Research Status, Hotspots, and Evolutionary Trends of Intelligent Education from the Perspective of Knowledge Graph

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Abstract: Intelligent education research has become a research hotspot in recent years. The Citespace software that operates a graph visualization function was used to clarify the current situation, hotspots, and evolutionary trends of intelligent education research development; the authors, institutions, and countries engaged in intelligent education research, as well as the basic knowledge structure, main keywords, citation clustering, dual-map overlay of journals and citation emergence of intelligent education research. The results show that the annual number of publications in the field has shown an upward trend since 2010, with strong communication among research institutions and countries, but weak communication among researchers. Among them, the United States is the center of the global collaborative network of intelligent education research. The basic knowledge structure of intelligence education research is mainly composed of Classroom Management, Evaluation Index, 5G Network, and Big Data Analytics. The dual-map overlay analysis of journals shows that the core areas of intelligence education are increasing, and the analysis of keywords and cited literature shows that Intelligence Tutoring System, AI system, Students and Education, Model, and System are high-frequency words with high-intensity burstness. In addition, research on intelligent education is characterized by multi-country, multi-field, and multi-disciplinary integration, and the adoption of Big Data, Distance Education Technology and Artificial Intelligence Technology to provide scientific support for teaching and learning will become the key research content in this field in the future.

Keywords: intelligence education; smart education; artificial intelligence technology; knowledge graph visualization; big data

1. Introduction

The development of society is inseparable from talents, it is a necessary way to cultivate talents in education. The application of artificial intelligence technology and big data analysis technology in the field of education can improve the effectiveness of teaching, reduce the teaching work of teachers, assist students in adaptive learning, and facilitate the cultivation of new talents. The application of AI technologies in the field of education has become the focus which is now able to assist and design the teaching and learning process with the help of intelligent technology, to create a more-effective learning environment for students [1,2]. Artificial intelligence technology provides the technical basis for education; however, it is too narrow to place intelligent education on the content of AI. Intelligent education is not only about intelligent teaching methods, but also about the use of scientific information technology to develop teaching processes, methods, educational management, and learning, with the goal of human cognitive development [3,4]. Intelligent education is driven by developing students’ thinking skills, acquiring knowledge in the process of intelligent teaching and learning, and promoting students’ thinking, innovation, and problem-solving skills [5–7]. As a new educational model for talent development,
intelligent education has received attention and attracted a lot of research by a wide range of researchers worldwide.

The technological era of continuous development and improvement of information technology has arrived, while the proportion of education as the country’s core competitiveness is increasing. Intelligent education, as a teaching model to cultivate new talents, has received wide attention from countries around the world and the global education model has ushered in new opportunities. The United States, Germany, Japan, China, and the United Kingdom have all released policies related to intelligent education. For example, the Massachusetts Institute of Technology released the Modern Industrial Strategy indicating the possibility of the development of intelligent education [8]. In 2017, the White House Office of Science and Technology Policy proposed in the report Preparing for the Future of Artificial Intelligence that “all citizens should be prepared to receive Artificial Intelligence education”, which can not only improve the citizen’s level of data knowledge, but also prepare students to understand higher-level data concepts and courses after high school [9]. In the UK, several policies dealing with AI education were released consecutively in 2015 and 2016, including the Digital Strategy and the Opportunities and Impact of AI on Future Decision Making [10,11]. The German and Japanese governments have also developed pathways for AI development and launched high-tech strategic projects such as the “Superpower Society”, “Human Brain Project”, and “Intelligent Data Project”. In 2010, the Chinese government released the Outline of the National Medium- and Long-term Education Reform and Development Plan (2010–2020), which incorporated education informatization into the overall national informatization strategy, stating that information technology has a revolutionary impact on education and must be given high priority [12]. In 2017, China officially included “artificial intelligence” in its government work report. In July of that year, the State Council issued the New Generation Artificial Intelligence Development Plan where AI rose to become a national strategy, clearly pointing out that AI has become the new focus of international competition and should gradually carry out intelligent education projects for all, build a new education system including intelligent learning, interactive learning, and promote the application of AI in the whole process of teaching, management, and resource construction [13]. In April 2018, the Ministry of Education issued the Action Plan for Education Informatization 2.0, which emphasizes the practical integration of AI into the actual teaching environment through big data analysis and other technologies, so as to tailor the teaching method to each individual’s unique situation [14].

Intelligent education originated from the “post-industrial society” revolution in the late 1980s when Toffler [15] published The Third Wave, which marked mankind’s move towards the information age. The Okinawa Charter on the Global Information Society released in 2000 formally recognized that human society has transitioned from a post-industrial society to an information society, and intelligent education has become increasingly important in the field of education with the continuous development of information technology [16,17]. Since 2013, teaching analysis and evaluation reform have gained momentum with the advent of the big data era [18].

After 2016, with the continuous maturation of big data analysis technology that has driven the rapid development of AI education, researchers have started to conduct many practical analyses on the application of AI. Of course, many scholars have also conducted research on the application of intelligent technologies in education. For example, Han [19] analyzed the new advances in the application of AI in education in the context of Internet technology based on the web 3.0 era and concluded that AI education has far-reaching implications. Lu [20] investigated and analyzed theoretical models and applications of AI and objectively pointed out the trends in this field. Shvetsova [21] discussed various approaches to intelligent educational management in universities, analyzed the application of intelligent educational management methods in university training policy, and found that intelligent education is the future trend in education. Renz et al. [22] analyzed the practical path of intelligent technology in education. Neller [23] proposed the importance of intelligent education based on the role of AI technologies in aiding game design. Ibáñez and

With the outbreak of novel coronavirus disease at the end of 2019, intelligent education has played an important role in the field of education, providing effective implementation of educational and teaching activities in countries around the world [26]. Intelligent education can facilitate students’ learning and teachers’ teaching, opening a new avenue in the field of education [27]. This has created a huge impact on intelligent education, and the whole field of intelligent education has seen a huge change. For example, breakthroughs in key technologies and their deepening integration in educational scenarios had driven the accelerated development of online education, AI education, and adaptive learning [28–30]. With the rapid development of digital and intelligent education, the future application and development of intelligent education have become the focus of many researchers. Although a large amount of intelligent education research has been carried out, there is still a lack of systematic and objective organizational research. In this context, effective in-depth analysis of this field has become necessary and bibliometric methods are tools to explore core authors, institutions, and influential journals as an effective way to understand research hotspots and trends in a particular field. Therefore, this study aims to analyze the current situation regarding research hotspots and evolutionary trends in the field of intelligent education research based on bibliometric methods; this can provide useful research entry points for subsequent studies.

The rest of the paper is organized as follows: Section 2 contains an overview of research data and research instruments. Section 3 contains an overview of the authors, institutional distribution, and knowledge structure of Intelligent Education. It also explains the structure of the given graph. Section 4 illustrates the theoretical foundations and new driving forces of Intelligent Education and discusses the results of Intelligent Education. Finally, Section 5 concludes the work.

2. Research Materials and Methods

2.1. Research Data Sources

To ensure that the original data were comprehensive, accurate, and had a high degree of interpretation, the study used the Web of Science core collection (with SSCI and SCI-Expanded as the search focus) as the data source, and the retrieval search topic was limited to (“Intelligent Education”). Since the earliest inclusion of Intelligent Education Research literature in the database was around 2010, the time limit for screening research literature was “1 January 2010 to 5 May 2022”. Similarly, to improve the quality of research, the literature search was conducted by selecting “article” as the literature type and “English” as the language while filtering out “review” and “book review”. The filtering results were verified by experienced computer researchers, and the result was 1190 papers related to intelligent education.

2.2. Research Methods and Tools

The research mainly uses Citespace software for data mining and metrological analysis. Based on co-citation analysis theory, pathfinding network algorithm, minimum spanning tree algorithm, etc., the literature data were analyzed econometrically to detect the current situation, research hotspots, and evolutionary trends of the field by drawing a map. The analysis included author analysis, institutional analysis, country co-occurrence network analysis, keyword co-occurrence mapping analysis, journal dual-map overlay analysis, and citation mutability analysis. Thus, it reveals the current research status and development trend in the field of intelligent education research.
2.3. Data Processing

All literature information was exported to plain text format. Time was set to “January 2010–May 2022” and the time slice was set to 1 year. The four attributes of Title, Abstract, Author Keywords, and Keywords plus under the Terminology Resources menu bar were all checked, and the Selection Criteria under the Top N% column was set to 25%. Pathfinder, Minimum Spanning Tree, and Pruning the Merged Network were used to crop the co-occurrence knowledge network.

3. Results and Analysis


The statistical analysis of the number of papers published in the field of intelligent education research (Figure 1) can directly explain the status of research development [31]. Overall, the number of research papers related to “Intelligent Education” is increasing every year, which can be divided into two stages: (1) Stationary Development Stage (2010–2018) when a total of 524 papers were published and the average annual publication volume was less than 70, except for 79 papers in 2017 and 77 papers in 2018. This stage of research is mainly around the construction of digital classrooms and educational institutions to explore the initial course of AI; for example, technology-supported mathematics and language arts learning, mobile and ubiquitous learning, digital game learning, computer-supported collaborative learning, digital classrooms, online learning communities, virtual learning partners and teaching agents, etc. (2) Rapid Development Stage (2018–2022) where the research of intelligent education has entered a rapid development stage since 2018. In the past four years, the number of papers has been increasing swiftly, which indicates that more and more attention is paid to the application of intelligent education. For example, topics such as “Artificial Intelligence + Education”, personalized learning systems, intelligent distance education and AI technologies situation system, and other topics, reflect the impact of intelligent education research on more and more extensive applications [32–35].

![Figure 1. Statistical distribution of the number of articles issued per year.](image)

3.2. Research Power Analysis

3.2.1. Author Analysis

The study conducted a statistical analysis of the authors of intelligent education research since 2010 (Table 1) and a co-occurrence mapping analysis of the authors (Figure 2) to draw the following conclusions.
Table 1. Core Author Statistics.

<table>
<thead>
<tr>
<th>Author</th>
<th>Number of Papers</th>
<th>Serial Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARLOS DELGADO KLOOS</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>PEDRO J MUNOZMERINO; ZHIQUAN FENG; ADNAN BAKI; SATOSHI KANAZAWA</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>ANDREW E WALKER; BRIAN R BELLAND</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>JING ZHANG; NAM JU KIM; NEIL Y YEN; XIN MENG; HAN HE; DAN KONG; JIYUAN ZANG; SHAOFENG WANG; QUN JIN; YUNHE PAN; MITCHELL DANDIGNAC; BOTAO ZENG; BORIS ABERSEK; VALERIE F REYNA</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

Figure 2. Authors co-occurrence atlas analysis.

Price’s Theory states that an author is a core author in a research field if the number of publications by an author in that field is \( N \) and above [36]. Where \( N = 0.749 \sqrt{n_{\text{max}}} \), \( n_{\text{max}} \) are the maximum number of publications by a given author in that research area. The maximum number of publications in intelligent education research in the field of education \( n_{\text{max}} = 6 \), \( N \approx 2 \). Therefore, Price’s law indicates that the authors with two or more publications are core authors, and the authors with the top 20 publications are compiled into the table of core authors of intelligent education research (Table 1). In the field of intelligent education research, a core group of authors has been formed represented by CARLOS DELGADO KLOOS, ZHIQUAN FENG, ADNAN BAKI, SATOSHI KANAZAWA, and the majority of front-line teachers. The analysis of the author co-occurrence map reveals that the density of cooperation between author nodes, Density = 0.0018, shows that the cooperation among researchers in the field of intelligent education is scattered. In addition, the author’s co-occurrence map also shows that intelligent education research has formed a research group led by core scholars and in the future will show a trend of team-based development.

3.2.2. Institutional Analysis

The spatial distribution and collaborating institutions analysis using Citespace can provide effective information for countries and institutions to find partners. To uncover the distribution of core authors and the direction of cooperation among research institutions, a dual-map overlay analysis of research institutions was performed (see Figure 3).
Portfolio analysis of publication profiles is designed to provide analysts and decision-makers with an understanding of where the unit is, where it has been, and where it might go in a complex adaptive environment [37]. As shown in Figure 3, citation arcs, citation links, and trajectories over time facilitate the study of multiple groups of publications at the cross-disciplinary level, the organizational level, and the individual publication level, with the dotted line depicting the links across disciplinary boundaries. Thus, the distribution of publication composition groups shows the citation and citation intensity of 403 publishers, indicating closer collaboration between institutions (dashed line intensity on the right side of Figure 3). Further analysis revealed that global research on intelligent education mainly includes Educational Teaching Research, Computer Science Artificial Intelligence, Computer Science Intelligence Systems, and Interdisciplinary Applications of Computer Science [38–40].

According to the research institutions (Table 2), 264 articles from Education Educational Research, accounting for 22.185% of the Research sample, were reprinted from Intelligent Education Research journals since 2010. There were 181 articles from Engineering Electrical Electronic, accounting for 15.210% of the total, and 156 articles from Computer Science Artificial Intelligence, accounting for 13.109% of the total. The data show that the authors of the papers reprinted by AI education research institutions are mainly researchers and front-line teachers engaged in AI technologies work, and formed Educational Research, Engineering Electrical Electronic, and other institutions led by an important Research team. In addition, the research institutions of intelligent education can be divided into two categories: the first category is institutions of higher learning, such as Carnegie Mellon Univ, Arizona State Univ, Beijing Univ, and so on. The second category is Home Education, where for child discipline (especially the Confucian child discipline) Sheng [41] and Slote [42] conducted in-depth studies of Confucian child discipline motivation, teaching content, teaching methods, and outcomes. Knowles found that Confucian values and beliefs fit well with the Chinese child discipline model in terms of family, education, moral development, and social relations; Knowles et al. [43] explain the dynamics of the child discipline, and Henig [44] traces the development of child discipline to the rational and legitimate educational choices of an increasing number of families; the child discipline in Russia was the customary form of schooling for the great majority of the aristocracy [45].
Table 2. Reprint Statistics of Intelligent Education Research Journals.

<table>
<thead>
<tr>
<th>Web of Science Category</th>
<th>Number</th>
<th>Percentage of 1190</th>
</tr>
</thead>
<tbody>
<tr>
<td>Education Educational Research</td>
<td>264</td>
<td>22.185%</td>
</tr>
<tr>
<td>Engineering Electrical Electronic</td>
<td>181</td>
<td>15.210%</td>
</tr>
<tr>
<td>Computer Science Information Systems</td>
<td>156</td>
<td>13.109%</td>
</tr>
<tr>
<td>Computer Science Artificial Intelligence</td>
<td>148</td>
<td>12.437%</td>
</tr>
<tr>
<td>Telecommunications</td>
<td>121</td>
<td>10.168%</td>
</tr>
<tr>
<td>Computer Science Interdisciplinary Applications</td>
<td>100</td>
<td>8.403%</td>
</tr>
<tr>
<td>Engineering Multidisciplinary</td>
<td>94</td>
<td>7.899%</td>
</tr>
<tr>
<td>Education Scientific Disciplines</td>
<td>84</td>
<td>7.059%</td>
</tr>
<tr>
<td>Computer Science Theory Methods</td>
<td>43</td>
<td>3.613%</td>
</tr>
<tr>
<td>Computer Science Software Engineering</td>
<td>39</td>
<td>3.277%</td>
</tr>
</tbody>
</table>

In terms of the geographical distribution of publishing institutions, the location of research institutions is relatively dispersed, with North America and Europe, as well as Asia, becoming important publishing locations. As shown in Figure 4, a total of 198 inter-country cooperation lines (density = 0.0494) were formed between 90 countries, forming a close network of cooperation with countries such as the United States, China, and the United Kingdom. The top five countries include 342 articles from China, 215 articles from the United States, 66 articles from Spain, 56 articles from Chinese Taiwan, 47 articles from the United Kingdom, and 42 articles from India. The research on intelligent education is diversified, and the research contents and results are quite different in different countries and regions. For example, the research of intelligent education in China focuses on the combination of educational theory and practice. The United States focuses on the study of educational model construction, which is mainly related to economic development and the importance of artificial intelligence education.

![Figure 4. Co-current analysis of intelligent education research in various countries.](image)

3.3. Knowledge Structure Analysis

Visual analysis of the knowledge structure of intelligent education can better grasp the basic knowledge and research focus in the field of intelligent education. The study conducts a Reference clustering analysis of the knowledge base of intelligent education and adopts Minimum spanning Tree visualization to analyze a more aggregated knowledge structure of intelligent education map (Figure 5). In the evaluation index of network modularity, $Q = 0.95$, and the value interval of $Q$ is $[0, 1]$, a larger value indicates that its clustering
effect is better, and when $Q > 0.3$, the clustering structure is significant; the value of the evaluation index of network homogeneity, Silhouette, is closer to 1, reflecting the higher homogeneity of the network, and the figure Weighted Mean Silhouette = 0.989; therefore, presenting the knowledge structure is of reference value.

When interpreting the mapping of the knowledge structure analysis of intelligent education and elaborating on the development of the years of intelligent education research, the earliest research on intelligent education focused on classroom management. The most representative early study was the article published by VanLehn [46] in 2011, in which the effectiveness of teachers’ practice was analyzed in comparison with intelligent tutoring, and it was found that teaching effectiveness had relative validity. After 2014, the research knowledge structure shifted to computer-based scaffolding and the knowledge structure was mainly centered on the empirical evidence of intelligent education. Researchers such as Thistlethwaite et al. [51] reflected on the AMEE workshop held in Vienna in August 2011 and the most cited literature is Ma et al. [47], who empirically analyzed intelligent teaching systems and learning effectiveness. Starting in 2016, with the emergence of big data analytics, knowledge structures such as 5G network, Evaluation Index, and Big Data Analytics have emerged in the field of intelligent education research [48,52,53].

4. Theoretical Foundations and New Dynamics of Intelligent Education Research

4.1. Analysis of Research Theoretical Foundations

4.1.1. Foundations of Intelligent Education Research

Mastering the core literature to provide a solid foundation for the future role of AI technologies in educational research, this study analyzed the top 10 highly cited research articles (Table 3).

As shown in Table 4, six of the top 10 highly cited research articles are related to research on educational practices of AI, and the remaining four are theoretical studies of AI education based on the context of the times with all document types being reviewed. These highly cited studies show that intelligent education is mainly studied through the theory and practice of education. The practice includes the implementation of micro-certification [54], the application of AI technologies to develop student problem solving
and learning motivation [55], the application of learning analytics [56], and capturing students’ learning characteristics to improve engagement of learning [57]. The theoretical studies include AI based on the context of Industry 4.0 [58], theoretical studies on the transformation of engineering education over a century [59], towards a new generation of intelligent manufacturing and AI 2.0 [27,60].

Table 3. Top 10 Highly Cited References in Intelligent Education.

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Cited Frequency</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhong, RY et al. [58]</td>
<td>Intelligent Manufacturing in the Context of Industry 4.0: A Review</td>
<td>762</td>
<td>2017</td>
</tr>
<tr>
<td>Siemens, G [56]</td>
<td>Learning Analytics: The Emergence of a Discipline</td>
<td>334</td>
<td>2013</td>
</tr>
<tr>
<td>Belpaeme, T et al. [61]</td>
<td>Social robots for education: A review</td>
<td>300</td>
<td>2018</td>
</tr>
<tr>
<td>Abramovich, S et al. [54]</td>
<td>Are badges useful in education?: it depends upon the type of badge and expertise of learner</td>
<td>177</td>
<td>2013</td>
</tr>
<tr>
<td>Whitehill, J et al. [57]</td>
<td>The Faces of Engagement: Automatic Recognition of Student Engagement from Facial Expressions</td>
<td>175</td>
<td>2014</td>
</tr>
<tr>
<td>Froyd, JE et al. [59]</td>
<td>Five Major Shifts in 100 Years of Engineering Education</td>
<td>173</td>
<td>2012</td>
</tr>
<tr>
<td>Ma, WT et al. [47]</td>
<td>Intelligent Tutoring Systems and Learning Outcomes: A Meta-Analysis</td>
<td>172</td>
<td>2014</td>
</tr>
<tr>
<td>Zhou, J et al. [50]</td>
<td>Toward New-Generation Intelligent Manufacturing</td>
<td>164</td>
<td>2018</td>
</tr>
<tr>
<td>Pan, YH [60]</td>
<td>Heading toward Artificial Intelligence 2.0</td>
<td>131</td>
<td>2016</td>
</tr>
</tbody>
</table>

Table 4. Cited High-Frequency Co-cited Words (Top Five).

<table>
<thead>
<tr>
<th>Cluster ID</th>
<th>Size</th>
<th>Silhouette</th>
<th>Mean (Year)</th>
<th>Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>36</td>
<td>0.981</td>
<td>2017</td>
<td>artificial intelligence; scientometric view; intelligent tutoring systems research; intelligent personal assistant technology; enhancing problem-solving skill; intelligent online education; intelligent robot; comparative study; artificial intelligence technology</td>
</tr>
<tr>
<td>2</td>
<td>25</td>
<td>0.985</td>
<td>2010</td>
<td>intelligent tutoring system; learning outcome; academic learning; college student; data mining; adaptive e-learning system; secondary school; science classroom; science education; online functional literacy</td>
</tr>
<tr>
<td>5</td>
<td>19</td>
<td>0.974</td>
<td>2013</td>
<td>stem education; empirical research; synthesizing result; computer-based scaffolding; bayesian network meta-analysis; procedural training environment; predicting student action; systematic review; adaptive e-learning; health professional</td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td>1</td>
<td>2017</td>
<td>machine learning; English distance education; artificial intelligence algorithm; classroom management; intelligent manufacturing; cyber-physical production system; secure manufacturing—a perspective; classroom management; intelligent manufacturing; platform construction</td>
</tr>
<tr>
<td>9</td>
<td>13</td>
<td>1</td>
<td>2009</td>
<td>intelligent individualized e-learning environment; integration; mathematics classroom; evaluation; evaluation; development; intelligent individualized e-learning environment; intelligent e-learning system; design</td>
</tr>
</tbody>
</table>

4.1.2. Themes and Areas of Research on Intelligent Education

In the keyword co-occurrence timeline analysis of the research literature related to intelligent education (Figure 6), the top six keywords with the highest frequency were “intelligent tutoring system” (118), “education” (127), “model” (80), “system” (73), “student” (63), and “artificial intelligence” (71). The analysis of the out-degree and in-degree of other
nodes associated with the high-frequency keyword nodes shows that they are the key basics in the field of intelligent education.

Figure 6. Keyword Co-occurrence Timeline Analysis (The temporal distribution of keywords and their frequencies from 1 January 2010, to 5 May 2022, are shown, with the time slice set to 1 year. Each node in the graph indicates the first occurrence of a keyword in that year. If the keyword reappears in all subsequent years, it will be superimposed on the coordinates of the first occurrence).

The analysis of the above six high-frequency keywords enabled a division into three dimensions: (1) Theoretical knowledge of education; mainly involving “research paradigm of educational science”; and “empirical evaluation theory”. These two educational theories have broken the boundaries of traditional teaching and learning and were more likely to use network technologies and environments to carry out education; the scale of users is huge, so the combination of intelligent education and AI technologies is closer [33,62]. (2) Typical applications of AI technologies in the field of education mainly involve the keyword “intelligent tutoring system”, which can provide better learning paths by analyzing learning behaviors and correcting dangerous behaviors of students [63]. Common Intelligent Tutoring systems (ITS) include CAI and Intelligent Computer Assisted Instruction (ICAI), but their shortcomings are also obvious. For instance: The inability to conduct dialogues with the student in natural language; the Inability to understand the subject being taught; The program cannot accept unanticipated responses; the Inability to understand the nature of the student’s mistakes or misconceptions, Inability to profit from experience with students or to experiment with the teaching strategy. (3) The keyword “intelligent manufacturing”, which is a human–machine integrated intelligent system composed of intelligent machines and human experts, makes the process of manufacturing automation highly integrated and intelligent, and this hotspot is mainly applied to vocational skills training in the manufacturing industry in the field of intelligent education [64].

Research on “Intelligent Tutoring System” was conducted mainly in 2011–2013. AI technologies continue to evolve toward cognitive intelligence and intelligent teaching assistance systems are improved and upgraded along with the emergence of new technologies to guide learners and assist teachers. Buche and Querrec [65] integrated an adaptive intelligent tutoring system (PEGASE), where a multi-intelligent body system that emits a set of knowledge (operations performed by the learner, knowledge of the domain, etc.) is used by AI to make pedagogical decisions. With the 2nd International Conference on Modern Education and Social Sciences in 2016, the application of data mining in the field
of education started to gain a lot of popularity. By using machine learning and data mining techniques, education-related work is improved after using information mined from data in the field of education [66,67]. In addition, educational analysis based on big data has the longest time period of all hot keywords and can be applied to various forms of education such as school education, family education, and allied education, providing a strong theoretical basis and technical support for achieving personalized learning [38,68,69].

4.2. Research Frontiers and Development Trends of Intelligent Education

4.2.1. Frontiers of Intelligent Education Research

Cluster analysis of keywords can better grasp the research frontiers and hot topics in the field of intelligent education research. The LLR algorithm was used to cluster the web literature, and the 198 analyzed clusters were smoothed to ensure the relevance of clusters, where clusters with low relevance were eliminated; 20 strongly associated clusters were finally analyzed, as shown in Figure 7. \( Q = 0.9203 \); \( S = 0.747 \) represents a significantly high modular network of co-cited clustering networks and good homogeneity of clustering nodes. To demonstrate the accuracy of clustering, the top five clusters with the highest number of citations and the highest homogeneity were extracted (Table 4).

![Figure 7. Co-citation Clustering Analysis.](image-url)

The textual interpretation of the research literature on the highly cited topic of intelligent education in the clusters yielded branches of research in each cluster. We identified the following four key Intelligent Education research paths.

(1) Focus on the institutional system path of human–machine integration.

One of the reasons for the shift in the direction of smart education research is the maturation of smart manufacturing technologies, especially in 2022. Education should be adept at using the human–machine integration mindset to enable both large-scale coverage and personalized development of education that matches individual capabilities [70–82]. Human–computer integrated education is mainly reflected in intelligent educational environments, intelligent teacher assistants, intelligent educational management and services, and intelligent educational evaluation [73–76].

(2) The multidisciplinary integration development path.
AI technologies have promoted the development of integration and innovation between information technology and education. Big data intelligence takes data-driven and cognitive computing as the core method to discover knowledge from big data and then make intelligent decisions based on the knowledge [77,78]. In the field of education, data can explain educational phenomena as well as reveal educational laws and can predict future trends [40,79,80]. Therefore, the era of digital education has arrived. Data-driven AI will lead the new direction of multidisciplinary integration of intelligent education [81].

(3) Focus on students’ souls and well-being development paths

Intelligent education is a human-centered education, which should lay a solid foundation for students’ future happiness and growth. The development of intelligent education allows teachers to have enough energy to care about students’ well-being and feelings, and to make them more creative by implementing more humanistic teaching and learning with students on an equal footing [29,82]. During the COVID-19 period, intelligent education has reduced the work of teachers to a certain extent, using a combination of online and offline, with a more subdivided teacher and more humanistic teaching [83,84].

(4) Adaptive Learning Pathways

Future students should not only actively learn knowledge and master key skills. It is more important to be able to transform knowledge and skills into higher-order cognitive abilities, critical thinking, and innovative and creative talents in their social lives [85,86]. Therefore, providing adaptive learning pathways for students’ competency development should be considered an important pathway to meet future challenges and enhance national educational strength and civic literacy. For this reason, intelligent education must focus on adaptive education to develop and hone students’ abilities, literacy, and attitudes [87–89].

4.2.2. New Dynamics of Intelligent Education Research

Intelligent education has been a research hotspot in recent years and a new dynamic in educational research [90]. Visualizing the growth time of intelligent education research literature (see Figure 8), further analysis can yield the following information.

![Figure 8](image_url)  
**Figure 8.** Top 10 References with the Strongest Citation Bursts (Because both DOIs of author Steenbergen-Hu, S. point to the same article, there are only the Top 10) [46–50].

The dark green line in Figure 6 indicates the citation timeline for a given Citation Burst, and the period time for each Citation Burst is presented as a red line. The Strength of Figure 8 indicates the sudden growth rate of citation. Thus, intelligent tutoring systems (6.41) and intelligent computer tutoring systems (4.39) are the two research topics with the highest intensity of Citation Bursts in the last decade of intelligent education research [46,48]. The frontier of intelligent education research in the period 2011–2014 focused on the development and monitoring of computer tutoring systems to intelligent assistive systems [91]. From 2015 to 2017, this period saw the maturation of intelligent tutoring systems (ITS), and researchers’ application of ITS to different professional disciplines.
and school-age groups became the research frontier of the time [47,49]. From 2018 to 2022, with the maturation of big data analytics and the development of AI techniques, Intelligent Tutoring Systems transformed into intelligent analytics systems [92–94]. Furthermore, in the context of COVID-19, the provision of adaptive guidance programs for teachers, students, families and schools, based on in-depth analysis of large data sets, is the most recent research frontier of interest [26,32,95].

5. Discussion

This study used Cite Space (5.8.R3) and Microsoft Excel 2019 analysis tools to conduct a scientometric analysis of authors, institutions, countries, publications, keywords, and citations of intelligent education research. It found that intelligent education research has become a topic of interest in various education research studies worldwide, especially in the context of the 2019 coronavirus outbreak that has pushed this research to the next wave.

A co-occurrence knowledge mapping analysis of the authors, institutions, and countries of intelligent education research revealed a collaborative network among intelligent education research around the world with the United States at the center. The highest number of publications were in Asia, with more-frequent connections between research institutions but more-discrete authors. Therefore, communication and collaboration among authors should be strengthened in subsequent studies.

A visual analysis of highly cited references, keywords, and journals revealed that the research hotspot of intelligent education has changed from early research on intelligent tutoring systems to research on AI education based on big data support. Technically, it involved aspects such as neural network algorithms and big data computing. Li and Wong [96] by analyzing the research and practice pathways of intelligent education, found that the current hotspot of intelligent education research is big data-based educational practices, which coincides with the analysis of this study. In terms of theoretical research, AI research can provide students with a more-scientific adaptive learning approach that is consistent with their cognitive development [97]. Presently, many educational researchers have compared AI education with other educators to show that AI education is executable and effective, and therefore AI education research has been emphasized [98,99].

In general, the practice of AI + Education is one of the hotspots of intelligent education research in recent years. Therefore, it is necessary to fit the teaching practice of AI education, and the human–computer integration curriculum model is guided by AI technology for teaching research design while the human–computer integration curriculum model is a global development trend. Chan and Zary [100] confirmed the importance of AI technology practice in the field of medical education. Bin and Mandal [101] found that AI in English teaching has powerful educational functions. However, due to the epidemic, the study found that strategies and policies of different countries and regions can create a large digital divide in the practice of intelligent education [102]. In addition, the content of this study can be integrated with the actual teaching and learning of big data to promote the implementability and effectiveness of human–computer integrated teaching.

In addition, focusing on students’ happiness is one of the future trends of intelligent education research. Moussa and Ali [103] explored the relationship between students’ academic levels and happiness levels during COVID-19 and found that students’ happiness levels were positively correlated with their academics when they felt happy, positive, and satisfied with their current situation. Tannert and Gröschner [104] studied students’ happiness utilizing a questionnaire study and concluded that students’ happiness can provide a direct pedagogical basis for intelligent educational research, but there are still many difficulties to be resolved in improving students’ happiness, including teacher–student communication, students’ self-efficacy, and teaching environment support. Therefore, in the face of a large amount of educational data for network analysis, enhancing students’ well-being will become possible.

The statistical analysis shows that no one has made a more-comprehensive bibliometric study in the field of intelligent education research. This study systematically analyzes the
knowledge structure and development history of this field, which can provide relevant information for core authors, institutions, research teams, countries, etc. Finally, this study provides an objective prediction of research trends in intelligent education to inform subsequent research.

6. Conclusions

The application of AI technologies in the field of intelligent education has gathered the attention of a wide range of scholars. The application area of AI technologies is relatively wide, and in the field of education, it mainly revolves around the human–computer interaction path, the adaptive learning analysis path, the focus on students’ spiritual health and well-being path, and the multi-disciplinary integration development path. In-depth analysis of educational data to provide adaptive guidance solutions for teachers, students, families, and schools has become a research frontier and trend in recent years. Therefore, the focus of future research on intelligent education will revolve around the application of AI technologies in education data.

But this research also has some deficiencies: First, the data analyzed in this study were not comprehensive enough and were mainly based on data from representative SSCI and SCI-Expanded databases. Second, the presence of different DOIs or Terms with the same meaning in an article makes it difficult to distinguish between them. These deficiencies need to be further improved in the follow-up study.

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