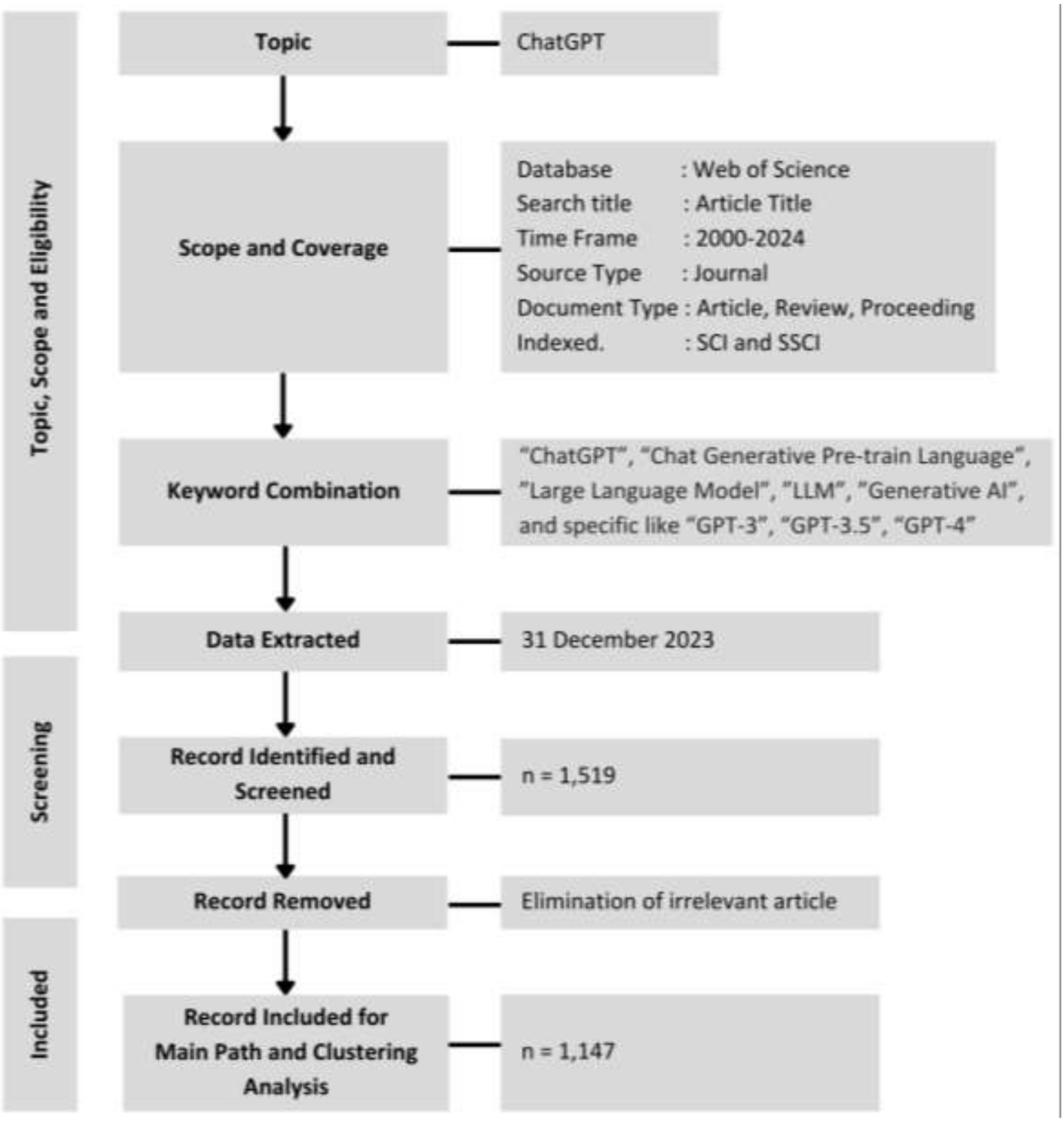


Fig. 1. Steps Involved in conducting a bibliometric analysis

Academic research is inherently interconnected, with researchers citing prior studies that address similar issues. This practice creates a network of related articles linked through citations [13]. In network analysis, these closely connected groups of articles are termed subnetworks. These subnetworks feature strong internal connections but relatively few links to external nodes [14].

Our study harnesses this network structure to identify emerging themes in ChatGPT research. By constructing and analysing citation networks, we aim to discern patterns and trends within the academic literature, offering a comprehensive overview of this rapidly evolving field [15].

It's crucial to recognize that not all subnetworks necessarily represent cutting-edge topics. Some significant subnetworks may encompass well-established themes rather than current ones [16]. Moreover, the size of a subnetwork alone doesn't guarantee its relevance to ongoing research. We consider article growth as a key factor in identifying current topics, as subnetworks covering dynamic and exciting subfields tend to expand over time. Consequently, we look for two primary indicators of emerging research topics: coherent subnetworks of substantial size and observable growth in article numbers over time.

Citation networks are inherently directional and acyclic, with each connection following a specific path without loops [17]. While recent years have seen the development of methods for clustering directed networks, these approaches are still evolving and present significant challenges [18]. Given this complexity, we adopt a conservative approach, treating the citation network as undirected. This allows us to utilize well-established clustering methods while acknowledging the ongoing development of techniques for directed networks [19].

To identify coherent subnetworks, we combine the concepts of network modules and edge-betweenness clustering [20]. Unlike the K-means algorithm, which requires a predetermined number of clusters, our approach automatically determines the optimal number based on modularity - a measure of network partitioning quality [21,22]. The process involves gradually fragmenting the network by removing intermediate links or those with significant connectivity roles [23].

Highly modular networks display dense connections within subnets but sparse connections between different subnets [24]. The ideal network decomposition achieves the highest modularity value among several alternatives found through the link elimination process. We implement this clustering technique using the igraph package, a robust tool for network analysis [25].

By employing these advanced clustering techniques, we aim to provide a detailed and accurate representation of the research landscape surrounding ChatGPT. This methodological rigor ensures that our analysis captures the most relevant and emerging themes, offering valuable insights for future research directions [26]. Our approach allows us to identify key research clusters, understand their interrelationships and highlight potential areas for further investigation in the dynamic field of ChatGPT studies [27].

2.2 Network Construction and Clustering Method

When writing articles on a topic, researchers typically cite prior studies addressing similar issues, creating a network of related articles linked through citations. In network analysis, these closely connected networks are known as subnetworks. Subnetworks feature strong internal connections but relatively few links to external nodes.

This study utilizes this network structure to identify emerging themes in ChatGPT research. By constructing and analysing these citation networks, we aimed to uncover patterns and trends within the academic literature, providing a comprehensive overview of the current state of research in this rapidly evolving field. However, it is essential to note that not all subnetworks reflect the most recent topics. Some significant subnetworks may encompass older, well-established themes rather than the most current research areas. Additionally, assuming that smaller subnetworks represent the latest topics can be misleading.

To identify emerging research topics, we looked for two primary indicators:

i. Coherent subnetworks of substantial size
ii. Observable growth in the number of articles over time.

2.2.1 Clustering methodology

Citation networks are directional and acyclic, meaning each connection follows a specified path without looping back. The standard approach to dividing a citation network into subnetworks is converting it into an undirected network, which simplifies the analysis by allowing well-established clustering methods [6]. However, this approach loses the directional information that indicates the flow of knowledge between nodes, potentially missing insights into how research ideas propagate.

This study uses edge-betweenness clustering to identify densely interconnected groups of articles. While effective, this method treats the network as undirected, which overlooks the directional nature of citations and may fail to recognize smaller, specialized clusters representing cutting-edge research themes.

Recent literature has proposed new methods for clustering directed networks, including direction-preserving transformations and new techniques [27,28]. Some studies have demonstrated these methods in citation networks, but clustering-directed acyclic networks remain challenging [18,23]. For example, Wu *et al.,* [28] introduced "modularity" for acyclic networks, showing that subnetwork modularity values were consistent regardless of directionality. Nonetheless, clustering-directed networks are acknowledged as more complex than clustering undirected ones [7].

Given these challenges, we conservatively treat the citation network as undirected, utilizing well-established methods while recognizing the limitations. This approach aims to robustly analyse the network structure and identify emerging research themes in ChatGPT. Future studies should explore clustering methods that preserve directionality or combine techniques to enrich findings.

As defined by Girvan and Newman, edge-betweenness centrality is one of the methods used to run cluster analysis. In the context of social network analysis, this algorithm focuses on the "importance" of each node to emphasize the shortest paths in the network; as a consequence, it will also remove the edge(s) with the most significant betweenness centrality [16].

The usage of edge-betweenness centrality in a process to group edges that are most likely "between" communities is called edge-betweenness clustering. Community detection using edge-betweenness centrality involves four significant steps, as illustrated in Figure 2. First, the betweenness of all edges in the network is calculated mathematically, determining how often each edge appears on the shortest paths between pairs of nodes. Next, the edge(s) with the highest betweenness centrality are removed from the network, as they are the most critical connections between different network parts. After this, the betweenness centrality of all remaining edges is recalculated, as removing the edges may affect the shortest paths and connectivity between nodes. Finally, this process is repeated by recalculating the betweenness for all edges after each removal until no edges remain, effectively partitioning the network into separate communities.

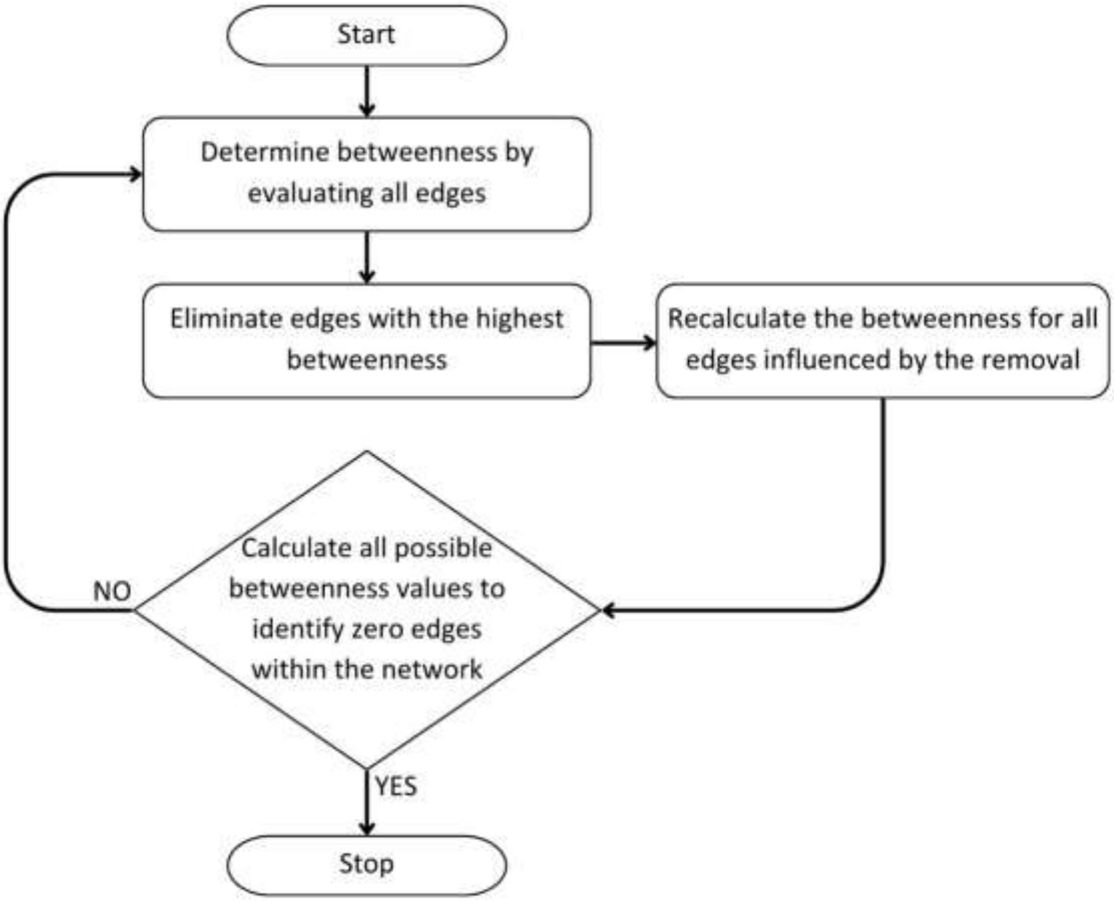


Fig. 2. Flowchart of Girvan-Newman algorithm

Initially, a network with several communities or groups of nodes is densely hooked and forms a connectivity, as seen in Figure 3. This network shows three communities with network edges of 8 (blue) - 4 (orange) - 10 (green).

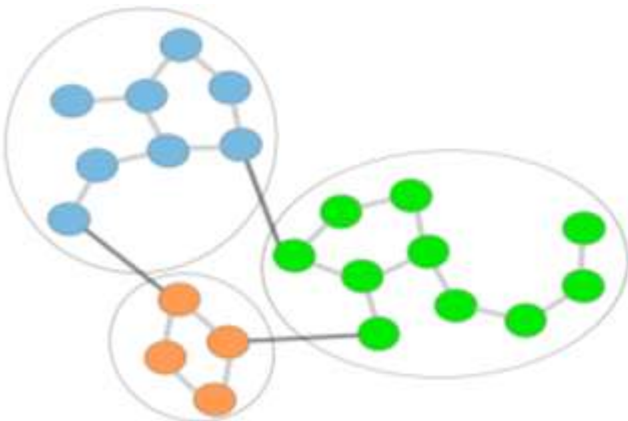


Fig. 3. A Network with three communities of coloured linked vertices interconnected with three bridges of grey lines

Applying the edge betweenness centrality algorithm to a network will compose separated groups Figure 4. In order to cluster each of the most prominent groups in the network, there is a recent term called modularity. Modularity is one of the "highly effective" optimizations approaches to abridge the large-scale cluster network to illustrate the higher quality edge-betweenness network topologies [16].

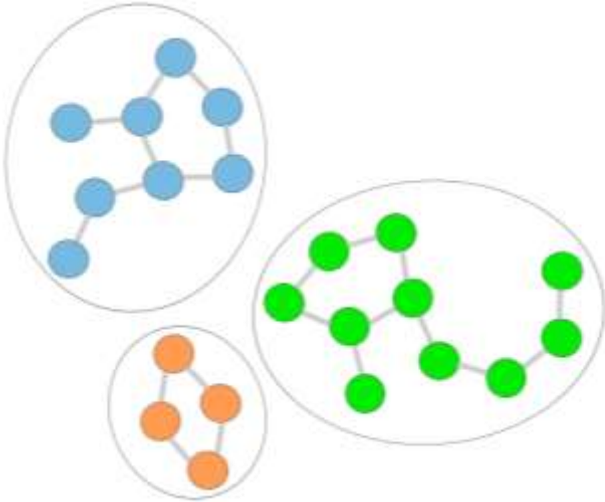


Fig. 4. A network with three communities of coloured linked vertices after eliminating three bridges of grey lines

Thus, in this research, we use a plug-in application named Group Finder, which mainly calculates the betweenness, removes the bridges of large datasets and measures modularity value concomitant with highlighted relevant clusters.

By employing these advanced techniques, we aim to represent the research landscape around ChatGPT accurately. However, treating the network as undirected may require more focus on crucial directional information. Future research should address these challenges to improve the robustness of cluster identification and understanding of knowledge flows within the field. Despite these limitations, our methodological rigor ensures that our analysis captures relevant and emerging themes, providing valuable insights for future research directions.

2.3 Main Path Analysis

We combined citation network analysis with Main Path Analysis (MPA) and the Global Main Path (GMP) method to explore the evolving landscape of ChatGPT research [29]. Citation networks provide a broad view of interconnections between studies, while MPA identifies key knowledge pathways and GMP determines the single most influential path in the flow of knowledge. In this study, we specifically used Search Path Count (SPC), as recommended by Batagelj [30], to calculate the GMP. SPC measures the importance of documents (nodes) by counting the number of logical paths that pass through them in a citation network represented as a Directed Acyclic Graph (DAG).

For example, in a network where document A cites B, B cites C, A also cites C and C cites D, there are two logical paths from A to D: A→B→C→D and A→C→D. SPC assigns values based on how many paths traverse each node, making it suitable for identifying both pivotal documents and the most critical pathways. Using SPC, we calculated the GMP to trace the most influential sequence of studies in ChatGPT research, highlighting foundational works and state-of-the-art advancements.

By applying MPA and GMP, we revealed the intellectual lineage of ChatGPT innovations and identified critical developments and research gaps. While citation-based methods like MPA and GMP may overemphasize highly cited studies, they provide valuable insights into emerging sub-fields and knowledge flows. This combined approach offers guidance for future research, aiding stakeholders in navigating the rapidly evolving field of AI language models [31-33]. Addressing biases and updating data will further enhance the effectiveness of these methods.

3. Results

3.1 Growth of ChatGPT Publications

Figure 5 illustrates the exponential growth in ChatGPT-related papers from 2003 to 2024. From 2003 to 2018, there needed to be more activity, indicating little interest in ChatGPT research. However, starting around 2019, a gradual increase in publications marked the beginning of growing interest. The most significant change occurs between 2022 and 2023, with the number of papers skyrocketing, reflecting a substantial surge in research activity driven by advancements and widespread adoption of ChatGPT and similar AI models. By 2024, the number of published papers is expected to peak, continuing the exponential growth trend and highlighting the increasing importance of ChatGPT as a critical area of study.

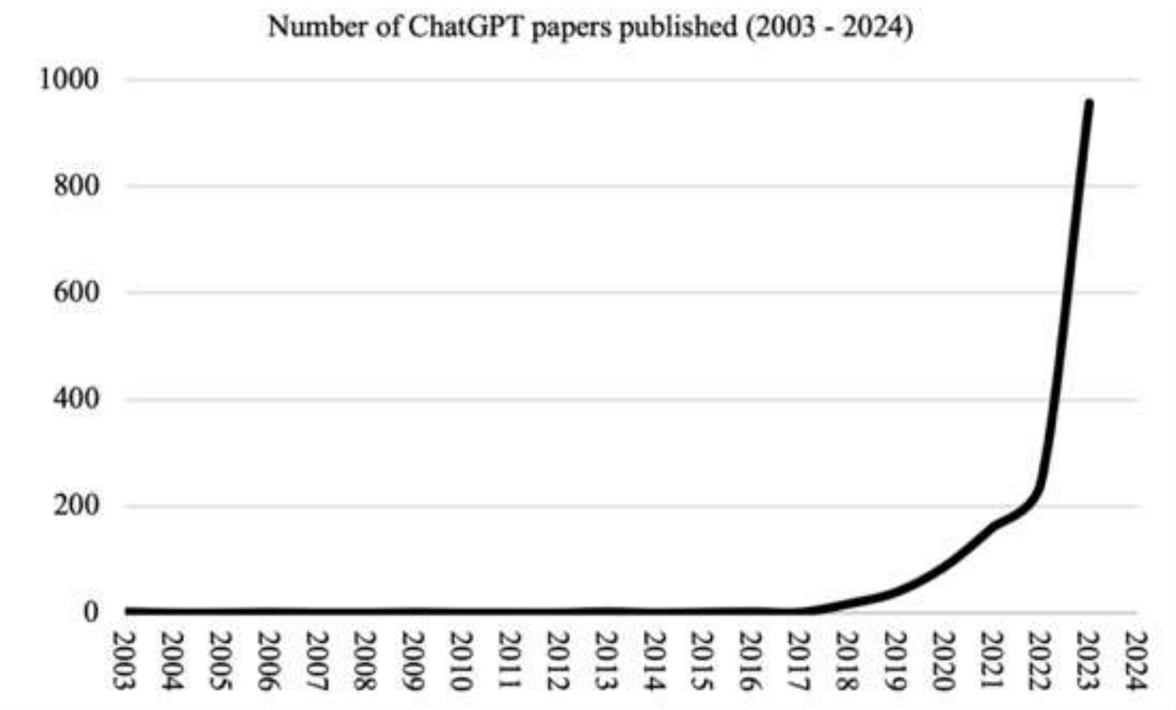


Fig. 5. The number of ChatGPT papers

Figure 6 depicts the trend in ChatGPT-related publications from 2000 to 2030, with observed data up to 2023 and future projections. From 2000 to 2018, there was minimal activity, indicating little interest in ChatGPT research. Starting around 2019, a noticeable publication increase began, followed by a dramatic spike between 2022 and 2023. This surge reflects significant growth in research driven by advancements and widespread adoption of ChatGPT. The dashed line, projected using Loglet Lab 4 software, suggests continued publication growth up to 2030, emphasizing ChatGPT's escalating influence and relevance across various fields.

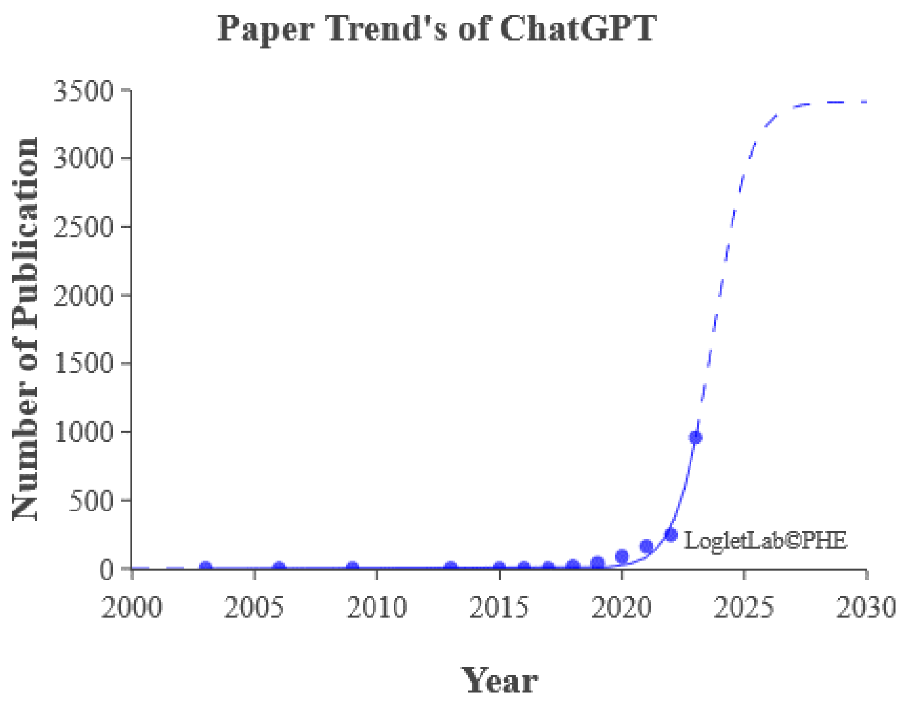


Fig. 6. The growth rate of ChatGPT papers

3.2 Top Publishing Countries on ChatGPT

Figure 7 and Table 1 present an analysis of ChatGPT-related publications from 2003 to 2023, focusing on the top 10 publishing countries. The research encompasses contributions from 75 countries, with the USA, China, India, England, South Korea, Taiwan, Australia, Spain, Italy and Germany leading the way. The data shows a comparable level of research activity between Eastern and Western countries, with minimal publication activity from 2003 to 2019, followed by a slight increase around 2020 and a dramatic surge from 2022 onwards. China and the USA lead this rapid expansion, indicating their significant investment in AI research.

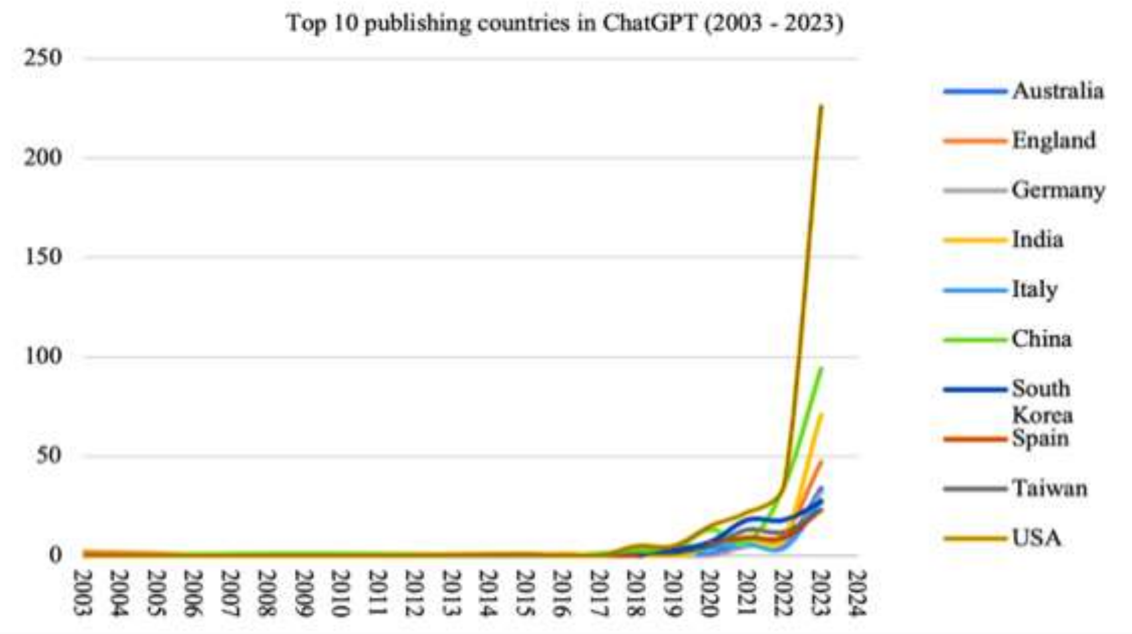


Fig. 7. Top 10 countries of annual published ChatGPT papers

Table 1 provides a detailed breakdown of the number of publications, authors and citations for each of the top 10 countries. The USA leads in all three categories, followed by China and India. Categorizing the contributions by continents reveals that America accounts for 20.42% (310 papers), Europe 13.83% (210 papers), Asia 24.9% (378 papers) and Australia 3.23% (49 papers). This analysis highlights the global nature of ChatGPT research, with substantial contributions from both Eastern and Western countries, underscoring its growing academic importance.

Table 1
Top 10 Most Influential countries based on the number of publications and total citations

Country	No. of Publication	No. of Authors	No. of WOS Citation
USA	310	1.361	2.765
China	157	673	1.429
India	93	288	247
England	74	254	811
South Korea	73	222	899
Taiwan	55	187	385
Australia	49	179	320
Spain	47	234	203
Italy	45	181	383
Germany	44	195	158

3.3 Top Publishing Journal on ChatGPT

Describing the most influential journals on ChatGPT requires timely and reliable assessments, with a high impact factor being a key indicator. This chapter lists the top ten prolific publishers, including their country of origin, active years and total documents published. It is valuable for researchers and scholars aiming to publish their articles on ChatGPT studies.

Table 2 presents the top ten most influential journals in ChatGPT research for 2023. The Cureus Journal of Medical Science leads with 131 citations, 22 articles and the highest g-index (11) and h-index (6) originating from England. The Integrity and Policy Journal from the USA follows with 26 citations, four papers and a g-index of 4. The Annals of Biomedical Engineering, also from the USA, has a g-index of 4, an h-index of 3 and 30 citations from 26 papers. Other notable journals include Education Sciences from Switzerland, Aesthetic Plastic Surgery, Applied Sciences-Basel, Frontiers in Artificial Intelligence, Education and Information Technologies, Finance Research Letters and the Journal of Medical Internet Research from Canada.

These ten highest-ranking journals cover various topics, although health topics dominate. Other topics include education, technology, finance, computer science and social sciences. The geographic distribution spans Western and Eastern countries, indicating global interest and effort in advancing ChatGPT research.

Table 2
Top significant journals in ChatGPT research themes

Journals	g-index	h-index	Total Citations	Total Papers	Active Years	Country of Origin
Cureus Journal of Medical Science	11	6	131	22	2023	England
Accountability in Research-Ethics Integrity and Policy	4	3	26	4	2023	USA
Annals of Biomedical Engineering	4	3	30	26	2023	USA
Education Sciences	4	2	36	4	2023	Switzerland
Aesthetic Plastic Surgery	3	2	15	6	2023	USA
Applied Sciences-Basel	3	1	11	4	2023	Switzerland
Education and Information Technologies	3	2	13	5	2023	USA
Finance Research Letters	3	1	35	3	2023	USA
Frontiers in Artificial Intelligence	3	1	17	3	2023	Switzerland
Journal of Medical Internet Research	3	2	10	5	2023	Canada

3.4 Cluster Analysis: ChatGPT Research Themes

Using the Edge-betweenness method, this study's results divided ChatGPT documents into several subgroups. Each subgroup consists of papers that refer to each other more frequently than papers outside the group. The eight most significant clusters contain 335, 185, 260, 69, 32, 27, 23 and 20 articles, respectively. Most clusters contain approximately one-fifth of the papers in the dataset and are currently considered primary ChatGPT documents. These clusters include papers that elaborate on ChatGPT, which has been extensively discussed in previous studies. This study focused on consistent subnetwork sizes, emphasizing our analysis of these eight groups. The appearance of the eight network groups is depicted in Figure 8. Their themes are identified as “The Impact and Ethics of ChatGPT Across Sectors”, “AI Chatbots Transform Healthcare”, “Trust and Personalization in Chatbot Efficacy”, “ChatGPT's Impact on Education”, “ChatGPT in Medical Case Reporting”, “ChatGPT in Medical Education and Healthcare”, “GPT-4's Advancements and Future Directions in Healthcare” and “ChatGPT-4 in Enhancing Medical Research” as shown in Table 3.

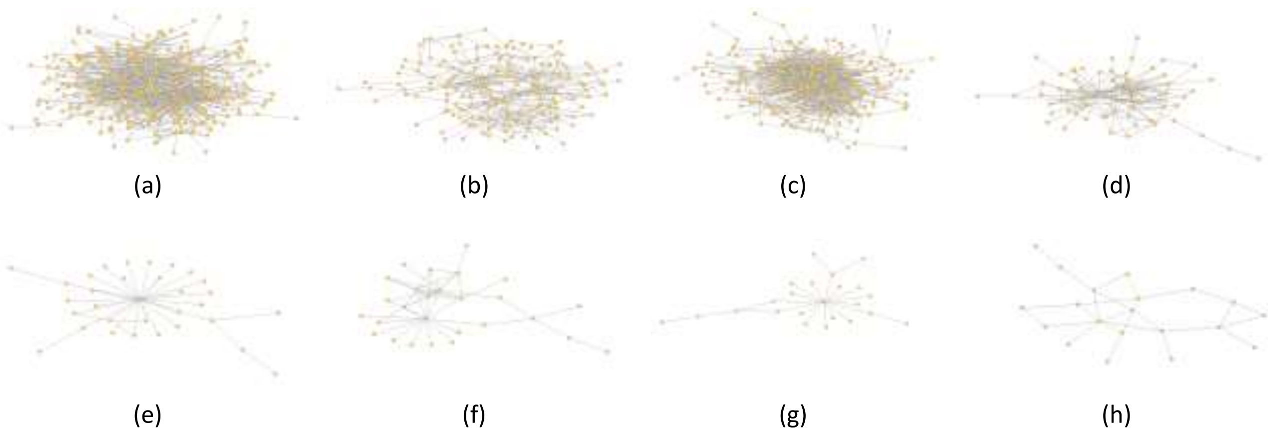


Fig. 8. Eight significant ChatGPT research clusters map in visualization view (a) Cluster 1 - 335 articles (b) Cluster 2 - 185 articles (c) Cluster 3 - 260 articles (d) Cluster 4 - 69 articles (e) Cluster 5 - 32 articles (f) Cluster 6 - 27 articles (g) Cluster 7 - 23 articles (h) Cluster 8 - 20 articles

Annual Growth Rate (AGR) measures the yearly percentage increase in research articles. Yearly Average Growth Rate (YAGR) averages this growth over a period of time, providing a long-term view of trends. Relative Growth Rate (RGR) contextualizes the growth by comparing it to the current size of the field. Together, these metrics offer complementary insights: AGR and YAGR focus on absolute growth trends, while RGR highlights proportional growth relative to the existing volume of articles.

As highlighted in Table 3 and Table 4, the research dynamics across the clusters reveal key trends in the growth, focus and challenges of ChatGPT-related research. Cluster 1 is the leading area with the most articles (335), accounting for 29.2% of the total dataset. This cluster's high AGR and RGR values indicate its rapid growth, establishing it as an emerging "hot topic." The focus on the impact and ethics of ChatGPT across various sectors, including healthcare, hospitality and cybersecurity, underscores its transformative potential. However, challenges such as trustworthiness and ethical considerations remain central themes in ensuring its practical adoption.

Cluster 2, with 185 articles (16.1%), reflects steady and consistent growth, as demonstrated by its moderate AGR and an RGR slightly above 1. This cluster explores healthcare transformation through AI chatbots, emphasizing user engagement, satisfaction and scalability in mental health support and chronic condition management. Despite its promising applications, personalization and content uniformity challenges highlight areas for improvement. Cluster 3, contributing 22.7% of the articles, focuses on trust and personalization in chatbot efficacy. Its relatively lower AGR and RGR values, alongside stable YAGR trends, suggest that this cluster represents a more mature research area with steady but slower growth. This stability highlights its established importance in ensuring chatbot responsiveness and user satisfaction but also points to ethical concerns and the need for service recovery strategies.

In contrast, Clusters 4 through 8 represent specialized or niche topics with minimal growth. These clusters, with percentages ranging from 1.74% to 6.02%, exhibit low AGR and RGR values, indicating limited expansion. For instance, Cluster 5 focuses on ChatGPT's role in medical case reporting, emphasizing the need for human validation to ensure quality and reliability. Similarly, Cluster 8 highlights the advanced applications of ChatGPT-4 in medical research and systematic reviews but faces challenges related to performance in non-English languages and the need for continuous development.

The analysis also underscores the emergence of Clusters 7 and 8, which explore cutting-edge advancements in GPT models, particularly GPT-4. These clusters signify the ongoing evolution of AI technologies, with potential implications for biomedical engineering, patient communication and systematic reviews. However, challenges such as originality issues, language variations and the need for specialized models like ChatDoctor emphasize the complexity of integrating these technologies into professional contexts.

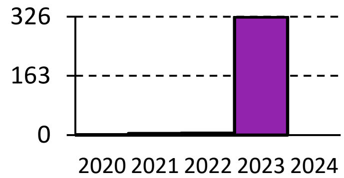
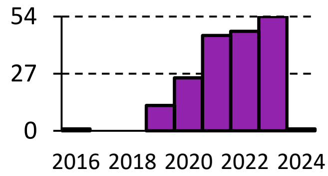
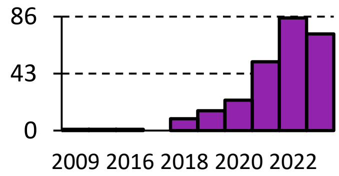
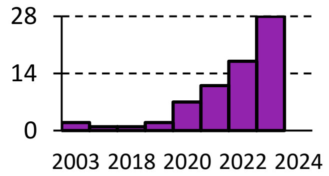
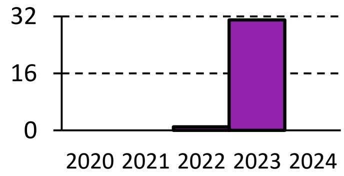
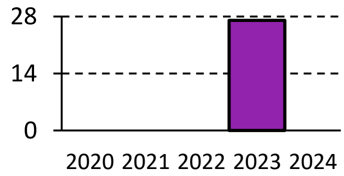
Table 3
Top 8 cluster themes in ChatGPT research

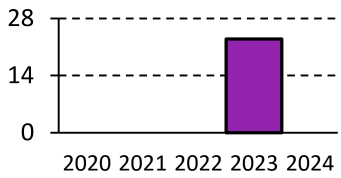
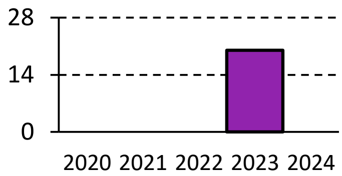
Cluster	Research Themes	Total Articles	%	Authors (Major Research)	Key Themes	Challenges/Notable Insights
1	The Impact and Ethics of ChatGPT Across Sectors	335	29,2%	Korngiebel *et al.,* [34], Gursoy *et al.,* [36], Farhat *et al.,* [9]	• Opportunities and challenges of ChatGPT across various sectors. • Potential advancements in healthcare, hospitality and cybersecurity. • Ethical implications and trustworthiness. • Cautious adoption to ensure safety and effectiveness.	• Ensuring trustworthiness and addressing ethical concerns are critical when adopting ChatGPT, particularly in sensitive fields like healthcare. • While ChatGPT holds transformative potential, it is essential to carefully assess both the risks and benefits to prevent misuse and ensure its positive impact. • The wide-ranging applications of ChatGPT across different sectors emphasize the need for sector-specific guidelines and policies to facilitate safe and practical integration.
2	AI Chatbots Transform Healthcare	185	16,1%	Entenberg *et al.,* [42], Rebelo *et al.,* [45].	• High user engagement and satisfaction. • Effective in mental health support, cancer treatment education and chronic condition management. • • Positive psychological impacts and scalability.	• Need for more personalized interactions. • Technical issues and content uniformity.

3	Trust and Personalization in Chatbot Efficacy	260	22,7%	Alagarsamy *et al.,* [49], Silva *et al.,* [50], Ciechanowski *et al.,* [89], Selamat *et al.,* [51], Chen *et al.,* [52], Li *et al.,* [53], Song *et al.,* [54], Klein *et al.,* [55]	• Trust as a critical factor influencing satisfaction and behavioural intentions. • Importance of responsive, personalized features. • • Benefits of anthropomorphic chatbots.	• Ethical concerns around trust. • Influence of language style and effective service recovery strategies.
4	ChatGPT's Impact on Education	69	6,02%	Young *et al.,* [58], Topal *et al.,* [59], Fryer *et al.,* [60], Zhang *et al.,* [61], Javier *et al.,* [62], Chen *et al.,* [63], Li *et al.,* [64], Essel *et al.,* [65], Al-Abdullatif *et al.,* [66]	• Enhancing language learning and higher education. • Providing comprehensible and stimulating dialogues. • Positive impact on academic performance and motivation.	• Limitations in accuracy. • Need for good background knowledge to utilize effectively.
5	ChatGPT in Medical Case Reporting	32	2,79%	Zamarud *et al.,* [67], Lantz *et al.,* [68], Hegde *et al.,* [69], Chauhan *et al.,* [70], Santandreu-Calonge *et al.,* [71]	• Versatility in documenting treatment outcomes and summarizing rare cases. • Potential to enhance hospital communication.	• Human validation is crucial for quality and reliability.
6	ChatGPT in Medical Education and Healthcare	27	2,35%	Mondal *et al.,* [72], Wang *et al.,* [73], Meo *et al.,* [74], Banerjee *et al.,* [77], Friederichs *et al.,* [76]	• Generating educational materials. • • Assisting in medical training and examinations.	• High similarity index indicating potential originality issues. • Need for continuous improvement and careful evaluation.
7	GPT-3.5 to GPT-4's Advancements and Future Directions in Healthcare	22	1,92%	Kaneda *et al.,* [78], Lee *et al.,* [79], Cheng *et al.,* [80], Gebrael *et al.,* [75], Li *et al.,* [81], Zhu *et al.,* [82]	• Significant improvements in accuracy and applicability. • Impact on medical practice and biomedical engineering.	• Enhanced triage efficiency and patient communication. • Specialized models like ChatDoctor for improved medical advice.

8	ChatGPT-4 in Enhancing Medical Research	20	1,74%	Moshirfar *et al.*, [83], Gupta *et al.*, [84,86], Qu *et al.*, [85], Cohen *et al.*, [87].	• Advanced capabilities in answering professional questions. • Generating systematic review ideas and case-based learning.	• Performance variations in non-English language capabilities. • Need for continuous development and improvement.

Table 4
Top 8 AGR, YGAR and RGR

Cluster	Research Themes	Time Range	AGR	YAGR	RGR	Grow Paper Per Year y:sum of paper, x:year
1	The Impact and Ethics of ChatGPT Across Sectors	2020-2023	0.47	108.67	0.96	
2	AI Chatbots Transform Healthcare	2016-2023	0.29	13.33	0.59	
3	Trust and Personalization in Chatbot Efficacy	2009-2023	0.14	13.67	0.29	
4	ChatGPT's Impact on Education	2003-2023	0.05	5.33	0.1	
5	ChatGPT in Medical Case Reporting	2022-2023	0.02	10.33	0.04	
6	ChatGPT in Medical Education and Healthcare	2023	0.01	9	0.02	

7	GPT-3.5 to GPT-4's Advancements and Future Directions in Healthcare	2023	0.02	23	0.04	
8	ChatGPT-4 in Enhancing Medical Research	2023	0.03	22	0.06	

Combining AGR, YAGR and RGR metrics provides a comprehensive view of cluster research trends. While Clusters 1 and 2 drive the majority of research momentum, steady areas like Cluster 3 and niche topics in Clusters 4-8 offer insights into the diverse applications and challenges of ChatGPT. This analysis serves as a guide for identifying promising research themes and addressing gaps in underexplored or emerging areas, contributing to the broader understanding and development of ChatGPT-related research.

The following sections briefly discuss the eight recent research themes, combined with a Chi-Square analysis of the keywords in each cluster. The Chi-Square test analyses keyword distribution across clusters to identify thematic differences, with a x^2 value of 6954.03, 721 degrees of freedom and a p-value of 0.0 indicating significant deviations from the expected distribution. Significant clusters highlight thematic dominance or research gaps, revealed through observed versus expected frequencies.

3.4.1 The impact and ethics of ChatGPT across sectors

Chi-Square analysis indicates that keywords such as "ChatGPT" (305 occurrences), "artificial intelligence" (212 occurrences) and "generative" (100 occurrences) dominate this cluster, with observed frequencies significantly deviating from expected distributions. These results position Cluster 1 as a key area of research, emphasizing the transformative role of ChatGPT across multiple industries and raising critical discussions about its ethical implications.

The research highlights ChatGPT's profound impact across healthcare, hospitality, education and cybersecurity sectors. In healthcare, Korngiebel *et al.,* [34] discuss GPT-3's potential in advancing medical science through AI-driven conversational agents, stressing the importance of trustworthiness and ethical use [35]. In the hospitality industry, Gursoy *et al.,* [36] emphasize ChatGPT's disruptive potential to enhance customer interactions, while Dwivedi *et al.,* [37] propose a research agenda to address sector-specific challenges. Similarly, McIntosh *et al.,* [38] demonstrate GPT-4's effectiveness in generating cybersecurity policies, sometimes outperforming human efforts. Grassini and Glaser highlight the benefits of personalized learning with ChatGPT in education but warn of ethical concerns and its potential impact on human interactions [39,40].

Across these studies, trustworthiness and ethics emerge as central themes. Farhat *et al.,* [9,41] emphasize ChatGPT's low reliability in bibliometric analyses and advocate for caution in its application. The findings reveal ChatGPT's potential to revolutionize industries like hospitality and cybersecurity. At the same time, the Chi-Square analysis underscores its prominence in research and highlights the ongoing need for ethical considerations in its integration across sectors.

3.4.2 Cluster 2: AI chatbots transform healthcare

Chi-Square analysis highlights keywords like "chatbot" (181 occurrences), "health" (107 occurrences) and "support" (62 occurrences), emphasizing the role of AI chatbots in healthcare. With high user engagement and satisfaction, these tools have demonstrated potential in mental health support, cancer education and chronic condition management. For instance, 66.3% of parents completed a parenting skills chatbot with high satisfaction Entenberg *et al.,* [42], while Tess sustained engagement for 46 days [43]. Chatbots have reduced anxiety post-cancer treatment Greer *et al.,* [44], supported paediatric obesity management and lowered anxiety through radiotherapy education chatbots [45]. They also improve medication adherence for breast cancer patients Bibault *et al.,* [46] and enhance psychological well-being by increasing gratitude and reducing negative emotions [47].

While these tools offer scalability and continuous support, challenges in personalization, technical refinement and content consistency remain [48]. Addressing these will be key to realizing AI chatbots' transformative potential in healthcare.

3.4.3 Cluster 3: Trust and personalization in chatbot efficacy

Cluster 3 emphasizes trust and personalization as critical factors in chatbot effectiveness, with keywords like "chatbot" (247 occurrences), "interaction" (74 occurrences) and "user" (80 occurrences) reflecting the focus on user-centric design. The cluster's significant contribution to the Chi-Square statistic reflects the pivotal role of user experience and conversational capabilities in chatbot adoption and reliability. Trust significantly impacts satisfaction and behavioural intentions, as shown in banking chatbots Alagarsamy *et al.,* [49] and broader ethical concerns [50]. Personalization enhances engagement Selamat *et al.,* [51], while usability and responsiveness improve customer experiences [52]. Effective communication strategies, such as informal language Li *et al.,* [53] and appreciation in service recovery Song *et al.,* [54], along with anthropomorphism Klein *et al.,* [55], further boost satisfaction.

While these findings highlight the transformative potential of chatbots, the rise of GPT-3 and GPT-4 presents new challenges. Future research should explore ethical implications, emotion recognition and long-term impacts on customer relationships [56,57].

3.4.4. Cluster 4: ChatGPT's impact on education

Cluster 4 examines ChatGPT's role in education, focusing on teaching, learning and student engagement. Keywords like "education" (23 occurrences), "teaching" (20 occurrences) and "students" (41 occurrences) highlight a growing interest in its educational applications, though this area remains underexplored.

Chatbots enhance language learning and higher education by improving comprehension, engagement and motivation. Young *et al.,* [58] and Deveci *et al.,* [59] showed their effectiveness in EFL and science education, while Fryer *et al.,* [60] highlighted their value as practice partners. Challenges include initial impacts on self-efficacy Zhang *et al.,* [61] and the need for prior knowledge [62]. Despite this, chatbots have improved academic performance, as shown in studies on vocabulary learning Chen *et al.,* [63], linguistic ambiguity Li *et al.,* [64] and higher education motivation [65,66]. Addressing issues like accuracy and dependency will further enhance their educational impact.

3.4.5 Cluster 5: ChatGPT in medical case reporting

Cluster 5 focuses on ChatGPT's role in documenting and summarizing medical cases, with keywords like "medical" (7 occurrences) and "health" (4 occurrences) reflecting its niche nature. Though underexplored, this area highlights significant potential for innovation in healthcare communication and case reporting.

ChatGPT has shown promise in synthesizing complex medical data into coherent, publishable formats. Zamarud *et al.,* [67] demonstrated its utility in rare disease reporting, while Lantz [68] highlighted its effectiveness in detailing complex cases like toxic epidermal necrolysis. Hegde *et al.,* [69] and Chauhan *et al.,* [70] utilized ChatGPT to summarize rare cases and chronic pain management, showcasing its ability to distil specialized information. Santandreu-Calonge *et al.,* [71] suggested ChatGPT could improve hospital communication, enhancing efficiency and accuracy in patient care. However, human oversight remains essential to ensure accuracy and ethical use, emphasizing the need for robust protocols as AI advances in healthcare.

3.4.6 Cluster 6: ChatGPT in medical education and healthcare

Cluster 6 explores the use of ChatGPT in medical education and training, with keywords like "medical" (16 occurrences), "education" (11 occurrences) and "language" (18 occurrences), reflecting its focus on creating educational tools for healthcare professionals. The relatively low observed frequencies indicate that this research area has substantial growth potential, emphasizing ChatGPT's role in enhancing personalized and compelling learning experiences.

Studies highlight both the capabilities and limitations of ChatGPT in medical education. Mondal *et al.,* [72] found it could generate understandable dermatological materials but raised concerns about originality. Wang *et al.,* [73] noted that its performance on the Chinese National Medical Licensing Examination lagged behind medical students, though its learning potential is promising. Meo *et al.,* [74], Gebrael *et al.,* [75] demonstrated its utility in assessments, scoring 72% on multiple-choice exams, while Friederichs *et al.,* [76] showed ChatGPT performed comparably to advanced medical students, answering 65.5% of progress test questions correctly. Banerjee *et al.,* [77] observed variability in addressing core physiology concepts, underscoring the need for further refinement.

These findings suggest ChatGPT's potential as a valuable tool for generating educational materials, assisting medical training and improving patient education. However, continuous evaluation and improvement are essential to address its limitations and ensure quality outcomes in medical education.

3.4.7 Cluster 7: GPT-4's advancements and future directions in healthcare

Cluster 7 focuses on advancements in GPT models, particularly their healthcare and biomedical engineering applications. Keywords such as "GPT-4" (8 occurrences) and "future" (5 occurrences) highlight the speculative and forward-looking nature of this research area. Although the observed frequencies are low, this cluster represents a promising innovation and future exploration niche.

The transition from GPT-3.5 to GPT-4 has significantly enhanced AI capabilities in healthcare. Kaneda *et al.,* [78] demonstrated GPT-4's improved accuracy on the Japanese National Nursing Examination, rising from 59.9% to 79.7%, showcasing the value of specialized training. Lee *et al.,* [79] explored GPT-4's broader impact on medical practice, while Cheng *et al.,* [80] highlighted its potential in biomedical engineering, including medical imaging and bioinformatics. Gebrael *et al.,* [75] showed GPT-4's ability to improve triage efficiency for metastatic prostate cancer patients in emergency care.

Li *et al.,* [81] addressed the limitations of general AI models through the development of ChatDoctor, a fine-tuned system providing more reliable medical advice. Zhu *et al.,* [82] further demonstrated GPT-4's potential to enhance communication in non-English-speaking outpatient clinics.

These studies underline GPT-4's transformative impact on healthcare, from education to clinical decision-making. However, ongoing refinement is necessary to ensure its safe, reliable and effective integration into medical practice.

3.4.8 Cluster 8: ChatGPT-4 in enhancing medical research

Cluster 8 explores the use of ChatGPT-4 in medical research, focusing on supporting systematic reviews and generating new research ideas. Keywords such as "gpt-4" (3 occurrences), "medical" (7 occurrences) and "research" (6 occurrences) reflect its specialized nature and emerging potential in leveraging AI for scientific discovery and knowledge generation. Despite low observed frequencies, this cluster highlights a promising area for innovation.

Studies demonstrate ChatGPT-4's advanced capabilities in various medical applications. Moshirfar *et al.,* [83] found GPT-4 outperformed GPT-3.5 and human experts in ophthalmology questions, showcasing its diagnostic potential. Gupta *et al.,* [84] highlighted its utility in generating systematic review ideas in cosmetic surgery, while Qu *et al.,* [85] observed high agreement between ChatGPT and physicians in otolaryngology diagnostics. Gupta *et al.,* [86] noted its potential in plastic surgery resident education, though Cohen *et al.,* [87] found lower accuracy in non-English exams, such as Hebrew OBGYN residency tests.

These findings underline GPT-4's transformative potential in medical research and education. However, continuous refinement is necessary to ensure its safe and effective integration into diverse medical fields.

3.5 Main Path Analysis Result

As shown in Figure 9, retail line trajectories illustrate the knowledge flow and evolution of ChatGPT research. MPA was used to identify the most influential studies within a citation network of 1,147 articles. This method constructs a DAG, where nodes represent articles and edges represent citation relationships. The SPC quantifies the importance of each node by measuring how frequently it appears in logical citation paths. Thicker lines in the diagram represent higher SPC values, highlighting the flow of ideas through pivotal studies.

The GMP, a specific outcome of MPA, traces the single most impactful sequence of studies within the network. This pathway identifies foundational works, critical transitions and emerging trends in ChatGPT research. The trajectory begins with early studies and foundations (2015–2019), such as Hill *et al.,* [88], which analysed human-chatbot communication dynamics and Ciechanowski *et al.,* [89], which explored user emotional responses, emphasizing the importance of natural and comfortable interactions. These foundational studies set the stage for the emerging applications and trust phase (2020–2021), including Youn *et al.,* [90], which investigated trust-building in customer relationship management (CRM) and Brandtzaeg *et al.,* [91], which examined emotional bonds formed between users and social chatbots.

The trajectory then progresses into advanced applications and ethical considerations (2022–2023), where ChatGPT became integrated into education and healthcare. For instance, Henrickson (2023) explored the ethical implications of generative AI, Dwivedi *et al.,* [92] provided a multidisciplinary perspective on its applications and Temsah *et al.,* [93] highlighted its role in the medical literature. Finally, the GMP culminates in specialized medical applications (2023), including studies like Meo *et al.,* [74], which demonstrated ChatGPT's potential in clinical decision-making and Almazyad *et al.,* [94], which illustrated its utility in paediatric palliative care. These studies show the progression from foundational research to practical applications in complex decision-making processes as shown in Table 5 (Appendix 1).

The exploration of ChatGPT technology has significantly progressed, attracting wide attention for its ability to provide articulate responses across various disciplines. Initial studies in medical education showed ChatGPT performing satisfactorily, indicating its potential for assisting students and faculty. However, challenges like "artificial hallucinations" and reliability issues in literature reviews highlighted the need for rigorous data verification. ChatGPT demonstrated high accuracy in patient education on urolithiasis and potential benefits in clinical decision support, though limitations such as biases and contextual understanding persist. ChatGPT's applications showed promise in plastic surgery but require further validation and ethical considerations.

The significance of MPA and GMP lies in their ability to uncover hidden patterns and relationships within a vast body of literature. By systematically mapping the flow and evolution of knowledge, MPA and GMP enable the identification of critical contributions, offering a comprehensive view of the intellectual structure of ChatGPT research. This approach highlights the progression from foundational concepts to specialized use cases and reveals persistent challenges such as bias, ethical considerations and contextual understanding. Forecasting future trends, increasing specialization, diverse field applications and integration into complex decision-making will be essential. Understanding key contributions and the flow of knowledge is crucial to harnessing AI technologies for future advancements, ensuring the evolution of GPT technology provides more excellent value across various fields.

4. Discussions

In the study of ChatGPT, MPA and GMP reveal key pathways that illustrate the evolution of this technology from its foundational stages to its more specific applications, with a close relationship between the growth of publications, research topics and technological advancements. Cluster 1, focusing on the impact and ethics of ChatGPT across various sectors, demonstrates rapid growth with an AGR (0.47) and RGR (0.96), reflecting significant interest in the application of ChatGPT in sectors such as healthcare, hospitality and cybersecurity, despite major challenges related to trust and ethics that remain significant barriers. MPA reveals that research initiated between 2015 and 2019, such as the studies by Hill *et al.,* [88] and Ciechanowski *et al.,* [89], serves as the foundation for subsequent developments.

Meanwhile, Cluster 2, which highlights AI chatbots in the healthcare sector, shows stable growth with an AGR (0.29) and RGR (0.59), though challenges persist regarding personalization and content consistency. In Cluster 3, focusing on trust and personalization in the effectiveness of chatbots, the lower AGR (0.14) and RGR (0.29) suggest that while this topic is already established, further improvements in personalized interaction and user experience will be crucial to enhancing the adoption of this technology. MPA indicates that while ethical challenges and the influence of language on users persist, studies from 2020 to 2023 on trust and emotional relationships with chatbots show significant developments.

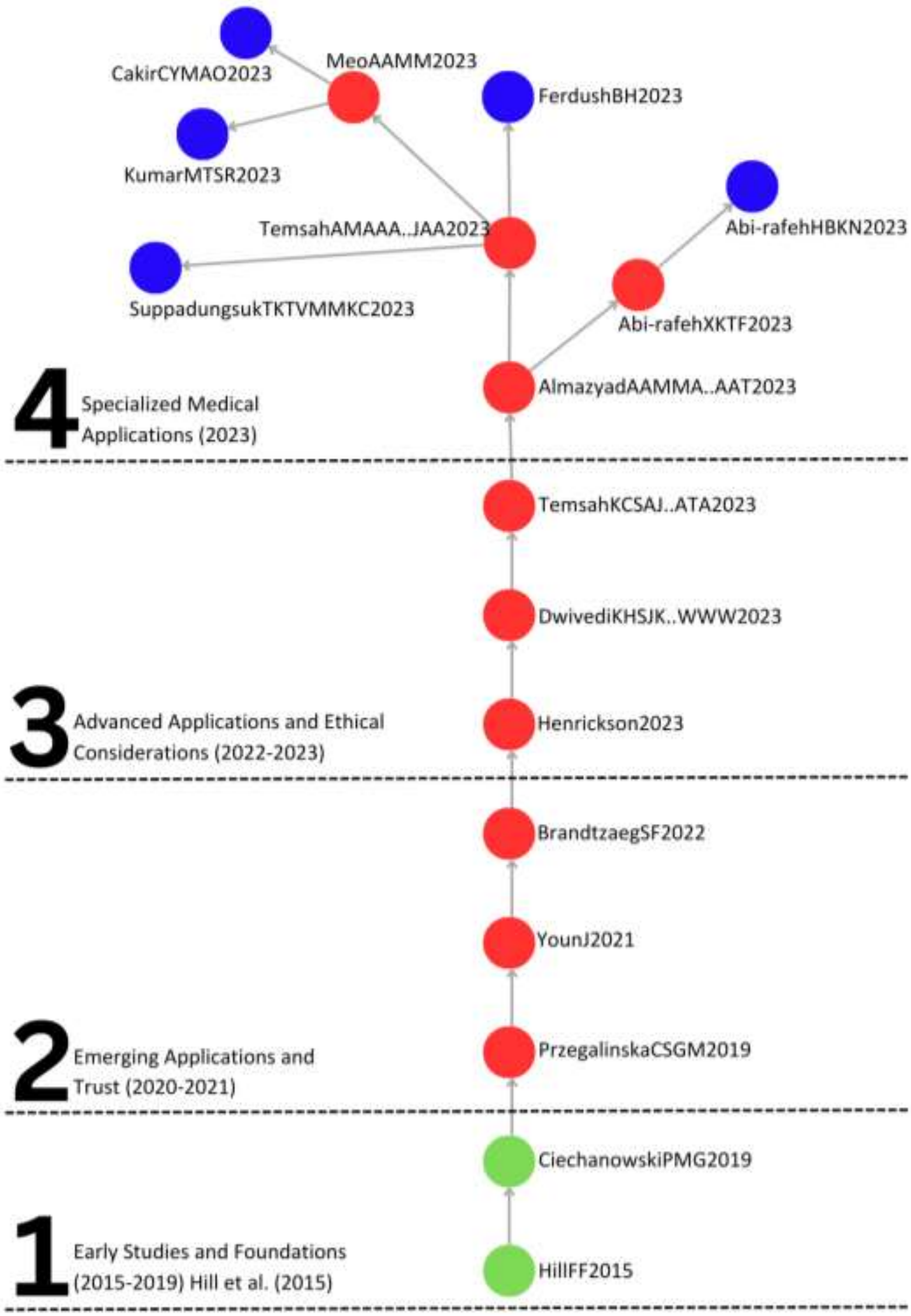


Fig. 9. ChatGPT knowledge development trajectory (redraw from Pajek Software result)

Cluster 4, which examines ChatGPT in education, presents lower AGR and RGR (0.05 and 0.1), reflecting slower growth. However, the potential for enhancing language learning and higher education remains, with key challenges related to accuracy and the background knowledge required from users. Clusters 5 through 8, which focus on more specific themes, show slower growth despite significant potential in advancing medical applications using GPT-4, with challenges such as non-English language processing and the need for continuous development still posing primary obstacles. MPA also highlights significant advancements in GPT-4, such as in prostate cancer triage and ophthalmology diagnosis, demonstrating how this technology could revolutionize medical practices if further refined.

However, despite the vast potential of ChatGPT across various sectors, fundamental challenges remain, mainly related to user trust, limitations in handling unstructured information and the potential for AI to generate inaccurate or biased responses. For example, health chatbots have shown promising results in supporting patient care in the medical sector. However, the scale of personalization and content consistency remains an issue that needs to be addressed to optimize their implementation. ChatGPT has enhanced language comprehension and academic motivation in education, but accuracy and reliance on the user's prior knowledge remain challenges to be tackled.

While ChatGPT holds significant potential to transform various sectors, it is essential to continue developing and adapting this technology while ensuring ethical use and reliability across diverse fields. Future research should prioritize trust and ethical considerations, as trust is critical in human-chatbot interactions. Personalization and user engagement must be the main focus, with further exploration of the optimal integration of ChatGPT in education and healthcare to balance the roles of AI and humans. Continuous evaluation and refinement of AI models, such as GPT-4, are vital to ensuring their reliability and application in more complex decision-making processes. This research provides a comprehensive overview of ChatGPT research, highlighting key areas and emerging trends. These findings emphasize the transformative potential of ChatGPT in various fields and underscore the importance of addressing ethical considerations, trust and user personalization in future research. By harnessing ChatGPT's capabilities and overcoming its challenges, researchers and practitioners can enhance human-computer interactions and improve outcomes across diverse domains.

5. Conclusions

In conclusion, this study provides a comprehensive analysis of the evolution of ChatGPT technology, from its foundational stages to its more specific applications across various sectors. By utilizing MPA and GMP, the study identifies key pathways that highlight the growth of publications, research topics and technological advancements. The findings emphasize the significant potential of ChatGPT, particularly in sectors such as healthcare, hospitality and cybersecurity, while acknowledging the ongoing challenges related to trust, personalization and ethics. Despite its promise, challenges such as handling unstructured information and addressing biases remain crucial obstacles that must be overcome to realize its full potential.

Moreover, the study provides several unique contributions to the existing literature on ChatGPT, including the identification of eight distinct research clusters, a focus on the pivotal role of trust, personalization and ethics in AI adoption and a chronological examination of the technology's development from 2015 to 2023. These contributions offer a more nuanced understanding of ChatGPT’s evolution, development trends and sector-specific challenges. The study also proposes actionable recommendations for overcoming these challenges, particularly emphasizing the need for continued research into user engagement, the integration of ChatGPT in healthcare and education and addressing ethical concerns to improve the acceptance and effectiveness of AI systems.

Overall, the research underscores the transformative potential of ChatGPT across multiple fields and provides valuable insights for researchers and practitioners. ChatGPT can continue to evolve and significantly enhance human-computer interactions across diverse domains by addressing the identified challenges and focusing on improving trust, personalization and ethical considerations.

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