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Visualization analysis of artificial intelligence education research in primary and secondary schools based on CiteSpace knowledge map

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Abstract: With the explosive growth of artificial intelligence; the development of AI technology has also transformed various aspects of life. New industries under “Artificial Intelligence+” leadership—including smart healthcare; smart homes; and smart transportation—are flourishing. In addition; AI has also made an impact on the education sector. AI education in primary and secondary schools is an important initiative to cultivate innovative and interdisciplinary talent. Based on the CNKI and Web of Science database. Web of Science database; this study employs knowledge graph analysis and content analysis methods; using CiteSpace software widely used by researchers in scientometrics. It analyzes knowledge graphs visually on 2611 papers published between 2014 and 2024; focusing on the current status; hotspots; and frontiers of AI education in primary and secondary schools. The objective is to serve as a guide for tracking the advancement and forthcoming trends in AI education within elementary and high schools. The study found that the research interest in AI education has been steadily rising; with publishing countries concentrated in China; the United States; the United Kingdom; and others. The majority of publications come from universities; while the number of publications from primary and secondary schools and frontline teachers is somewhat lower. The research hotspots in this field focus on aspects such as “smart education”; “robotic education”; and “intelligent education”. In light of this; this study attempts to provide suggestions for future development from three dimensions.

Keywords: artificial intelligence education; CiteSpace; research hotspots.

1. Introduction

In recent years, artificial intelligence has begun to explode, especially in 2016, when AlphaGo defeated the human Go champion, making people’s attention to artificial intelligence continue to rise. The State Council released the “New Generation of Artificial Intelligence Development Plan” in July 2017, explicitly declaring the broader use of artificial intelligence in educational contexts. Establishing artificial intelligence classes in elementary and high schools and conducting cross-disciplinary studies is crucial, especially as artificial intelligence research has surged in popularity recently [1]. The Ministry of Education’s General Office released the “Key Points of Education Informatization and Network Security in 2019”, and published several sets of textbooks related to artificial intelligence education [2].



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The year 2022 saw the release of the mandatory Education Information Technology Curriculum Standards (2022 Edition), involving artificial intelligence education and affirming its importance [3]. In addition, countries such as the United States, Japan, the United Kingdom, and Singapore have incorporated robot learning, artificial intelligence education, interdisciplinary STEM courses, and programming courses into the curriculum system of elementary and high schools. Integrating artificial intelligence training in elementary and high schools forms the foundation for establishing a nationwide intelligence education system that is both fundamental and universal.

In addition, integrating artificial intelligence into elementary and high school education holds significant practical value in enhancing students' abilities in computational reasoning, intellectual literacy, and innovative skills. There is a widespread tendency to implement artificial intelligence training in elementary and high schools. However, at present, there is still a lack of visual analysis and research in this field. In addition, there are some problems in artificial intelligence education, such as a lack of teachers and no unified curriculum standards. Therefore, this study combines bibliometric research and knowledge visualization and uses CiteSpaceV 6.2.R6 software to visualize the research hotspots, current situation, and future research frontier trends of artificial intelligence education in schools for elementary and high school education, to explore the research status of artificial intelligence education, grasp the research hotspots, and provide reference for future artificial intelligence education.

2. Research design

2.1. Data sources

This study mainly uses CNKI and Web of Science database as the main data sources. In CNKI, the "advanced search" function is selected, the "topic" search is selected, the "primary and secondary school AND artificial intelligence education" is used as the subject word, the "title" search is selected, and the title is set to "artificial intelligence education" OR "artificial intelligence teaching" OR "education artificial intelligence", and the secondary search is carried out accordingly. All matching ranges are set to "precise" to ensure the accuracy and relevance of the screening results. The time span was from 2014 to 2024, and 443 and 1003 articles were retrieved respectively, with a total of 1446 related articles. The retrieved documents were manually screened for invalid documents (*i.e.*, 45 conferences, 25 newspapers, 3 books, and 3 results), software deduplication, and literature abstracts. Finally, 1525 valid documents were obtained from the CNKI database as research samples.

Web of Science is a Web-based product developed by Clarivate Analytics in the United States. It has become an important academic resource platform widely used in academia due to its comprehensiveness, authority, powerful retrieval function, timely data update, and convenient resource acquisition. Search date: 2024-11-05, search time: 2014-11-01/2024-11-01. The search topic is: "Primary and secondary school" OR "artificial intelligence course" OR "artificial intelligence education". The second search topic is: "Primary and secondary school" AND "artificial intelligence course" OR "artificial intelligence education". The search language type was limited to "English", and the literature type was limited to "article" and "review article". After excluding reviews, book reviews, annotations, *etc.*, 1086 articles were finally obtained after deduplication. After deduplication, 1086 articles were obtained, and the literature data were derived in pure text format in the form of full records

and cited references. Finally, a total of 2611 valid documents in CNKI and Web of Science databases were saved in download_*.txt format, and then imported into CiteSpace software for data analysis.

2.2. Research method

This study mainly uses two map analysis methods: keyword co-occurrence map analysis and clustering map analysis to show the hot frontiers and research trends in this field. Literature analysis and content analysis methods are adopted in this paper, which can reveal the essence of literature content and predict the future development trend so that the research results are objective and credible. In addition, CiteSpaceV 6.2.R6 software are used to draw maps from keywords, publishing institutions, and authors, and count the annual number of publications and publishing institutions and authors. Based on the visualization results, the research progress, research hotspots, and frontier trends of artificial intelligence education in elementary and high schools in various countries are obtained.

First of all, the literature export format is selected from the CNKI and Web of Science databases as the plain text format, and then the downloaded literature is imported into CiteSpace software for format conversion and literature deduplication. After the import is successful, the annual interval (Time Slicing) is set to 2014–2024, the time slice (Years Per Slice) is set to 1, the node type (Node Types) selects the keyword (Keywords), and the citation frequency threshold (Top N) is set to TOP 50. Pathfinder and Pruning Sliced Networks are selected for cutting mode, and keyword co-occurrence and clustering maps are drawn respectively.

2.3. Research tool

In the field of scientometrics, CiteSpace and VOSviewer are widely used by researchers in visualization software. Dr. Chen Chaomei of Drexel University's School of Computing and Information created the visual data analysis tool CiteSpace for this research, utilizing the Java platform [4].

3. Analysis of the research status of artificial intelligence education

3.1. Distribution of annual publication volume

To understand the number of papers published in artificial intelligence education in the past ten years, and to explore the development trend in this field, this study derived data from CiteSpace and used Excel software to analyze the changes in the number of papers published in artificial intelligence education in elementary and high schools over the past ten years. The analysis results are shown in Figure 1. It can be seen from Figure 1 that since 2017, the number of literature related to artificial intelligence education has increased year by year, and the largest increase has been in 2022 and 2024, especially reaching a peak of 563 in 2024. It can be seen that artificial intelligence education has received unprecedented attention since 2017, which is closely related to the implementation of China's policies. As an illustration, the State Council released the "New Generation of Artificial Intelligence Development Plan" in 2017, emphasizing the need for courses related to artificial intelligence in elementary and high schools. Under the guidance of national policies, artificial intelligence education is still a hot topic for researchers today and in the future.

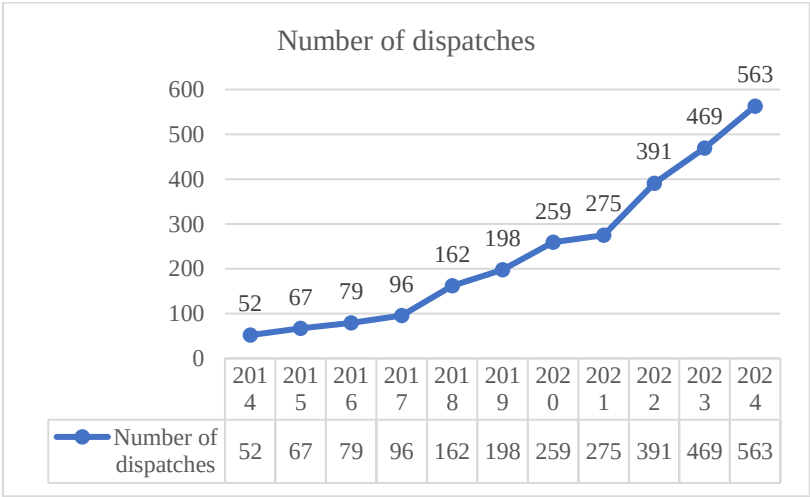


Figure 1. Change chart of the number of published papers with year.

It can be seen from Figure 1 that on the whole, the number of documents in the field of artificial intelligence education has shown an upward trend in the past decade, which can be divided into three stages: (1) germination period (2014–2016), a total of 198 articles were published during this period. This period mainly focuses on artificial intelligence teaching, and related hot words are budding. (2) During the period of rapid development (2017–2021), the literature related to artificial intelligence education in this period showed an upward trend. The number of publications rose from 198 in the previous period to 990, from 96 in 2017 to 275 in 2021. In the four years, the number of publications rose rapidly. It can be seen that artificial intelligence education has been paid more and more attention to and favored by researchers. Related research hotspots and topics have also mushroomed, such as artificial intelligence education, programming education, *etc.* (3) Sustainable development period (2022–2024) From 2021 to 2023, the number of papers published in the past decade is the largest and the most concentrated in three years. This period focuses on some hot words such as intelligent literacy and robot education. In a word, the research on artificial intelligence education in various countries is still under exploration and will continue to develop in the future.

3.2. Distribution of countries and institutions

To study the distribution of publishing countries and core publishing institutions and their research results, a visual analysis of publishing countries and research institutions is made. Table 1 shows the number of articles published in CNKI and WoS in each country (2014–2024). It can be seen from Table 1 that China has published 485 articles, which is the most published country, followed by the United States, which has published 231 articles, followed by England, which has published 115 articles. The reason why China ranks first in the number of published articles is the country’s emphasis on artificial intelligence education.

With the advent of the AIGC era, the research results of artificial intelligence education are constantly emerging, which has attracted more and more researchers to pay attention to and try to study this frontier field. Based on CiteSpace, this study draws a map of publishing institutions with more than two articles, as shown in Figure 2.

Table 1. Statistics of publications by country.

Sorting	Frequency	Year	Country
1	485	2014	PEOPLES R CHINA
2	231	2014	USA
3	115	2014	ENGLAND
4	98	2014	AUSTRALIA
5	92	2014	SPAIN
6	48	2014	GERMANY
7	35	2015	NETHERLANDS
8	33	2016	ITALY
9	23	2015	TURKEY
10	21	2014	CANADA
11	21	2014	BELGIUM
12	20	2016	NORWAY

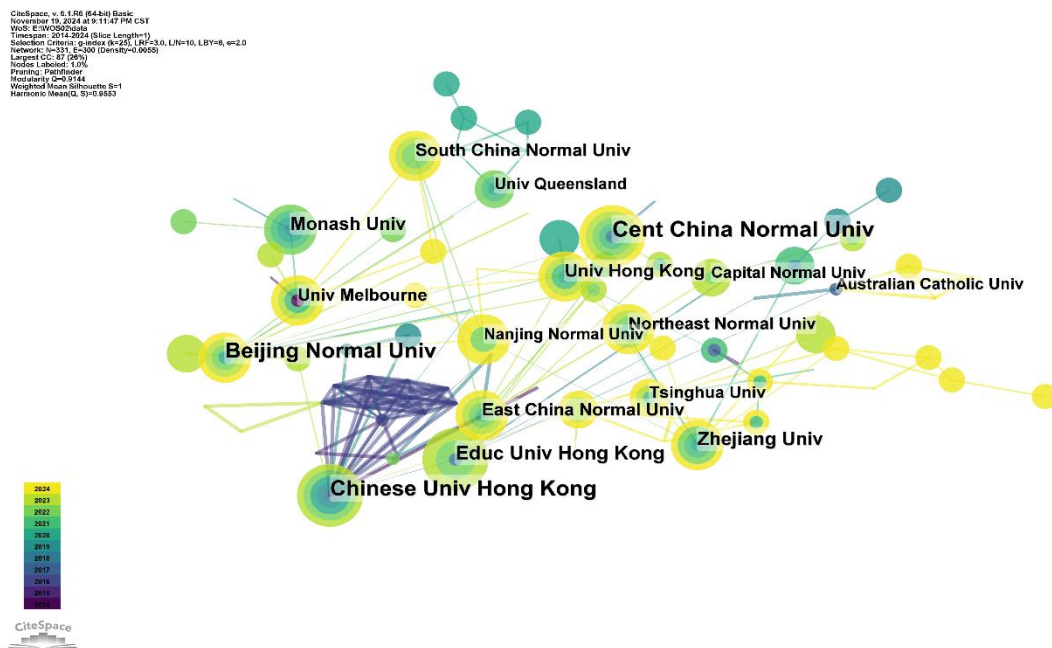


Figure 2. Knowledge map of publishing institutions based on CiteSpace.

It can be seen from Figure 2 that the institutions that published the most foreign articles from 2014 to 2024 were Beijing Normal University and Cent China Normal University, which were ranked first, followed by Chinese University Hong Kong, ranked second, and University Melbourne, ranked third. The starting time is still 2014, and most of the institutions that publish foreign articles are Chinese universities. At the same time, a team of close cooperation and communication has been formed among institutions in various countries, as shown in Figure 2. Teams represented by Chinese University Hong Kong, Harvard University, Boston University, and Balamand University have been formed. In particular, Chinese University Hong Kong has closer exchanges with other universities and should pay more attention to strengthening international exchanges and cooperation in the later period.

Researchers from various research institutions have tried to implement artificial intelligence education in elementary and high schools from the frontier development and application of artificial intelligence education. At the same time, there is no lack of research on the ethical and moral judgment of artificial intelligence education, but further research results need to be strengthened.

4. Analysis of the research results of artificial intelligence education

4.1. Visual analysis of research hotspots and frontier

4.1.1. Keyword co-occurrence analysis

This study uses the software tool CiteSpace to conduct keyword co-occurrence and betweenness centrality analysis on the literature of artificial intelligence education in elementary and high schools. Keywords are the core summary of the literature. Through the analysis of the keywords of the literature, we can more intuitively explore and grasp the research direction and research focus of the literature. Betweenness centrality refers to the central position of keywords in the whole collinear graph, and nodes with centrality greater than 0.1 are usually called key nodes. Keywords are selected as nodes, and the threshold of keywords is adjusted to 4, and the keyword co-occurrence map based on CiteSpace is obtained, as shown in Figure 3. The network density in the map is Density = 0.0138, network node N = 275, and network connection E = 521, that is, the keywords of the map are closely related.

In the keyword co-occurrence graph, each circle in the graph represents a keyword, and the size of the circle represents the frequency of the keyword. The larger the frequency, the larger the circle and the keyword appear in the same literature. There will be a connection, the thickness and density of the connection represent the closeness of the connection between the keywords, and the top horizontal axis uses different colors to indicate the year when the keyword appears. It can be seen from Figure 3 that the keywords with high frequency are “artificial intelligence”, “elementary and high schools”, “education”, “robot”, “machine learning”, “intelligent education”, “intelligent literacy”, “maker education”, “deep learning”, etc., and the redder color of the outer frame indicates that this field is a research hotspot in recent years, especially the hot words such as “artificial intelligence”, “intelligent literacy” and “robot”. To a certain extent, this shows that artificial intelligence education in elementary and high schools in various countries is closely related to the frontier research hot words, and these hot words will also be a research direction for future researchers.

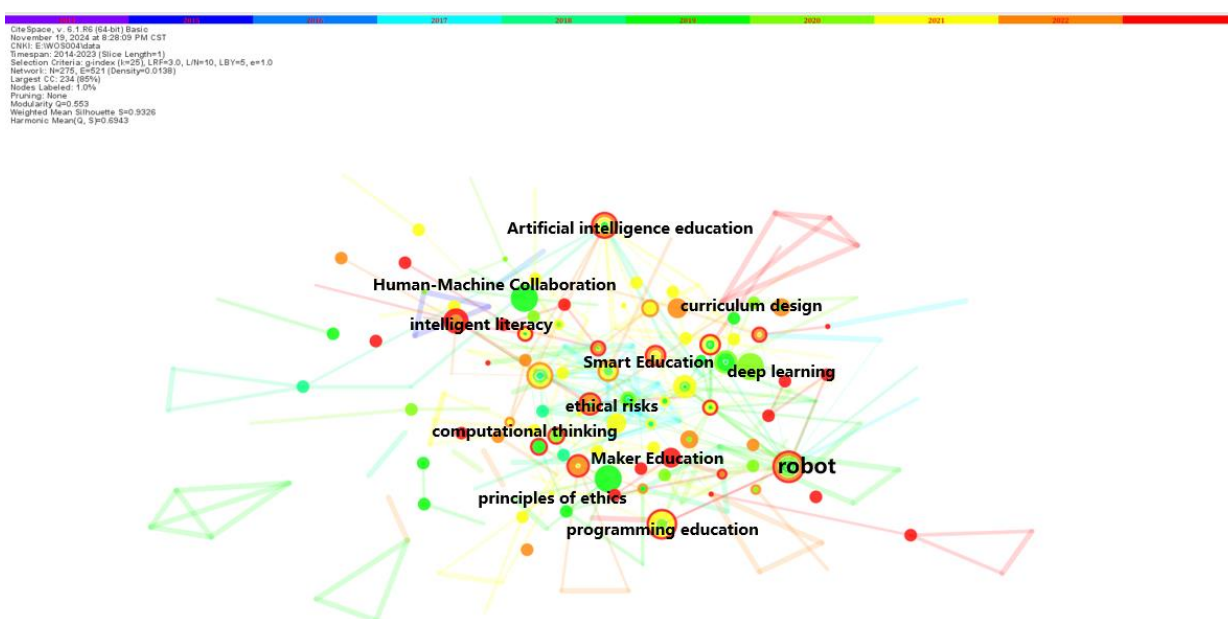


Figure 3. Keyword co-occurrence map based on CiteSpace.

4.1.2. Keyword clustering view analysis

Keyword clustering analysis is a process of simplifying the keyword co-occurrence map into a relatively small number of clusters through statistical methods to understand the scope of research hotspots in this field. Based on the keyword co-occurrence analysis, this study uses the log-likelihood algorithm (LLR algorithm) for cluster analysis, and obtains a knowledge map with a cluster number of 9, as shown in Figure 4. In the cluster diagram, $Q = 0.553 > 0.3$, $S = 0.7963 > 0.7$. The values of Q and S indicate that the cluster is significant and the conclusion is credible. Therefore, the results of clustering can be divided into six areas: artificial intelligence education, robot education, information technology, deep learning, teaching models, and ethical judgment.

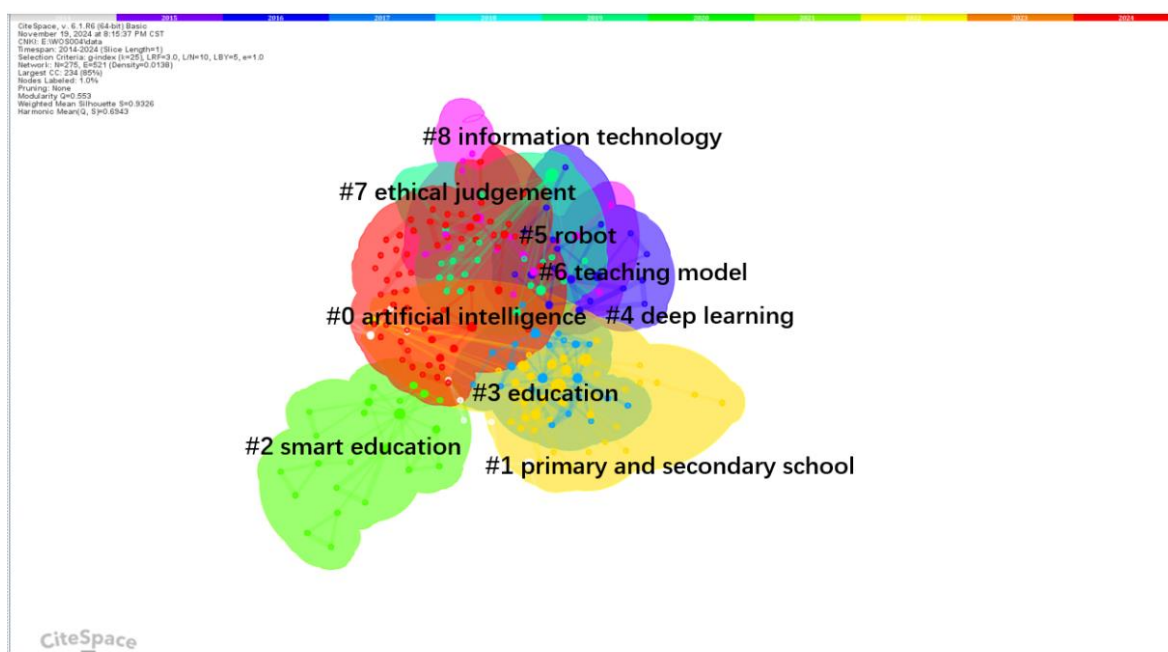


Figure 4. Keyword clustering map based on CiteSpace.

(1) Artificial Intelligence Education

The clusters related to artificial intelligence education are # 0 artificial intelligence, # 1 elementary and high schools, # 2 intelligent education, and # 3 education. The key technologies of artificial intelligence education include machine learning, natural language processing, computer vision, knowledge graphs, human-computer interaction, and robots [5]. The arrival of the era of human-computer interaction and robot AIGC will profoundly change the intelligent learning environment and conditions, and also make the interactive and personalized learning needs more urgent [6]. Smart education is a future education paradigm that optimizes the teaching process and promotes the better development of learners through human-computer collaboration [7]. It can be seen that human-machine collaboration and intelligent education are closely related to artificial intelligence education.

(2) Robot Education

The clustering related to robot education has # 5 robots. The so-called robot education usually refers to the theory and practice of learning the basic knowledge and basic skills of robots or using educational robots to optimize the effect of education and teaching. The application of robots in the field of education has shown unparalleled educational value and development prospects. Its multi-disciplinary cross-integration characteristics provide a good platform for cultivating wide-caliber, high-quality, and compound

engineering talents. The introduction of educational robots will be a new trend in education, which will enable students to produce many new applications [8]. The educational robot programming course is divided into three stages: primary, intermediate, and advanced. The introduction of robots in programming design can effectively improve the cultivation of students' computational thinking abilities [9]. It can be seen that robot education and programming education in China are closely related, which is also the main form of artificial intelligence education in elementary and high schools in China.

(3) Information Technology

The cluster related to information technology is # 8 information technology. Cultivating students' information consciousness is one of the core qualities of information technology. The teaching goal of information technology teaching is to let students understand, perceive, and experience artificial intelligence. Carrying out artificial intelligence teaching in the process of information technology teaching in elementary and high schools is conducive to popularizing new information technology knowledge. Researchers proposed that "intelligent literacy" is a multi-dimensional composite structure that integrates knowledge, ability, and emotion, including four dimensions, namely, intelligent knowledge, ability, attitude, and ethics. In the current education, we are trying to change from focusing on students' "information literacy" to focusing on cultivating "intelligent literacy" in information technology teaching.

(4) Deep Learning

The clustering related to deep learning is # 4 deep learning. Deep learning is the optimal integration of information deep processing process, teachers' deep guidance process, and technical deep support process from the perspective of learning science [10]. Chen *et al.* [11] constructed a learning model based on knowledge construction and blended learning theory. The experimental results show that the model can effectively improve students' computational thinking ability and promote their computational deep learning ability. The research in the field of primary and secondary education is based on solving practical problems in teaching and improving students' computational thinking ability as the core of quality education. Yu *et al.* [12] integrated computational thinking into the subject literacy of "artificial intelligence". Through the curriculum design based on "project-task-activity", they emphasized the cultivation of computational thinking ability and weakened the traditional teaching. Computational thinking has also become an essential literacy for learners in the era of intelligence. How teachers cultivate and improve students' computational thinking in their daily teaching work will also be a new concern.

(5) Teaching Model

The cluster related to the teaching model is # 6 teaching model. Professor He Kekang proposed that the educational thought of constructivism changed from "student-centered" to "dominant-subject combination". The "student-centered" teaching mode helps to give full play to students' initiative and creativity, while the "leading-subject combination" teaching mode helps to improve the degree of students' internalization of knowledge. The teaching mode of artificial intelligence education based on the theory of "paying equal attention to learning and teaching" combines theoretical teaching with practical operation [13]. This theory is of great significance for cultivating students' innovative ability and cooperative ability, computational thinking, and intelligent literacy.

(6) Ethical Judgment

The cluster related to ethical judgment is # 7 ethical judgment. In the process of promoting educational reform, artificial intelligence technology also inevitably brings unpredictable ethical risks to

education. Some researchers discussed the ethical principles of educational artificial intelligence systems from the macro and micro levels and predicted the ethical problems that may be encountered in the future. Finally, based on China's national conditions, they gave suggestions for educational artificial intelligence in the face of ethical problems. Zhao *et al.* [14] sorted out the four dimensions of the ethical principles of educational artificial intelligence, namely, algorithm dimension, relationship dimension, emotion dimension, and resource dimension, and constructed the risk elimination path of four dimensions based on this. Scott *et al.* [15] puts forward that the current artificial intelligence lacks moral standards to express serious concern. The impact includes the ability to immediately use some artificial intelligence tools to improve course planning, and the ability to use artificial intelligence as a tool to improve student work.

5. Suggestions on the research and development of artificial intelligence education

By combing and studying the relevant literature in this field in the past ten years, it is found that the research heat of artificial intelligence in the basic education stage is still on the rise, and the relevant researchers in various countries are still in the exploration period of artificial intelligence education. Therefore, there is still a lot of room for exploration in the field of artificial intelligence education in the future. Future research can combine theoretical research with practical application, cultivate professional teachers in the direction of artificial intelligence, focus on stimulating students' innovative ability, and lay a foundation for cultivating innovative and computational thinking talents. Based on this, to better promote the application of artificial intelligence in primary and secondary education, this study attempts to put forward suggestions for the future development of artificial intelligence education from the following three dimensions:

5.1. Strengthen collaboration and share scientific research achievements

First, strengthen cooperation and share scientific research results. Some universities in some countries have formed relatively stable research groups, but they are relatively closed and independent. It is necessary to further establish a cross-institutional and interdisciplinary communication mechanism, which not only helps to improve the teaching level of teachers, but also promotes the transformation of research results to a certain extent. For example, an interdisciplinary communication platform can be established. Using Internet technology, an online communication community for information technology teachers in elementary and high schools can be created. Different theme sections can be set up in the community, such as teaching resource sharing, subject research, and practical experience sharing, so as to facilitate teachers to learn and communicate with each other. For example, interdisciplinary courses can be set up in elementary and high schools to cultivate students' artificial intelligence literacy and reserve talents for the future development of education.

In addition, a centralized sharing platform for scientific research results is established, so that different viewpoints can generate sparks of innovative thinking in the collision of each other, and a virtuous circle is realized. Starting from the aspects of teaching objectives, teaching content and teaching process, we should integrate all resources, unite multiple forces, and promote the formation of a standardized artificial intelligence curriculum system for elementary and high schools.

5.2. Improve curriculum cognition and clarify curriculum orientation

Second, improve curriculum cognition and clarify curriculum positioning. At present, 11 countries around the world have developed and implemented artificial intelligence courses. China has also mentioned in a number of policy documents that it is necessary to set up artificial intelligence courses in elementary and high schools. Setting up artificial intelligence courses in elementary and high schools is an important way to cultivate students' innovative thinking and scientific and technological literacy. In order to design artificial intelligence courses suitable for primary and junior high schools, the following aspects can be considered: First, the goal and orientation of the course should be clarified, that is, to cultivate students' basic cognition, interest and preliminary application ability of artificial intelligence. Secondly, the content selection should be suitable for students' cognitive characteristics, and introduce the basic concepts, historical development and simple programming and data processing skills of artificial intelligence from shallow to deep. Third, teaching methods should be diversified, combined with modern educational techniques, such as multimedia and online platforms, to improve teaching effectiveness. The fourth evaluation system should be diversified and timely feedback of students' learning progress. At the same time, strengthen the professional training of teachers, improve their teaching ability, and ensure that schools have sufficient resources to support the teaching of artificial intelligence courses. Finally, we will strive for the support of the government, enterprises and society to provide the necessary financial and policy guarantees for artificial intelligence education in elementary and high schools, and jointly promote the development of artificial intelligence courses in elementary and high schools.

However, in the specific practice process of artificial intelligence courses, there are often problems such as teachers' nowhere to start or treating artificial intelligence courses as programming courses. The fundamental reason is that teachers lack a clear understanding of artificial intelligence courses, and the curriculum positioning is ambiguous. Therefore, at the school level, schools should provide teachers with learning opportunities and platforms, organize regular professional training for teachers, let them understand artificial intelligence in depth, and be able to apply what they have learned, so as to bring better artificial intelligence education to students. At the individual level of teachers, teachers should constantly update the knowledge system, expand artificial intelligence knowledge, innovate education and teaching methods, identify curriculum positioning, and focus on the cultivation of students' core literacy.

5.3. Focus on ethics, pay attention to the power of emotional education

Third, pay attention to ethics, pay attention to the power of emotional education. With the advent of the era of AIGC (generative artificial intelligence), the advent of the AI-based big language model Chatgpt has brought new opportunities and challenges to the field of education. In the future, it is necessary to strengthen supervision in ethical judgment and ethics and comply with the ethics of artificial intelligence. In addition, more attention should be paid to the humanistic concept, the cultivation of emotional education power, and the internalization of artificial intelligence education into students' skill knowledge, so as to lay a solid foundation for the cultivation of talents with comprehensive development of intelligent literacy, computational thinking and information literacy.

6. Conclusion and future work

Based on the CNKI and web of science database, this study uses CiteSpace and Excel software to briefly analyze the development status, hot spots, and frontier trends of artificial intelligence education in elementary and high schools. From a macro perspective, artificial intelligence education is still in the exploratory stage of development, and there is a lot of research space in the future. The development and improvement of artificial intelligence education need to be promoted jointly by the government, elementary and high schools, teachers, and researchers, to keep up with the forefront of artificial intelligence education.

In general, this study still has limitations. First, there are few journal literature research data from 2014 to 2024 for research hotspots, and software-related parameter settings need to be further optimized. Secondly, only the literature keywords are used to analyze the research hotspots and frontier trends. The follow-up research will be further improved, and other related analyses such as highly cited literature and literature source journals will be added to enhance the reliability of the conclusions.

Declaration of generative AI and AI-assisted technologies

The authors did not use generative AI or AI-assisted technologies in the writing of this manuscript.

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Authors' contribution

Conceptualization, Mengjiao Ruan and Feng Zhang; methodology, Feng Zhang; software, Xia Yang; validation, Mengjiao Ruan, Qin Mao and Xia Yang; formal analysis, Feng Zhang; investigation, Xia Yang; resources, Mengjiao Ruan; data curation, Xia Yang and Qin Mao; writing—original draft preparation, Mengjiao Ruan; writing—review and editing, Qin Mao and Feng Zhang; visualization, Mengjiao Ruan, Qin Mao and Xia Yang; supervision, Qin Mao; project administration, Qin Mao; funding acquisition, Qin Mao. All authors have read and agreed to the published version of the manuscript.

Conflicts of interests

The authors declare no conflict of interest.

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