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A Review on Big Data's Evolution and Application for Educational Decision-Making

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Abstract. The rapid digital transformation of education has created unprecedented opportunities for data-driven decision-making, with big data analytics emerging as a pivotal tool for enhancing educational quality. This paper employs a literature review and case studies to demonstrate how big data transforms educational decision-making through advanced analytics and artificial intelligence. While big data offers significant benefits, implementation faces challenges, including data privacy concerns, information quality issues, and shortages of talents with data science expertise. The review highlights emerging solutions and future directions, such as Artificial Intelligence (AI)-powered early warning systems and smart admissions processes. These innovations promise to enhance equity, optimize operations, and support lifelong learning in digital education ecosystems. The study contributes to the field by bringing together current methods, tackling critical challenges, and proposing future directions offers valuable insights for policymakers seeking to make the most of data's power in this digital learning age.

Keywords: Data-driven Decision-making, Big Data Analytics, Artificial Intelligence, Educational System

1. Introduction

After the release of the Blue Book on China's Basic Education, the application of big data in the education sector has been effectively promoted. Big data is regarded as a key means to promote educational modernization and enhance education quality [1]. Specifically, big data enables in-depth mining of learning trajectories, resource interaction data, and other relevant information, continuously driving personalized teaching and the precise allocation of educational resources. It serves as a critical tool for achieving the modernization of educational governance and provides a data-driven new pathway for improving education quality. Currently, there is widespread academic recognition of the empowering value of big data in education. Stil, numerous practical challenges remain, and there are certain gaps in research on the specific application directions of big data [2].

Therefore, this study employs literature review, case analysis, and interdisciplinary comparison to systematically outline the application perspectives of big data in empowering educational decision-making. This paper aims to specifically explore the concrete role of big data in the entire process of formulating educational decisions and its future development directions. Through the summarization and optimization of methodologies, this study aims to provide theoretical guidance for educational

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decision-makers, supporting precise policy implementation and sustainable development in the process of educational modernization.

2. Literature review

Big data is capable of rapidly collecting and storing massive amounts of information [3]. The effective educational leaders use data extensively to guide them in decision-making, goal-setting, and priority-setting, as well as progress monitoring [4]. Capable data-based decision makers understand the array of data that is needed for school improvement [4].

In recent years, scholars have actively explored the specific applications of big data in the field of education. Wang proposed the need to integrate AI to build a comprehensive data governance system, promoting enhanced privacy computing and security safeguards, thereby providing theoretical and practical references for the informatization of higher education management [2]. Song and other scholars explored new smart teaching models based on learning data [5]. Mao explored the implementation effect of precise high school English teaching driven by big data [6]. The key accomplishment of learning analytics in recent years may be identified as the growth of digital learning, which has improved the quality and accessibility of educational data [7]. However, there is still a certain gap in the comprehensive research on big data in the field of education.

3. The specific applications of big data in the field of education

3.1. The methods of empowering educational decision-making

Empowering educational decision-making with big data is a systematic project that requires the integration of multidisciplinary approaches, including data science, educational theory, and policy management. Some of the most common methods are divided into three parts:

3.1.1. Predictive analytics and pre-decision analysis

Before making educational decisions, prediction and analysis serve as foundational steps to inform proactive and targeted strategies. Predictive modeling is a data-driven technique that uses statistical algorithms and machine learning to analyze historical and current data to make predictions about future outcomes.

Complementing predictive modeling, learning analytics refers to the use of technological tools to collect, process, and analyze data generated by learners. By uncovering hidden learning patterns, predicting learning outcomes, and providing targeted feedback and intervention suggestions, It offers educators, learners, and managers with actionable insights. Together, these approaches ensure that educational strategies are not only reactive but also anticipatory, aligned with the actual needs and trajectories of learners and institutions.

3.1.2. Resource optimization and personalized recommendation during decision making

Effective educational decision-making relies on both strategic resource allocation and tailored learning support. Resource optimization encompasses a range of project management methods designed to align resources with institutional needs as efficiently as possible. Similarly, personalized recommendation systems leverage AI to analyze individual student data to deliver customized learning pathways.

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These approaches are already demonstrating real-world impact. Colleges and universities now use resource optimization to balance educator workloads and budget allocations. At the same time, adaptive learning platforms employ personalized recommendations to guide students toward relevant course materials or skill-building exercises. Together, they create a responsive educational ecosystem where institutional resources and individual learner needs are continuously aligned through data-driven insights.

3.1.3. Impact evaluation and sentiment analysis in post-decision

After decisions are implemented, ongoing assessment is crucial for continuous improvement. Impact evaluations provide policymakers with critical evidence to refine programs, such as identifying ineffective initiatives for discontinuation, successful ones for expansion, and areas requiring benefit adjustments. Sentiment analysis applies natural language processing to decode emotions and opinions in textual feedback, detecting not just overall positivity, negativity but nuanced reactions like frustration or enthusiasm. Colleges and universities now conduct impact evaluations to assess the effectiveness of new teaching initiatives before district-wide rollout, while sentiment analysis tools mine student forum discussions and course evaluations to gauge emotional responses to policy changes. Together, they form a robust post-decision feedback loop enabling truly responsive educational leadership.

3.2. Empirical applications and case studies of big data-enabled educational decision-making

3.2.1. Predictive modeling in educational planning and policy formulation

Big data enables precise predictions. For example, educational early warning systems utilize methods such as decision trees and feature engineering to collect indicators like students' historical attendance patterns, homework completion rates, and assessment scores. This allows for accurate identification of students at risk of academic failure, enabling schools to implement timely tutoring interventions.

Simultaneously, the introduction of enrollment prediction models in universities allows institutions to analyze historical admissions data to understand applicant preferences and admission outcomes. This supports the development of more rational enrollment plans. By leveraging indicators such as historical admission scores, these models can forecast enrollment trends for various disciplines in advance. Furthermore, through the analysis of data on student source regions and subject distribution, universities can better position themselves in the market and establish programs that meet evolving demands [6]. Additionally, universities continue to optimize course selection models to predict classroom demand, thereby optimizing resource allocation.

3.2.2. Real-time analytics for dynamic decision implementation

Big data algorithms can dynamically assist in adjusting educational decision-making and tailor educational resources based on demand. For instance, in the allocation of basic education resources in rural areas, severe imbalances exist in some regions. The continuous influx of educational resources has exceeded the cognitive capacity of rural teachers and students, leading to serious information ecology imbalances such as information overload, information pollution, and information gaps. By gaining an in-depth understanding of regional disparities in rural resource distribution and infrastructure configuration, educators can allocate resources rationally to ensure the effective utilization of educational resources.

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Data collection and aggregation services gather basic information such as the quantity and quality of course resources for rural teachers, track interactions between teachers and resources, and evaluate teachers' acceptance and satisfaction levels with resources. This data serves as a scientific basis for optimizing resource supply [9].

Meanwhile, during specific teaching activities, big data technology can monitor students' classroom participation and interaction frequency in real time. To some extent, this helps teachers promptly adjust teaching pace and methods, focusing on explaining knowledge points that students find difficult to grasp [10]. Secondly, big data algorithms can analyze students' learning behavior data, such as browsing history, study duration, and homework completion, to accurately recommend suitable learning materials. It ensures a high degree of alignment between teaching content and student needs, promoting efficient matching of educational resources. Additionally, educators can use online questionnaires and assessments to gauge students' genuine psychological states and engage in real-time online interactions with them. This approach continuously optimizes teaching plans and content, not only enhancing students' focus and comprehension but also improving the teaching quality of mental health education courses [11]. Overall, Big data enables dynamic student performance tracking and responsive interventions.

3.2.3. Outcome evaluation and assessment

Big data-driven educational decision-making enables a self-validating and continuously optimized dynamic closed-loop system. By focusing on post-decision core aspects such as effect evaluation and optimization, data is transformed into tangible educational productivity.

After the implementation of decisions, big data facilitates continuous tracking and quantification of their actual effects. With big data support, it is possible to persistently monitor metrics such as the number of visits, types of downloaded content,and usage frequency of government policy resource platforms by schools in different regions. By analyzing this data, the effectiveness of policy implementation can be evaluated [12].

In the context of higher education, instructors can use specific outcome data such as quiz results and video replay rates as feedback to optimize subsequent teaching. For example, if case-based explanations lead to better student comprehension compared to playing related videos, this approach can be adopted as a standard teaching method.

Big data technology has significantly transformed and expanded approaches to mental health education for university students. Educators can systematically collect behavioral data related to students' engagement with mental health content. Additionally, diverse educational resources have greatly enriched the content of mental health courses. Big data technology enables mental health educators to conduct courses through online teaching platforms and present knowledge in innovative formats such as videos, music, and images [11].

4. Challenges

4.1. Data quality assurance and scalability

Diverse data can provide comprehensive information support for educational decision-making, but it also increases the complexity of data processing and analysis. In terms of data quality, educational institutions often face significant challenges with inconsistent data formats, missing values, and unstandardized collection methods across different departments and systems. Additionally, the lack of data validation mechanisms can lead to biased or inaccurate datasets, particularly when

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integrating information from multiple sources like learning management systems, attendance records, and socioeconomic indicators.

With the popularization of educational informatization and the advancement of smart education, the volume of educational data continues to expand. The enormous volume of data encompassing student numbers, course quantities, and school statistics requires extensive processing and analysis. Confronted with such massive datasets, efficiently storing, managing, and analyzing data has become a significant challenge [13].

4.2. Data privacy and shortage of talent

In the process of promoting the application of educational big data, data privacy protection and the shortage of professional talents are the most urgent issues to be addressed. Educational big data often involves sensitive personal information, such as students' identity details and academic performance. Therefore, protecting the privacy of students and teachers and ensuring the legality and security of data usage are primary principles [14]. It is necessary to dynamically balance the relationship between data utilization and privacy protection, to fully leverage the value of data while avoiding excessive collection of personal information.

The shortage of talent is also a major factor restricting the application of big data in education. At present, there is a lack of interdisciplinary professionals. Training programs in universities and research institutions are still in their early stages, and due to factors such as lengthy training cycles, the scale of talent cultivation falls far short of actual demand. Furthermore, the existing education system's understanding of and ability to apply big data remain limited, which to some extent hinders the widespread adoption and implementation of big data in the education sector [15].

5. Future directions

5.1. Enhancing data infrastructure and governance frameworks

Higher education institutions should prioritize establishing comprehensive data governance systems to address quality and scale challenges [3]. Additionally, institutions should create cross-functional data stewardship teams comprising IT specialists, educators, and administrators to oversee data quality maintenance and system interoperability. These measures will enable reliable analysis of longitudinal educational data while accommodating growing datasets from emerging sources like IoT-enabled classrooms and mobile learning platforms.

5.2. Talent cultivation and privacy-preserving analytics

To effectively protect privacy and overcome the dual challenges of talent shortages, universities should develop comprehensive strategies. First, educational institutions need to significantly strengthen talent development in related fields such as computer science, and establish comprehensive curriculum systems and practical training platforms. Furthermore, relevant ethical standards and regulations should be established to ensure that the personal privacy information and legal rights of teachers and students.

6. Conclusion

The integration of big data in educational decision-making marks a transformative shift toward data-driven learning environments. By using methods such as predictive modeling, learning analytics,

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and resource optimization, educators can enhance teaching effectiveness and improve student outcomes. Practical applications such as early warning systems and strategic resource allocation demonstrate the tangible benefits of data-driven insights. However, this study has some limitations, including insufficient integration of case studies to contextualize theoretical frameworks and a lack of quantitative empirical analysis to validate observed trends. Future directions should prioritize interdisciplinary collaborations (e.g., combining cognitive science with analytics) and rigorous longitudinal studies to assess long-term impacts.

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