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Review Article

Unlocking the power of blockchain in education: An overview of innovations and outcomes

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ABSTRACT

Blockchain is a revolutionary technology that has the potential to revolutionize various industries, including finance, supply chain management, healthcare, and education. Its decentralized, secure, and transparent nature makes it ideal for use in industries where trust, security, and efficiency are of paramount importance. The integration of blockchain technology into the education system has the potential to greatly improve the efficiency, security, and credibility of the educational process. By creating secure and transparent platforms for tracking and verifying students' academic achievements, blockchain technology can help to create a more accessible and trustworthy education system, making it easier for students to showcase their skills and knowledge to potential employers. While the potential benefits of blockchain in education are significant, there are also several challenges that must be addressed in order to fully realize the potential of this technology in the educational sector. Some of the major challenges include adoption, technical knowledge, interoperability, regulation, cost, data privacy and security, scalability, and accessibility. The necessary equipment for the implementation of blockchain technology in education is diverse and critical to the success of this innovative technology. Organizations should carefully consider this equipment when planning their implementation of blockchain technology in education to ensure the efficient and secure transfer of educational data and transactions within the blockchain network. Blockchain technology has the potential to play a significant role in promoting sustainability education and advancing the sustainability goals of both individuals and organizations. Organizations should consider incorporating blockchain technology into their sustainability education programs, in order to enhance the transparency, verifiability, and efficiency of their sustainability-related activities. While the use of blockchain technology in education is still in its early stages, the available data suggest that it has significant potential to transform the education sector and improve the efficiency and transparency of educational systems.

1. Introduction

Blockchain is a distributed, digital ledger that records transactions in a secure, transparent, and tamper-proof manner. It is a decentralized system that operates on a network of computers, allowing for the secure and efficient exchange of information and value. At its core, blockchain technology uses cryptography to secure transactions and ensure their integrity. Each transaction is recorded in a block, which is then added to the chain of blocks, forming a chronological chain of transactions. This chain of blocks is maintained by a network of computers, which work together to validate and verify transactions, ensuring that the data stored on the blockchain are accurate and up-to-date. One of the key features of blockchain technology is its decentralization, which eliminates the need for intermediaries in transactions. This results in greater

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security, as it eliminates the risk of data tampering or theft by a single central authority. Additionally, the use of cryptographic algorithms and digital signatures makes it virtually impossible to tamper with the data stored on the blockchain, making it highly secure and trustworthy. Blockchain technology also has the potential to greatly improve efficiency, as it enables real-time and near-instantaneous transactions. This can greatly reduce transaction processing times, as it eliminates the need for intermediaries to validate transactions [1–3].

The use of blockchain technology in education has the potential to revolutionize the way we approach learning and education. By incorporating blockchain into the educational system, we can create a secure and transparent platform for tracking and verifying students' academic achievements, credentials, and certifications. This can greatly improve the efficiency and reliability of the education system while also making it easier for students to showcase their skills and knowledge to potential employers [4].

One of the primary benefits of blockchain in education is the creation of a tamper-proof and secure digital transcript. This transcript can store a student's academic history, including grades, certifications, and other achievements, in a decentralized and secure manner. This can eliminate the need for traditional paper-based transcripts, which can be easily lost, damaged, or tampered with [5].

Another potential benefit of blockchain in education is the creation of a centralized platform for the issuance and verification of digital credentials. This can greatly simplify the process of obtaining and verifying academic credentials, as it eliminates the need for intermediaries to validate them. Additionally, the secure and transparent nature of blockchain can help to prevent fraud, as it provides a reliable and tamper-proof record of a student's achievements [6].

Another area where blockchain can have a significant impact is in the area of online education. By incorporating blockchain technology into online learning platforms, educators can create secure and trustworthy systems for delivering and tracking online courses and certifications. This can help to improve the credibility and recognition of online education, making it a more attractive option for students and employers alike [7]. Starting with the general idea, blockchain is a revolutionary technology with the potential to revolutionize various industries, including education. Going deeper to address the fundamental gap: The integration of blockchain technology into the education system has the potential to improve the efficiency, security, and credibility of the educational process. By creating secure and transparent platforms for tracking and verifying students' academic achievements, blockchain technology can help to create a more accessible and trustworthy education system, making it easier for students to showcase their skills and knowledge to potential employers.

However, several challenges must be addressed to fully realize the potential of blockchain technology in the education sector, such as adoption, technical knowledge, interoperability, regulation, cost, data privacy and security, scalability, and accessibility. The necessary equipment for the implementation of blockchain technology in education is diverse and critical to the success of this innovative technology, which organizations should carefully consider when planning their implementation to ensure the efficient and secure transfer of educational data and transactions within the blockchain network.

Blockchain technology also has the potential to play a significant role in promoting sustainability education and advancing the sustainability goals of both individuals and organizations.

Organizations should consider incorporating blockchain technology into their sustainability education programs to enhance the transparency, verifiability, and efficiency of their sustainability-related activities. The available data suggest that blockchain technology has significant potential to transform the education sector and improve the efficiency and transparency of educational systems, even though its use in education is still in its early stages.

The problem gap that motivates this study is the need to address the challenges in fully realizing the potential of blockchain technology in the education sector. While the potential benefits of blockchain in education are significant, the abstract mentions several challenges that need to be addressed, such as adoption, technical knowledge, interoperability, regulation, cost, data privacy and security, scalability, and accessibility. These challenges can hinder the implementation of blockchain technology in education and prevent it from improving the efficiency, security, and credibility of the educational process. Therefore, the overview aims to provide an understanding of how blockchain technology can potentially revolutionize the education sector, its potential benefits, and the challenges that must be addressed to fully realize its potential.

The main objectives of this study highlighted the following issues.

- Blockchain can change many industries, like finance, healthcare, and education.
- Adding blockchain to education can improve efficiency, security, and credibility.
- Blockchain can make education more accessible and trustworthy for students and employers.
- Using blockchain in education has challenges like adoption, technical knowledge, and regulation.
- Equipment is diverse and necessary for successful blockchain implementation in education.
- Blockchain can promote sustainability education and help individuals and organizations reach their sustainability goals.
- Organizations should add blockchain to their sustainability education programs to make them more efficient and transparent.
- Blockchain technology can transform education and make it more efficient and transparent.

Blockchain technology has the potential to transform education by making it more efficient, transparent, and trustworthy. While there are challenges to implementing blockchain in education, the benefits it can provide make it a promising technology worth exploring. As blockchain continues to evolve and mature, it will be interesting to see how it can be leveraged to enhance and transform the educational landscape.

By leveraging the decentralized and transparent nature of blockchain, educational institutions can streamline administrative processes, reduce costs, and increase the trustworthiness of credentials and qualifications.

One of the key benefits of using blockchain in education is that it can make education more accessible and trustworthy for students and employers. Blockchain can help prevent fraud and ensure that credentials are genuine, allowing students to showcase their qualifications with confidence. Similarly, employers can quickly verify the credentials of job candidates, reducing the time and resources spent on background checks.

However, using blockchain in education also comes with its own set of challenges. One major obstacle is the issue of adoption, as many educational institutions may not be familiar with blockchain technology or may be hesitant to adopt it due to the associated costs and technical expertise required. There is also the challenge of navigating regulatory frameworks, as different countries may have varying laws and regulations regarding the use of blockchain in education.

Another challenge is the diversity of equipment necessary for successful blockchain implementation in education. Institutions will need to invest in specialized hardware and software, and train staff to use and maintain the technology. Technical knowledge and expertise will also be crucial, as institutions will need to ensure that the blockchain implementation is secure and effective.

In addition to improving efficiency and security in education, blockchain can also promote sustainability education and help individuals and organizations reach their sustainability goals. Blockchain can be used to track and verify sustainability initiatives and help institutions demonstrate their commitment to environmental responsibility. By adding blockchain to their sustainability education

programs, organizations can make them more efficient and transparent, enabling them to better engage with stakeholders and demonstrate their impact.

The proposed work is distinguished by its exploration of the impact of blockchain technology in the education sector, offering valuable guidance to universities and specialists seeking to implement distance learning and secure their information and data, particularly with regard to certification. The study further presents a comprehensive analysis of the challenges and suitable environments for establishing blockchain technology in education, providing critical insights into this rapidly developing area. Additionally, the research investigates the role of blockchain technology in promoting sustainability in education, particularly in the context of pandemics and seismic shifts. The study also offers a comparative analysis of the five leading blockchain platforms, namely, Bitcoin, Ethereum, Cardano, Algorand, and Polkadot, evaluating their potential to enhance educational sustainability. Furthermore, the research outlines the common universities that have implemented blockchain technology in education and analyzes their various attempts to integrate blockchain into their educational processes. The findings of this study offer valuable insights for universities and educational organizations seeking to leverage the benefits of blockchain technology to enhance educational sustainability and secure data and certification. Overall, this work serves as a significant contribution to the growing body of research in this area and offers guidance for future efforts to implement blockchain technology in education.

2. Literature survey

The use of blockchain technology in education is still in its early stages, but there are already many promising projects and initiatives underway. As technology continues to evolve, it has the potential to revolutionize the way we teach and learn, and to create more equitable and accessible educational opportunities for people around the world. Some of the current efforts of blockchain in education include Refs. [8–10]:

Credentialing and Certification: Blockchain technology can be used to create secure and tamper-proof digital credentials and certifications. This can help prevent fraud and ensure that employers and educational institutions can easily verify the authenticity of an individual's qualifications.

Record-keeping: Blockchain technology can be used to securely store and share educational records, including transcripts, diplomas, and certificates. This can help streamline the process of transferring credits between institutions and reduce administrative overhead.

Decentralized Learning Platforms: Blockchain technology can be used to create decentralized learning platforms that are owned and controlled by the learners themselves. This can help reduce the influence of intermediaries such as educational institutions and create a more democratic and equitable learning environment.

Micro-credentialing: Blockchain technology can be used to create and manage micro-credentials, which are smaller and more focused than traditional degrees or certifications. This can help learners acquire specific skills and knowledge that are in high demand in the job market.

Funding and Financial Aid: blockchain technology can be used to create decentralized and transparent systems for funding and financial aid in education. This can help ensure that funds are allocated fairly and efficiently, and that students have access to the resources they need to succeed.

A systematic literature review on the use of blockchain technology in education is presented in Ref. [11], with the aim of providing a comprehensive understanding of its current status, benefits, barriers, and potential future applications. Data from the SCOPUS are collected and examined using bibliometric analysis, and the study focuses on three research questions: how blockchain technology has been defined in educational settings, how it has been examined, and what the results of using it in education have been. The benefits and barriers of using blockchain technology in education are identified by this study, and it is suggested that while it is still a young discipline, it has significant potential to benefit the sector. A foundation for policymakers, education institutions, and researchers to further explore the potential applications of blockchain technology in education is provided.

The opportunities and challenges of applying blockchain technologies in the education sector are further discussed in Ref. [12]. They introduced the key blockchain-in-education applications that include the digitalization and decentralization of educational certifications, as well as the enhancement and motivation of lifelong learning. Their work explores some of the key challenges, such as data protection laws like the General Data Protection Regulation and the California Consumer Protection Act, which impede application developers, and scalability challenges that arise due to slow-speed blockchain transactions and the Scaling Trilemma. Furthermore, they highlighted market adoption and innovation challenges, indicating that blockchain-in-education is a relatively immature innovation that governance bodies within educational institutions often disregard or perceive cautiously.

Despite several works having been published on the topic, limited work covering educational projects based on blockchain can be found, creating new opportunities for higher education trends. Blockchain-based projects in the field of higher education are aimed at solving problems that educators face today. Based on this observation, there is a need for a systematic literature review. The study presented by Guustaaf et al. [8] focuses on the protocol used in blockchain-based higher education projects, analyzing the current blockchain features in use and the services offered by existing educational projects, with the aim of improving the implementation of technology in education through the use of blockchain features. The gap between education projects and blockchain-based projects will be reviewed systematically in this paper.

Higher education's contributions to and impact from the Fourth Industrial Revolution (4IR) have been widely discussed and reviewed. However, most of these studies have focused on individual 4IR technologies in isolation, as noted in the review studies cited in this paper. The current study presented by Chaka [13] reviews, discusses, and synthesizes the applications, prospects, and challenges of Artificial Intelligence (AI), robotics, and blockchain in Higher Education Institutions (HEIs) between 2013 and 2019, as reported in 26 selected journal articles. Using a slightly modified version of the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for searching and screening, three key findings are worth mentioning. First, chatbots are the dominant AI technology used for learning, and AI holds the potential for personalized, scalable, and affordable learning. Second, the applications of robotics tend to be exploratory, with a meta-teaching and meta-learning orientation. Third, some of the applications of blockchain technology relate to digital grading, digital credentialing, digital certification, and real-time contracting and timestamping of learning.

In the world of digital record keeping, blockchain is a distributed ledger that adheres to the principle of "write once, never erase." Physician and practitioner credentialing is a tedious process that involves verifying medical school diplomas, residency completion, board certification, and continuing education. Obtaining medical board licensing and hospital privileges can be time-consuming and expensive, and often requires a considerable amount of blind trust in the competency of the physician or practitioner. As non-physician providers expand their scope of practice and telemedicine laws become more relaxed, the credentialing process becomes even more demanding. Point-of-care ultrasound is a specific procedural skill in medicine that requires practice to perfect. Historically, there has been significant variation in skill level among operators with varying experiences from medical school, residency, and hospital use. Blockchain technology offers a solution to this problem by providing a natural ledger for standardized reporting of competency documents and a record of the quality of procedures performed, including ultrasound. It also simplifies the credentialing process, making it more efficient and adding a new level of integrity by

offering a direct means for the universal distribution of credentials for each provider [9].

The standard blockchain, along with its procedures and qualities, is described in this paper. The current applications of blockchain in education, including learning record keeping, decentralized education ecosystems, and credential issuance and management, are thoroughly summarized. The authors in Ref. [14] discussed technical and other obstacles, including a comprehensive review of the potential applications of blockchain, facilitating the creation of new application systems, and supporting the evolution of education.

The metaverse, which encompasses technology gadgets and is connected to the Internet of Things (IoT), blockchain, AI, and other tech industries, including education, is defined in this paper. The educational sector has seen significant success with the metaverse, which has resolved many difficulties in this domain. During the COVID-19 pandemic, the metaverse enabled people to continue their educational activities virtually, making it the only sector that was not hampered by the pandemic. By using AI and IoT technology, the metaverse builds a digital virtual world where individuals can safely and freely engage in social and educational activities that transcend the limits of the real world. The paper presented by Mozumder et al. [15] introduces the future of the metaverse, including its history, explanation, and shared features.

E-Learning education systems are increasingly gaining attention in the distance education system due to their inclusive pertinence. The COVID-19 pandemic has further popularized the online learning education system, with most education systems using IoT-based E-Learning systems to continue students' education during lockdowns. While several E-Learning IoT schemes have been explored, privacy and security concerns still persist, making it necessary to develop a sustainable and secure E-Learning IoT system. The work presented by Haque et al. [5] discusses the characteristics and prospects of the IoT and provides an overview of the advantages and challenges of using the platform for E-Learning. They proposed an E-Learning IoT architecture with blockchain technology, featuring layers of different IoT and blockchain concepts to secure the online education system. By implementing E-Learning with IoT architecture, universities, and colleges can improve their distance learning programs and increase efficiency without affecting their academic activities. The study finds that E-Learning has a positive impact on students' learning experience and overall quality of education, as well as a significant positive impact on their flexibility and academic productivity.

Seismic shifts have recently occurred in the traditional classroom teaching-learning process, which uses blackboard techniques. Technology has significantly improved this process in the last few years, with teachers, students, robots, e-books, laptops, and books becoming players in the modern classroom. The teaching-learning process can now transcend geographical borders with the help of e-lectures and tutorials, and a vast amount of information is easily available. Additionally, the focus has shifted from "Teacher-centered" to "Student-centered". This article focuses on utilizing the applications of blockchain and IoT in the education sector and identifying the areas where they prove advantageous. Several technologies have played a significant role in modernizing the education industry, and a thorough literature review is necessary to comprehend and determine how these technologies can offer a solution to significant educational difficulties. The teaching and learning process should be understood in light of various factors, including changes to the participants, the process itself, and the results produced, among others, and related difficulties that should be identified. A thorough examination of these factors indicates that these technologies can revolutionize education for the better in the future. While blockchain is still relatively new, its advantages suggest that further study and adoption will undoubtedly alter the teaching-learning process [16].

The authors in Ref. [17] discussed the growing importance of the Industrial Internet of Things (IIoT) in industry consortium systems and the shortcomings of traditional security frameworks as IIoT networks become more complex. The paper proposes the use of blockchain technology to enable secure data distribution in IIoT networks and presents the element-based K-harmonic means Clustering Algorithm (CA) and Underweight Data Block (UDB) algorithm as solutions to efficiently share and store data among IIoT entities [18,19]. The paper evaluates the proposed model using performance metrics such as the sum of squared error, time complexity, and storage complexity with CPU utilization and suggests that it is a better solution for IIoT. The study was conducted using the MATLAB 2018a simulation environment.

For the literature review section, it is noted that a research gap exists concerning the utilization of AI and metaverse technology in the presence of blockchain technology to enhance the educational environment for universities and educational organizations. The question arises as to how these gaps can be mitigated using IoT in conjunction with AI and machine learning.

3. Challenges of blockchain in education

While the integration of blockchain technology in education holds tremendous promise, it is important to acknowledge the limitations and challenges that this technology faces. Here are some of the key limitations of blockchain in education:

Interventional studies involving animals or humans and other studies that require ethical approval must list the authority that provided approval and the corresponding ethical approval code [20].

1. **Adoption**: One of the biggest challenges facing the integration of blockchain in education is the need for widespread adoption. This involves the participation of students, educators, institutions, and employers, all of whom must be willing to embrace the technology to reap its benefits [11,14,21].
2. **Technical knowledge:** Another challenge is the need for individuals and organizations to have a sufficient understanding of the technology to effectively implement and use it. This includes understanding the technical details of blockchain, as well as the security and privacy implications of using the technology.
3. **Interoperability:** Blockchain technology is still in its early stages of development, and there is currently no standardization or interoperability between different blockchain platforms. This makes it difficult for institutions and organizations to use blockchain in a consistent and uniform manner, which can greatly limit its potential benefits.
4. **Regulation:** There are currently few regulations in place regarding the use of blockchain in education, and this can make it difficult for institutions and organizations to effectively implement the technology. This is especially true in regard to issues such as data privacy and security, which are of paramount importance in the educational sector.
5. **Cost:** Another challenge facing the integration of blockchain in education is the cost associated with implementing and maintaining the technology. This includes the costs of hardware, software, and personnel, as well as the costs associated with training and educating individuals on the use of blockchain.
6. **Data privacy and security:** Ensuring the privacy and security of sensitive educational data is a major challenge when implementing blockchain technology. This requires the development of secure systems and processes to protect student data as well as the development of methods to ensure that individuals have control over their own data.
7. **Scalability:** Blockchain technology must be able to handle large amounts of data to be effective in the education sector. This requires the development of scalable systems that can handle the increasing amounts of data generated by the educational process.
8. **Integration with existing systems:** The need to integrate blockchain technology with existing educational systems is a major challenge. This involves the development of systems and

processes that can effectively integrate blockchain technology into existing systems and processes while preserving the integrity and security of educational data.

9. **Standardization:** The need for standardization and consistency in the use of blockchain technology in education is essential for its success. This requires the development of common standards and protocols that can be used by institutions and organizations around the world.
10. **Education and training:** Educating and training individuals on the use of blockchain technology is essential for its successful implementation in the education sector. This includes the development of training programs and educational materials that can be used by educators, students, and other individuals to learn about the technology and how it can be used in education.
11. **Trust and reliability:** Trust and reliability are critical factors in regard to the use of blockchain technology in education. This requires the development of secure and reliable systems that can be trusted by individuals and organizations in the educational sector.
12. **Verification and validation:** Verifying and validating the authenticity and accuracy of educational data is a major challenge when using blockchain technology. This requires the development of secure and reliable systems for verifying and validating educational data, as well as methods for ensuring that the data remain accurate and tamper-proof over time.
13. **Data management**: Effective data management is essential for the successful use of blockchain technology in education. This involves the development of systems and processes for managing and organizing educational data, as well as methods for ensuring that the data remain secure and accessible over time.
14. **Accessibility:** Ensuring that students and educators have access to educational.

The implementation of blockchain technology in education requires a comprehensive and supportive environment that can handle the complex data and transactions associated with this emerging technology. This environment includes a range of hardware, software, devices, services, and security solutions that work together to ensure the successful deployment of blockchain in education [9,22]. Fig. 1 shows the most recent challenges for blockchain in education.

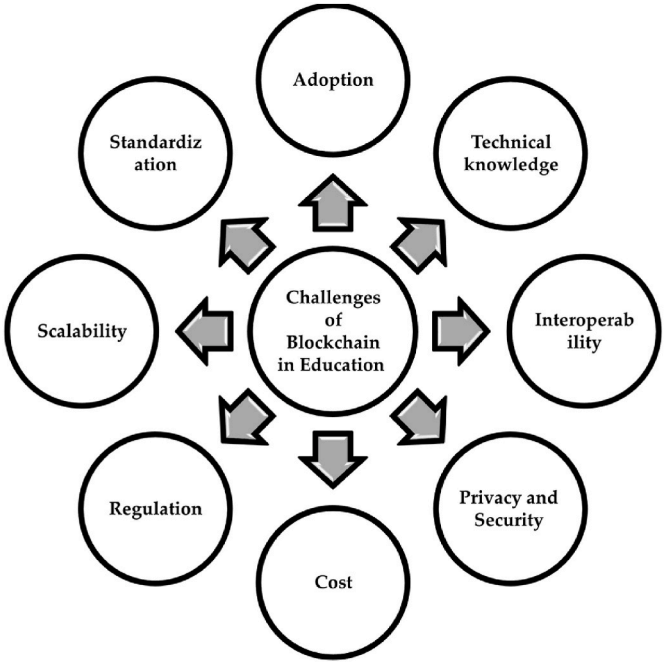

Fig. 1. The most common challenges of blockchain in education.

The COVID-19 pandemic has caused a significant change in the way higher education institutions provide training, with a shift from face-to-face interactions to virtual methods. This change has highlighted the need to manage the flow of knowledge, which is a crucial aspect of open innovation in universities. Universities that embrace open innovation during this crisis can overcome challenges and capitalize on opportunities to enhance their knowledge production. Despite their preference for face-to-face interactions, both teachers and students recognize the benefits of virtual learning. The study found that the lack of physical presence did not result in more meetings between teachers and students, and tutorials were less frequent and shorter. Students expressed a desire for a range of training resources, including podcasts and alternative forms of assessment, in pandemic and post-pandemic educational scenarios [23].

The challenges identified for blockchain in education aim to provide a comprehensive overview of the potential obstacles that may be encountered during the adoption of blockchain technology in the education sector. While it is true that blockchain technology can provide a trustworthy and secure system for education, it is important to acknowledge that there are potential challenges that must be addressed to ensure its successful implementation.

Issues such as data privacy and security, trust and reliability, verification and validation, and data management are important considerations that must be taken into account when implementing blockchain technology. These challenges arise because blockchain technology requires a significant shift in the traditional approach to data management, which can create challenges in terms of trust and reliability.

In addition to these challenges, adoption, technical knowledge, regulation, cost, education, and training are also important factors that must be considered when implementing blockchain technology in education. While these challenges may seem generic, they are still significant factors that can impact the successful adoption of blockchain technology in education.

The challenges of blockchain adoption in education may be similar to those encountered in the adoption of other technologies. However, it is essential to recognize that blockchain technology offers unique benefits, such as increased security, transparency, and immutability, that may justify the cost and regulatory challenges associated with its implementation.

Therefore, while it is important to acknowledge the challenges associated with blockchain adoption in education, it is equally essential to recognize the potential benefits and unique attributes that this technology can offer to the education sector. By addressing these challenges and leveraging the benefits of blockchain technology, educational institutions can enhance educational sustainability and secure their data and certification.

4. Environment and equipment (devices and services) of blockchain in education

The environment necessary for the implementation of blockchain in education is complex and requires a range of hardware, software, devices, services, and security solutions. Organizations should carefully consider these requirements when planning their implementation of blockchain technology in education to ensure the success of their initiatives. The implementation of blockchain technology in education requires a comprehensive range of hardware, devices, and services to ensure the successful deployment of this innovative technology. This equipment is critical in ensuring the efficient and secure transfer of educational data and transactions within the blockchain network [8, 24–27].

Hardware: The hardware requirements for blockchain in education are demanding, as the technology requires powerful and reliable computing resources to handle large amounts of data and transactions. This includes servers, storage devices, and other hardware components

that can store, process, and transmit data efficiently. The hardware should be designed to be scalable, secure, and able to handle increasing amounts of data as the blockchain network grows.

Software: The software environment is just as important as hardware in the implementation of blockchain in education. Blockchain technology requires a range of software platforms and tools to manage the data and transactions on the blockchain network. This includes blockchain platforms such as Ethereum, Hyperledger, and other similar solutions, as well as tools for managing the data and transactions on the blockchain network.

Devices: For individuals and organizations to participate in a blockchain network, they must have access to devices such as computers, smartphones, and other internet-connected devices. These devices should be secure, reliable, and equipped with the necessary software and applications to access the blockchain network and educational data.

Internet connectivity: Reliable and fast internet connectivity is also essential for the effective use of blockchain technology in education. This allows individuals and organizations to participate in the blockchain network and access educational data and resources from anywhere at any time.

Cloud services: Many institutions and organizations are turning to cloud-based services for the implementation of blockchain technology in education. This allows them to take advantage of the scalability and security benefits of the cloud while also reducing the costs associated with hardware and software infrastructure. Cloud services can also provide organizations with a more flexible and adaptable environment for implementing blockchain technology.

Blockchain-as-a-Service (BaaS) providers: BaaS providers offer cloud-based solutions for the implementation of blockchain technology. This includes services such as the hosting and management of blockchain networks, as well as the development of custom blockchain solutions for specific educational needs. BaaS providers can also provide organizations with a more streamlined and cost-effective way to implement blockchain technology in education.

Security solutions: Ensuring the security and privacy of educational data is essential when implementing blockchain technology in education. This requires the use of secure and reliable security solutions, such as encryption, firewalls, and intrusion detection systems. The security environment should also include disaster recovery and business continuity planning to ensure that educational data remain available and secure even in the event of a crisis. Fig. 2 shows the essential requirements, devices, and services needed to establish blockchain in education.

The implementation of blockchain technology in education requires a complex and comprehensive environment, including hardware, software, devices, and security solutions. It is crucial for organizations to carefully consider these requirements to ensure the success of their initiatives. Hardware requirements include powerful and reliable computing resources such as servers, storage devices, and other hardware components capable of storing, processing, and transmitting large amounts of data and transactions. The hardware should be scalable, secure, and able to handle increasing amounts of data as the blockchain network grows. Software platforms and tools are equally important for managing the data and transactions on the blockchain network. Blockchain platforms such as Ethereum, Hyperledger, and other similar solutions are essential, as well as tools for managing the data and transactions on the blockchain network. Access to devices such as computers, smartphones, and other internet-connected devices is necessary for individuals and organizations to participate in a blockchain network. These devices should be secure, reliable, and equipped with the necessary software and applications to access the blockchain network and educational data.

Reliable and fast internet connectivity is also essential for the effective use of blockchain technology in education. This allows individuals and organizations to participate in the blockchain network and access educational data and resources from anywhere at any time. Cloud-based services and BaaS providers can offer organizations more flexible and adaptable environments for implementing blockchain technology in education. They can also provide a more streamlined and cost-effective way to implement blockchain technology. Ensuring the security and privacy of educational data is essential when implementing

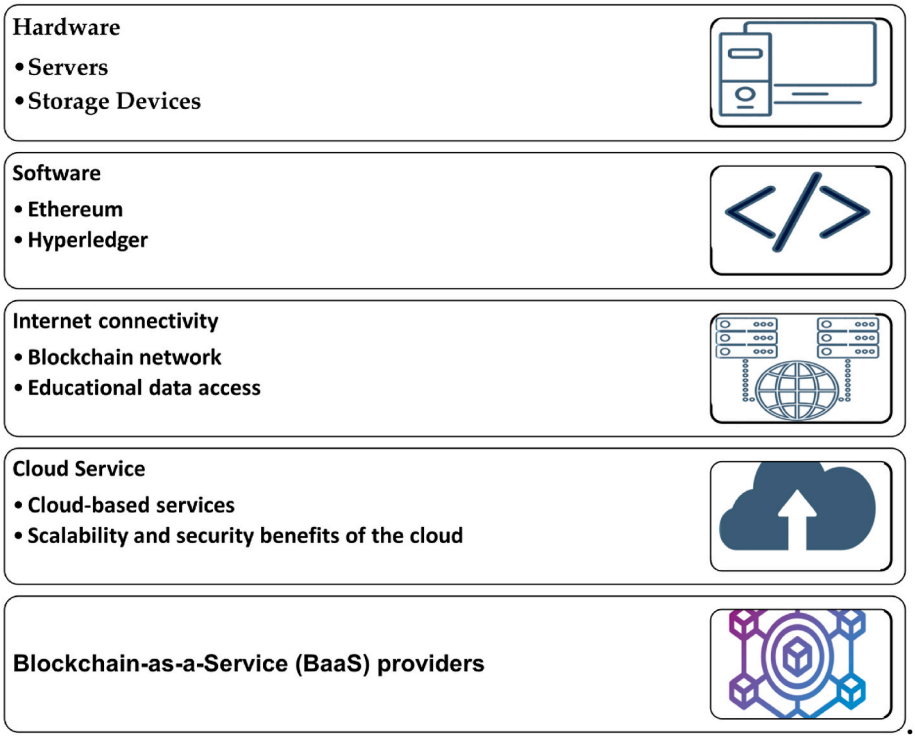

Fig. 2. The requirements, devices, and services of blockchain in education.

blockchain technology in education. This requires the use of secure and reliable security solutions, such as encryption, firewalls, and intrusion detection systems. The security environment should also include disaster recovery and business continuity planning to ensure that educational data remain available and secure even in the event of a crisis. Hence, a range of hardware, software, devices, and security solutions are needed for the successful implementation of blockchain technology in education. Organizations should carefully consider these requirements to ensure the efficient and secure transfer of educational data and transactions within the blockchain network.

5. The role of blockchain in sustainability for education

Blockchain technology has the potential to play a significant role in promoting sustainability education and advancing the sustainability goals of both individuals and organizations [28]. Here are some of the key ways in which blockchain technology can support sustainability education:

Transparency: Blockchain technology provides a transparent and tamper-proof record of transactions and data, making it possible to track the sustainability of educational materials and resources. This includes the use of renewable energy sources, the use of sustainable materials, and the reduction of waste and emissions [29].

Verifiable certifications: Blockchain technology can be used to provide verifiable and secure certifications of sustainability practices and performance. This can include certifications for sustainable products and services, as well as certifications for sustainable education and training programs [30].

Traceability: Blockchain technology can provide traceability for educational materials and resources, making it possible to track their production and consumption from the source to the end user. This allows individuals and organizations to make informed decisions about the sustainability of their educational materials and resources [31].

Supply chain management: Blockchain technology can be used to improve supply chain management in the education sector, making it possible to reduce waste and emissions and promote sustainable practices. This can include the use of blockchain-based tracking and reporting systems to monitor the sustainability of educational materials and resources, as well as the use of smart contracts to automate sustainable supply chain management processes [32].

Decentralization: Blockchain technology enables decentralized decision-making, which can help promote sustainability in education. This includes the decentralization of educational decision-making processes, the decentralization of educational content and resources, and the decentralization of educational funding and investment [33].

Increased efficiency: Blockchain technology can help to increase the efficiency of sustainability-related activities in education by reducing the need for intermediaries and increasing the speed and accuracy of transactions and data. This can help to reduce waste and emissions and to promote sustainable practices in the education sector [34].

Improved data management: Blockchain technology can improve data management in education by providing a secure and transparent record of sustainability-related data and transactions. This can help to promote data-driven decision-making and improve the accuracy and transparency of sustainability-related data and information [35].

Better outcome tracking: Blockchain technology can help to track the outcomes of sustainability-related activities in education, making it possible to measure their effectiveness and impact. This can include tracking the sustainability of educational materials and resources, tracking sustainable educational practices, and tracking sustainability-related educational outcomes [11].

Here is blockchain technology, which can be used to promote sustainability education in several ways, and there is growing evidence of its effectiveness in doing so.

Tracking and verifying sustainability initiatives: With blockchain technology, it is possible to track and verify sustainability initiatives such as carbon credits, renewable energy generation, and waste reduction. This can provide a transparent and auditable record of sustainability efforts, which can be used to promote education and awareness around sustainability.

Crowdfunding sustainability projects: Blockchain technology can also be used to crowdfund sustainability projects, allowing individuals to invest in and support sustainability initiatives. This can be an effective way to promote education and awareness around sustainability, as it engages individuals in the process of supporting and promoting sustainable practices.

Encouraging sustainable behaviors: Blockchain technology can be used to incentivize sustainable behaviors, such as reducing energy consumption or using public transportation. For example, a blockchain-based reward system could be used to incentivize individuals to use public transportation by offering rewards for each trip taken. This can be an effective way to promote sustainable behaviors and raise awareness about sustainability.

Supporting sustainable supply chains: Blockchain technology can also be used to support sustainable supply chains by providing a transparent and auditable record of the environmental and social impact of products and services. This can help to educate consumers about the sustainability of the products and services they purchase and encourage companies to adopt more sustainable practices.

The evidence of effectiveness includes several pilot projects and initiatives that have demonstrated the effectiveness of blockchain technology in promoting sustainability education. For example, the Plastic Bank is a blockchain-based platform that incentivizes individuals to collect and recycle plastic waste. The platform provides a transparent and auditable record of the plastic waste collected and recycled and rewards individuals with a digital token that can be exchanged for goods and services. The initiative has been successful in promoting sustainability education and raising awareness about plastic waste. Bext360 is a blockchain-based platform that provides a transparent and auditable record of the supply chain for products such as coffee and cocoa. The platform tracks the environmental and social impact of these products and rewards farmers for sustainable practices. The initiative has been successful in promoting sustainability education and encouraging more sustainable practices in the agriculture sector. The Energy Web Foundation is a blockchain-based platform that tracks renewable energy generation and consumption. The platform provides a transparent and auditable record of renewable energy usage and can be used to incentivize individuals and companies to adopt more sustainable energy practices. The initiative has been successful in promoting sustainability education and raising awareness about renewable energy.

Table 1 compares the sustainability of five different blockchain platforms (Bitcoin, Ethereum, Cardano, Algorand, and Polkadot) in the context of their potential for educational applications. The table highlights aspects such as environmental impact, scalability, support for smart contracts and Decentralized Applications (DApps), interoperability, and security and decentralization. Bitcoin is noted for its high energy consumption, limited scalability, and lack of support for smart contracts and DApps. Ethereum has better scalability and native support for smart contracts and DApps, but there have been security incidents in the past. Cardano, Algorand, and Polkadot are built with sustainability and security in mind, with varying levels of scalability and support for smart contracts and DApps. These platforms also emphasize interoperability to foster collaboration in the educational sector.

The role of blockchain in sustainability for education refers to the potential of blockchain technology to address the challenges faced by the education sector in promoting sustainable practices. These challenges include the need for secure and transparent systems for tracking and verifying educational credentials, the management of data privacy and security, and the need for efficient and reliable distance learning systems, especially in the face of pandemics and seismic shifts. The comparison of the five major blockchain platforms (Bitcoin, Ethereum, Cardano, Algorand, and Polkadot) in terms of their potential for

Table 1
Comparison between the five blockchain platforms (Bitcoin, Ethereum, Cardano, Algorand, and Polkadot) in terms of educational sustainability.

Aspect	Bitcoin	Ethereum	Cardano	Algorand	Polkadot
Environmental impact	High energy consumption due to Proof of Work (PoW) consensus mechanism. Not ideal for sustainability.	Transitioning from PoW to Proof of Stake (PoS) consensus mechanism, which is more energy-efficient and sustainable.	Built with PoS from the ground up, promoting sustainability by reducing energy consumption.	Designed with a Pure Proof of Stake (PPoS) mechanism, ensuring low energy consumption and promoting sustainability.	Uses Nominated Proof of Stake (NPoS) for greater energy efficiency and sustainability.
Scalability	Limited scalability due to slow transaction times and high fees. Not ideal for large-scale educational applications.	Better scalability than Bitcoin but still faces congestion issues. Layer 2 solutions, like sharding, are being developed to improve scalability.	Improved scalability through layered architecture and research-driven approach. Good potential for educational applications.	High scalability due to fast transaction times and low fees. Suitable for large-scale educational applications.	Provides cross-chain compatibility and parallel processing, enhancing scalability for diverse educational applications.
Smart contracts & DApps	Limited support for smart contracts and Decentralized Applications (DApps).	Native support for smart contracts and DApps, enabling the development of various educational tools and platforms.	Advanced support for smart contracts and DApps, with a focus on formal verification for secure and reliable educational applications.	Supports smart contracts and DApps, with features like Algorand Standard Assets (ASA) for creating custom tokens for educational purposes.	Offers a flexible environment for developing smart contracts and DApps, enabling the creation of various educational platforms and tools.
Interoperability	Lacks native interoperability with other blockchains, limiting the potential for collaboration and integration with other platforms.	Efforts to improve interoperability through bridges and cross-chain communication, but still a work in progress.	Designed with interoperability in mind, enabling seamless integration with other blockchains for cross-platform educational solutions.	Supports cross-chain communication and seamless integration with other platforms, fostering collaboration in the educational sector.	Focus on connecting multiple blockchains to create a unified ecosystem, promoting collaboration and interoperability in the educational space.
Security & decentralization	Highly secure and decentralized due to its large and distributed network.	Secure and decentralized, although there have been some incidents in the past (e.g., DAO hack).	Emphasis on formal verification and security, with a strong focus on decentralization through PoS.	Built with security and decentralization in mind, using cryptographic techniques like Verifiable Random Functions (VRF) to ensure a secure network.	Secure and decentralized, with an emphasis on shared security and the ability to spread risks across connected blockchains.

enhancing educational sustainability aims to provide insights into the suitability of these platforms for addressing the challenges faced by the education sector. The comparison is based on several factors, including the platforms' scalability, security, transaction speed, governance model, and ecosystem support. For example, Ethereum is known for its smart contract functionality, which enables the creation of DApps and the automation of complex workflows. This could be useful for creating blockchain-based systems for verifying educational credentials or managing academic records securely. Cardano, on the other hand, is known for its focus on governance and sustainability, which could be useful for creating sustainable and decentralized systems for education. The comparison aims to provide a starting point for educational organizations and universities to explore the potential of these blockchain platforms in addressing their specific needs and challenges. However, it is important to note that the suitability of a platform for a specific use case depends on various factors, such as the specific requirements of the use case, the resources available, and ecosystem support.

6. Universities around the world that are using blockchain technology

At present, there are limited statistical data available on the use of blockchain technology in education. However, recent studies and surveys suggest that the adoption of blockchain technology in education is still in its early stages, but it is expected to grow rapidly in the coming years [11,36].

According to a report by MarketsandMarkets, the global blockchain in the education market is expected to grow from USD 9.5 million in 2018 to USD 304.5 million by 2023, at a CAGR of 84.2 % during the forecast period. The growth of this market is primarily driven by the increasing demand for secure and transparent educational systems, as well as the growing awareness of the benefits of blockchain technology in education [37,38].

In a survey conducted by the nonprofit organization Education Blockchain Initiative, more than 60 % of education leaders indicated that they believe blockchain technology will play a significant role in the future of education. The survey also found that 44 % of education leaders believe that blockchain technology will help to improve the efficiency of educational systems, while 40 % believe that it will help to increase the transparency and security of educational data [20].

A recent study by Deloitte also found that blockchain technology has the potential to transform the education sector by increasing transparency, reducing costs, and improving the efficiency of educational systems.

The study found that the use of blockchain technology in education can help to improve the verification and sharing of credentials, as well as the management of educational content and resources [39].

There are many universities around the world that use blockchain technology in various aspects of their educational systems. Here are a few examples of universities that have implemented blockchain in their education [40–43]:

Massachusetts Institute of Technology (MIT): MIT has been at the forefront of the use of blockchain in education, having launched its own blockchain-based digital certificate system in 2015. The system allows students to receive secure and verifiable digital certificates for their coursework and achievements.

Stanford University: Stanford University has been exploring the use of blockchain technology in education, including its use for digital identity management, secure data sharing, and secure certificate management.

University College London (UCL): The UCL has implemented a blockchain-based platform for secure and transparent data management, which is used to store and manage student records, research data, and other sensitive information.

The University of Nicosia: The University of Nicosia in Cyprus was one of the first universities to embrace blockchain technology, having launched its own blockchain-based digital currency in 2013. The university also offers a master's degree in digital currency, which is taught entirely online and includes courses on blockchain technology.

The University of Melbourne: The University of Melbourne in Australia has been exploring the use of blockchain technology in education, including its use for secure data sharing, secure certificate

management, and digital identity management [44].

These are just a few examples of the many universities around the world that are using blockchain technology in their educational systems, as shown in Fig. 3. As the technology continues to evolve and more universities adopt blockchain, it is likely that we will see more and more universities leveraging blockchain technology to improve their educational systems.

It is difficult to determine the exact number of students who are using blockchain technology in their education, as the use of blockchain in education is still in its early stages and is being adopted by a relatively small number of universities and educational institutions [23]. However, as the use of blockchain in education becomes more widespread, it is likely that the number of students who are using the technology will continue to grow.

Table 2 summarizes the use cases of different blockchain technologies in various universities. These use cases include credentialing, payment processing, research collaboration, supply chain management, and Decentralized Autonomous Organizations (DAOs). The benefits of using these blockchain technologies include secure and tamper-proof storage of academic records, fast and cost-effective international payments, decentralized sharing of research data, improved transparency and traceability of supply chains, and decentralized decision-making and governance [45]. The universities mentioned are Arizona State University, University of Nicosia, University of Malta, Imperial College London, and Swiss Federal Institute of Technology Zurich (ETH Zurich).

7. Machine learning and blockchain in education

AI is a rapidly evolving field of computer science that involves the development of intelligent machines that can perform tasks that typically require human intelligence, such as visual perception, speech recognition, and decision-making. The emergence of AI has had a significant impact on various industries, including the field of journalism, where it has transformed the way information is collected, processed, generated, and distributed. In addition to its impact on education, AI has also affected the training processes of various fields, as it offers innovative solutions for enhancing knowledge production and personalized training. AI-based tools and technologies have the potential to revolutionize the way professionals are trained, allowing them to develop their skills and knowledge more efficiently and effectively [46].

Using machine learning and blockchain technology in education can bring a range of benefits, including improved security and privacy of student data, more personalized learning experiences, and enhanced evaluation and verification of educational achievements. Here are some ways machine learning and blockchain technology can be used in education [47–49].

1. Secure and private E-Learning environment: By integrating blockchain technology into E-Learning systems, student data can be securely stored and protected from unauthorized access and tampering. This can also provide a more private E-Learning environment, as students' personal information can be kept confidential [50].
2. Personalized learning experiences: Machine learning algorithms can analyze student data to identify individual learning patterns and preferences, allowing for more personalized learning experiences. This can result in improved student engagement, motivation, and academic performance [51].
3. Verification of educational achievements: Blockchain technology can provide a tamper-proof record of educational achievements, such as degrees and certifications, making it easier for employers and institutions to verify the credentials of job applicants and students.
4. Improved evaluation and assessment: Machine learning algorithms can help to automatically grade assignments and tests, reducing the time and effort required by instructors. This can also lead to more objective and consistent evaluations, as well as faster feedback for students.
5. Data-driven decision-making: By collecting and analyzing data on student performance, machine learning algorithms can provide insights into what teaching methods and materials are most effective. This can help instructors and institutions make more informed decisions about course design and pedagogical practices.

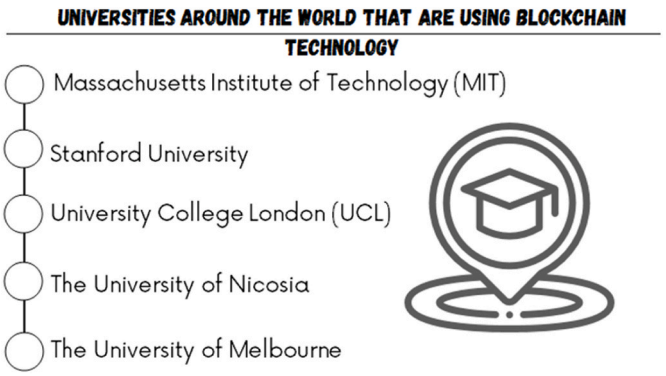

Fig. 3. The most common universities utilize blockchain in education.

Therefore, machine learning and blockchain technology have the potential to revolutionize education by providing more secure and personalized learning environments, as well as improving the evaluation and verification of educational achievements. However, as with any new technology, there are also challenges to be addressed, including data privacy concerns, lack of standardization, and the need for proper infrastructure. Nevertheless, the integration of machine learning and blockchain technology in education has the potential to improve the quality and accessibility of education for students all over the world.

Machine learning algorithms and blockchain technology have the potential to greatly enhance the accuracy of various processes in education, including grading, personalized learning, predictive analytics, fraud detection, and record keeping. By integrating these technologies, educational institutions can improve the quality and efficiency of their operations, leading to better outcomes for students.

The combination of AI and blockchain technology offers the potential for enhancing data privacy and security, facilitating trusted data sharing, creating decentralized AI model marketplaces, enabling AI model verification and auditing, supporting federated learning, and leveraging AI for blockchain analytics. While challenges remain, such as scalability and regulatory considerations, the integration of AI and blockchain holds promise for transformative applications across industries. Here are a few examples of how AI can be leveraged for blockchain analytics.

1. Fraud detection: AI algorithms can analyze blockchain data to identify patterns and anomalies that may indicate fraudulent activities, such as money laundering or illicit transactions. By training machine learning models on historical data, AI can learn to detect suspicious behaviors and flag potentially fraudulent transactions, contributing to improved security and compliance within blockchain networks.
2. Sentiment analysis: AI-powered natural language processing techniques can be applied to analyze text data within blockchain transactions, such as comments or descriptions associated with specific transactions. Sentiment analysis can help identify positive or negative sentiments expressed by users, providing insights into market trends, user behaviors, and potential risks.
3. Network analysis: AI algorithms can analyze the network structure of blockchain transactions to identify clusters, relationships, and patterns among different entities. This can help in understanding the flow of transactions, detecting potential fraud rings or money

Table 2
The most recent universities utilize blockchain technology in education.

University	Country	Use Case	Blockchain Technology	Benefits
Arizona State University	USA	Credentialing	Ethereum	Enables secure and tamper-proof storage of academic records, reducing administrative burden and increasing transparency for students and employers.
University of Nicosia	Cyprus	Payment Processing	Bitcoin	Allows for fast and cost-effective international payments for tuition and other expenses, bypassing traditional banking intermediaries.
University of Malta	Malta	Research Collaboration	IOTA	Facilitates secure and decentralized sharing of research data and collaborations with other universities and institutions.
Imperial College London	UK	Supply Chain Management	VeChain	Improves transparency and traceability of the university's supply chain, ensuring ethical and sustainable sourcing of goods and services.
Swiss Federal Institute of Technology Zurich (ETH Zurich)	Switzerland	Decentralized Autonomous Organizations (DAOs)	Tezos	Facilitates decentralized decision-making and governance, enabling greater participation and transparency for stakeholders within the university community.

laundering networks, and uncovering hidden connections that may be indicative of suspicious activities.
4. Predictive analytics: By leveraging machine learning algorithms, AI can analyze historical blockchain data to make predictions about future trends, transaction volumes, or network behaviors. These predictions can assist in decision-making, resource allocation, and risk management, enabling organizations to proactively address challenges and optimize their blockchain operations.
5. Anomaly detection: AI techniques can be employed to detect unusual or abnormal behaviors within blockchain networks. By establishing baseline patterns and training models to recognize deviations from those patterns, AI can help identify potential security breaches, insider threats, or technical issues that require attention.
6. Smart contract analysis: AI algorithms can analyze smart contracts deployed on blockchain networks to identify vulnerabilities, bugs, or potential security risks. This can assist in auditing smart contracts for accuracy, compliance, and adherence to best practices, ensuring the integrity and reliability of these self-executing contracts.

These examples demonstrate how AI can enhance blockchain analytics by providing insights, detecting patterns, predicting trends, and improving security. By leveraging the power of AI, organizations can gain valuable knowledge and make informed decisions within the context of blockchain technology [48,52,53].

8. The use of blockchain in credential verification

One of the most promising applications of blockchain technology in education is the use of blockchain for credential verification. With blockchain, educational institutions can issue and verify digital credentials that are stored securely on the blockchain.

These digital credentials can include degrees, diplomas, certificates, and even continuing education credits. By using blockchain, educational institutions can ensure that the credentials they issue are secure and tamper-proof, providing peace of mind to both students and employers [54,55].

8.1. How blockchain can improve credential verification

One of the biggest challenges with traditional credential verification is that it can be time-consuming and costly. Employers often have to request transcripts and certificates from multiple institutions and then verify their authenticity. This can be a tedious and costly process, especially for large organizations that need to verify the credentials of many candidates [56,57].

With blockchain, this process can be streamlined and made much more efficient. Employers can easily verify the authenticity of a candidate's credentials by checking the information stored on the blockchain. This eliminates the need for multiple verification requests and helps to reduce the overall cost of the verification process.

Another way that blockchain can improve credential verification is by providing real-time verification. With traditional verification methods, it can take several days or even weeks to receive the necessary information. With blockchain, verification can be performed in real-time, providing a much quicker and more efficient process [58].

8.2. Secure record keeping of blockchain in education

Blockchain technology has the potential to revolutionize many industries, including education. By providing a secure and decentralized ledger for recording transactions, blockchain technology can provide a new way of tracking student records, maintaining secure digital identities, and managing the flow of educational resources [59].

One of the key benefits of blockchain technology is its security. Transactions are stored in a decentralized network, meaning that there is no central point of failure that can be targeted by hackers. Additionally, each transaction is cryptographically secured, making it difficult to alter or erase records. This makes blockchain a perfect fit for maintaining secure student records, which contain sensitive personal information and academic achievements [60].

Another key benefit of blockchain technology in education is the creation of digital identities for students. A student's digital identity can include information such as their name, date of birth, and academic records. This information can then be used to track their progress throughout their educational career, and even into their professional life. By having a secure and decentralized digital identity, students can control who has access to their personal information and can ensure that their records are not lost or altered [8].

The use of blockchain technology in education can also help with the distribution of educational resources, such as scholarships and grants. By having a secure ledger of transactions, educational institutions can track the distribution of resources, ensuring that they are being used for their intended purpose. Additionally, the use of smart contracts can automate the distribution of resources, reducing the risk of human error and increasing the efficiency of the process [36].

8.3. Decentralized systems of blockchain in education

The use of decentralized systems in education has the potential to bring about significant changes in the way educational institutions operate and manage student records. The decentralized nature of blockchain technology means that there is no central authority that controls the flow of information and resources. This provides numerous benefits, including increased transparency, reduced risk of data breaches, and greater efficiency in record-keeping processes [61].

One of the main benefits of decentralized systems in education is increased transparency. By having a decentralized ledger that records transactions, educational institutions can create a more transparent system for tracking student records and educational resources.

This can help to reduce the risk of fraud and ensure that resources are

being used for their intended purpose. Additionally, students can have greater visibility in their academic records and can ensure that their personal information is being used in an ethical and responsible manner [62].

Another benefit of decentralized systems in education is the reduced risk of data breaches. As there is no central point of failure, the risk of a single data breach compromising sensitive student information is greatly reduced. Additionally, each transaction is cryptographically secured, making it difficult for unauthorized individuals to access or alter records. This increased security helps to ensure that student information remains confidential and protected [63].

Decentralized systems also bring about greater efficiency in record-keeping processes. By using smart contracts, educational institutions can automate the process of tracking student records and the distribution of educational resources. This can help to reduce the risk of human error and improve the accuracy and speed of these processes. Additionally, the use of blockchain technology in education can help to reduce the need for paper-based records, making it easier and more efficient to manage student information [26,64].

The use of blockchain technology in payment systems has the potential to revolutionize the way that educational institutions handle tuition and other fees. By providing a secure and decentralized ledger for tracking transactions, blockchain technology can help reduce the risk of fraud and ensure the accuracy and efficiency of payment processes.

One of the main benefits of using blockchain technology in payment systems is increased security. Transactions are recorded in a decentralized network, making it difficult for hackers to alter or erase records. Additionally, each transaction is cryptographically secured, reducing the risk of fraud and ensuring that payments are made to the correct recipient. This increased security helps to ensure that students' tuition and fee payments are protected from theft or fraud [65].

Another benefit of blockchain technology in payment systems is the ability to reduce transaction fees. Traditional payment systems often charge high fees for transactions, which can add up over time, especially for students who are paying for tuition and other fees on a regular basis. By using blockchain technology, the cost of transactions can be greatly reduced, making it more affordable for students to pay for their education [66].

The use of blockchain technology in payment systems can also help improve the efficiency of payment processing. By using smart contracts, educational institutions can automate the process of tracking payments and distributing resources. This can help to reduce the risk of human error and improve the speed and accuracy of payment processing. Additionally, the use of blockchain technology in payment systems can help to reduce the need for paper-based records, making it easier and more efficient to manage payments [67].

9. Blockchain applications

Generally, blockchain technology has been disrupting a wide range of industries and has the potential to bring about significant changes in the way we live and work. Here are 30 potential applications for blockchain technology:

Cryptocurrencies: One of the most well-known applications of blockchain technology is the creation of cryptocurrencies like Bitcoin, Ethereum, and others.

Digital wallets: Digital wallets can be used to securely store and manage cryptocurrencies and other digital assets.

Payment systems: Blockchain technology can be used to create fast, secure, and low-cost payment systems.

Supply chain management: Blockchain technology can be used to create secure and transparent supply chain management systems.

Asset management: Blockchain technology can be used to create secure and transparent asset management systems.

Decentralized identity management: Blockchain technology can be used to create secure and decentralized systems for managing personal identity information.

Voting systems: Blockchain technology can be used to create secure and transparent voting systems.

Health record management: Blockchain technology can be used to create secure and transparent health record management systems.

Property management: Blockchain technology can be used to create secure and transparent property management systems.

Music and media rights management: Blockchain technology can be used to create secure and transparent systems for managing music and media rights.

Intellectual property management: Blockchain technology can be used to create secure and transparent systems for managing intellectual property rights.

Real estate management: Blockchain technology can be used to create secure and transparent real estate management systems.

Food safety and traceability: Blockchain technology can be used to create secure and transparent food safety and traceability systems.

Energy trading: Blockchain technology can be used to create secure and transparent energy trading systems.

Insurance: Blockchain technology can be used to create secure and transparent insurance systems.

Fraud detection: Blockchain technology can be used to create secure and transparent systems for detecting and preventing fraud.

Gaming: Blockchain technology can be used to create secure and transparent gaming platforms.

Gambling: Blockchain technology can be used to create secure and transparent gambling platforms.

Stock trading: Blockchain technology can be used to create secure and transparent stock trading systems.

Crowdfunding: Blockchain technology can be used to create secure and transparent crowdfunding platforms.

Social media: Blockchain technology can be used to create secure and transparent social media platforms.

Online marketplaces: Blockchain technology can be used to create secure and transparent online marketplaces.

DAOs: Blockchain technology can be used to create secure and transparent DAOs.

Decentralized file storage: Blockchain technology can be used to create secure and decentralized file storage systems.

Decentralized domain name systems: Blockchain technology can be used to create secure and decentralized domain name systems.

Decentralized search engines: Blockchain technology can be used to create secure and decentralized search engines.

Decentralized prediction markets: Blockchain technology can be used to create secure and decentralized prediction markets.

Decentralized data marketplaces: Blockchain technology can be used to create secure and decentralized data marketplaces.

Decentralized content distribution: Blockchain technology can be used to create secure and decentralized content distribution systems.

Decentralized exchanges: Blockchain technology can be used to create secure and decentralized exchanges for trading cryptocurrencies and other digital assets.

Fig. 4 investigated the most recent applications in blockchain [22,68–70].

Blockchain technology has the potential to transform various industries, including education. Some possible applications of blockchain in education are as follows.

Credential verification: Blockchain can be used to securely store and verify academic credentials, including degrees, diplomas, and certifications. This can help to prevent fraud and ensure the authenticity of credentials [22].

Record keeping: Blockchain can be used to create and store tamper-proof records of academic achievements, such as grades, attendance, and extracurricular activities. This can help students build a comprehensive and accurate portfolio of their academic work.

Digital identity management: Blockchain can be used to create a

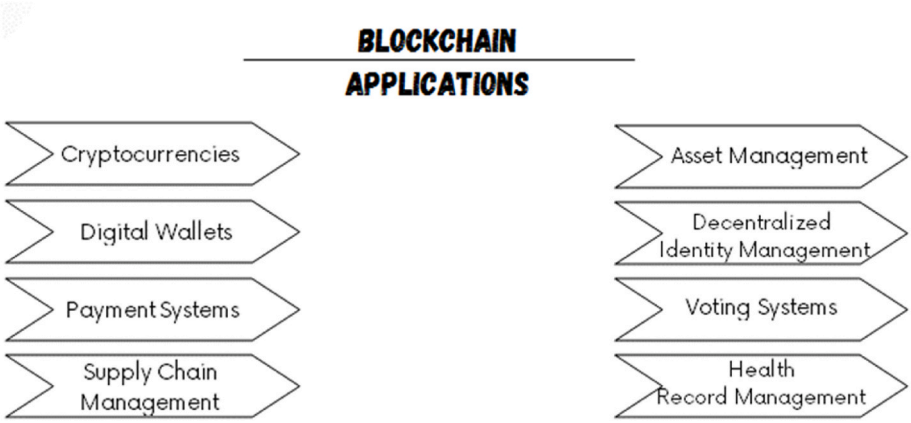

Fig. 4. Some recent applications in blockchain.

secure digital identity for students, which can be used to authenticate their credentials and provide access to various educational resources.

Micro-credentialing: Blockchain can be used to create and manage micro-credentials, which are smaller, more targeted certifications that demonstrate specific skills or competencies. This can help to improve employability and provide more flexible learning opportunities.

Student data privacy: Blockchain can be used to create a decentralized and secure system for storing student data, which can protect student privacy and prevent data breaches.

Some recent companies that are working on blockchain solutions for education include [41]:

Learning Machine: This company provides a blockchain-based system for creating, verifying, and sharing digital credentials.

BitDegree: This company offers a blockchain-based platform for online learning, which allows students to earn cryptocurrency by completing courses.

Blockcerts: This is an open source project that provides a standard for creating and verifying blockchain-based digital credentials.

ODEM: This company offers a blockchain-based platform for creating and delivering customized education and training programs.

Sony Global Education: This company is exploring the use of blockchain technology to create a secure and transparent system for storing and sharing academic records.

Table 3 outlines various use cases of blockchain in education. It compares the features of public and private blockchains for each use case. Public blockchains are decentralized and open to anyone, while private blockchains are permissioned and limited to specific organizations. The table highlights the benefits of each type of blockchain for the respective use case. Use cases include decentralized, immutable, and transparent credentialing systems, secure and privacy-preserving learning analytics, micro-credentialing systems, lifelong learning records, intellectual property management, distributed learning environments, and transparent funding and donation systems [71].

Table 4 summarizes various applications of blockchain in education, including their advantages, disadvantages, security, transparency, efficiency, cost, scalability, and adoption [72]. These applications include credential verification, distributed learning, micro-credentials, smart contracts, learning analytics, funding and donations, intellectual property, identity management, data sharing, and student record management. While each application has its benefits and challenges, they all provide secure and tamper-proof solutions with a high level of transparency and accountability. However, the initial cost of implementation may be high, and scaling across multiple institutions may be difficult. Nonetheless, adoption is growing as the need for more efficient and secure education solutions increases [73,74].

10. Enhancing efficiency and privacy

In this study, it would be beneficial to investigate alternative technologies or approaches that can complement or enhance the usage of blockchain in the education sector. While blockchain has distinct advantages, it is vital to explore various technologies and approaches that can complement blockchain or act as alternatives in specific cases. The following are some of such examples.

1. Federated learning: Federated learning is an approach where machine learning models are trained locally on decentralized devices, and only aggregated updates are shared instead of raw data. This approach can address privacy concerns in educational data while still allowing collaborative model training and knowledge sharing among educational institutions.
2. Secure Multiparty Computation (MPC): Secure MPC is a cryptographic technique that enables multiple parties to jointly compute a function on their private inputs without revealing any individual data. MPC can be used to perform calculations on sensitive educational data while preserving privacy, and it can be combined with blockchain for enhanced security and transparency.
3. Self-Sovereign Identity (SSI): SSI frameworks provide individuals with control over their digital identities, allowing them to manage and share their credentials securely. SSI can work alongside blockchain to enhance identity management in education, giving students more control over their educational records and simplifying the verification process.
4. Interoperability protocols: Interoperability protocols and frameworks facilitate seamless data exchange and integration between different educational systems and platforms. By adopting standardized protocols such as Ed-Fi, IMS Global Learning Consortium, or W3C's Verifiable Credentials, educational institutions can ensure interoperability between their existing systems and blockchain applications.
5. Cloud-based solutions: Cloud-based solutions offer scalability, cost-effectiveness, and ease of implementation compared to building and maintaining private blockchain networks. Cloud platforms can provide secure storage, data processing, and analytics capabilities for educational institutions while leveraging blockchain selectively for specific use cases that require its unique features.
6. Internet of Things (IoT): Combining blockchain with IoT devices can enable new educational applications. For example, IoT devices can collect data on student activities or monitor classroom environments, and blockchain can provide a secure and transparent data storage and verification mechanism for these IoT-generated data.

Table 3
The comparison between public and private blockchains in education.

Feature	Public Blockchains	Private Blockchains
Credentialing	Decentralized, immutable, and transparent credentials can be created, verified, and shared without intermediaries.	Permissions can be granted to specific organizations, enabling them to create and manage their own blockchain-based credentialing systems.
Learning analytics	Data can be securely stored, shared, and analyzed in a decentralized manner, enabling educators to gain insights into student learning without compromising privacy.	Data can be shared and analyzed among authorized parties in a permissioned network, enabling more effective data-driven decision-making.
Micro-credentials	Decentralized micro-credentialing systems can be created and managed by educators and learners, enabling more granular and relevant forms of recognition.	Permissions can be granted to specific organizations, enabling them to create and manage their own micro-credentialing systems within a private blockchain network.
Lifelong learning	Decentralized, lifelong learning records can be created and managed by learners themselves, enabling them to take control of their learning journeys and showcase their skills and competencies.	Permissions can be granted to specific organizations, enabling them to create and manage their own lifelong learning records within a private blockchain network.
Intellectual property	Decentralized, immutable, and transparent systems can be created for managing intellectual property in education, enabling greater innovation and protection of creators' rights.	Permissions can be granted to specific organizations, enabling them to create and manage their own intellectual property management systems within a private blockchain network.
Distributed learning	Decentralized learning environments can be created, enabling learners and educators to connect and collaborate without intermediaries.	Permissions can be granted to specific organizations, enabling them to create and manage their own decentralized learning environments within a private blockchain network.
Funding and donations	Transparent and secure systems can be created for managing funding and donations in education, enabling greater accountability and trust.	Permissions can be granted to specific organizations, enabling them to create and manage their own transparent and secure funding and donation systems within a private blockchain network.
Credentialing	Decentralized, immutable, and transparent credentials can be created, verified, and shared without intermediaries.	Permissions can be granted to specific organizations, enabling them to create and manage their own blockchain-based credentialing systems.
Learning analytics	Data can be securely stored, shared, and analyzed in a decentralized manner, enabling educators to gain insights into student learning without compromising privacy.	Data can be shared and analyzed among authorized parties in a permissioned network, enabling more effective data-driven decision-making.

By exploring these alternative technologies and approaches, a more comprehensive analysis of the options available to educational institutions beyond blockchain alone can be performed. Understanding the strengths and limitations of different technologies helps stakeholders make informed decisions and choose the most suitable solutions for their specific needs in the education sector.

11. Examples demonstrate how blockchain can revolutionize traditional education processes through its use

Blockchain is a distributed ledger technology that has the potential to revolutionize many industries, including education. This section will introduce some examples of how blockchain can be used to improve traditional education processes.

11.1. Example 1: blockchain in credential verification

In traditional education systems, verifying the authenticity and validity of academic credentials, such as degrees and certificates, can be a time-consuming and cumbersome process. Educational institutions, employers, and other stakeholders often rely on manual verification methods, which can be prone to errors and fraudulent practices. However, by leveraging blockchain technology, the process of credential verification can be revolutionized, providing a more secure and efficient solution.

In this example, let us consider a hypothetical educational subject called "blockchain-based credential verification", which explores how blockchain technology can reform traditional educational processes.

Scenario: John is a job seeker who recently completed a degree in Computer Science from a reputable university. He is applying for a job at a technology company that values academic qualifications and requires verification of his degree. The company, instead of relying on traditional methods, has implemented a blockchain-based credential verification system.

How Blockchain is Employed.

1. Issuance of credentials: When John completes his degree, the university generates a digital certificate for him. The certificate includes relevant information such as the degree title, completion date, and John's unique identifier.
2. Creation of a blockchain network: The university, along with other educational institutions and relevant entities, participates in a blockchain network specifically designed for credential verification.
3. Certificate registration: The university registers John's digital certificate on the blockchain. This process involves creating a unique cryptographic hash of the certificate and storing it in a block, which is added to the blockchain.
4. Decentralized verification: When John applies for a job, the potential employer requests verification of his degree. Instead of contacting the university directly, the employer queries the blockchain network. The information stored on the blockchain includes the cryptographic hash of John's certificate.
5. Verification process: The blockchain network utilizes consensus algorithms to validate the authenticity of John's certificate. The distributed nature of the blockchain ensures that multiple nodes in the network verify the certificate independently.
6. Immutable and transparent records: Once the verification is complete, the employer receives confirmation of John's degree. The blockchain's immutability ensures that the verification record cannot be tampered with, providing a high level of trust and transparency.

11.2. Example 2: blockchain in digital rights management for online music education

In the context of online music education, blockchain technology can be employed to revolutionize Digital Rights Management (DRM) and transform traditional practices. Currently, copyright infringement and unauthorized use of musical compositions are significant challenges in the music industry, including online educational platforms. By leveraging blockchain, music education platforms can establish a transparent and immutable system for managing copyrights, royalties, and licensing in a decentralized manner.

In this example, an online music education platform called "Harmony Academy" adopts blockchain technology to address these challenges. Here's how it could work.

1. Copyright registration: Harmony Academy utilizes blockchain to register original musical compositions created by their students and

Table 4
The comparative study of the most recent applications of blockchain in education.

Application	Description	Pros	Cons	Security	Transparency	Efficiency	Cost	Scalability	Adoption
Credential verification	Blockchain can be used to verify academic degrees, certifications, and other credentials.	Reduces fraud and misrepresentation of qualifications.	High initial cost of implementation.	Highly secure and tamper-proof.	High level of transparency and accountability.	Saves institutions time and money.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is growing rapidly as the need for credential verification increases.
Distributed learning	Blockchain can be used to develop peer-to-peer learning networks where learners can share knowledge and resources with each other.	Encourages collaboration and peer-to-peer learning.	May be difficult to ensure quality and accuracy of information.	Highly secure and tamper-proof.	High level of transparency and accountability.	Expands learning opportunities for learners.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in distributed learning models.
Micro-credentials	Blockchain can be used to issue and manage micro-credentials that represent specific skills or competencies.	Provides a more granular way to represent skills and competencies.	May be difficult to ensure quality and accuracy of assessments.	Highly secure and tamper-proof.	High level of transparency and accountability.	Enables learners to showcase specific skills to potential employers.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in micro-credentialing.
Smart contracts	Blockchain can be used to develop smart contracts that automate the process of verifying and issuing credentials.	Provides a streamlined and automated way to issue credentials.	May be difficult to ensure quality and accuracy of assessments.	Highly secure and tamper-proof.	High level of transparency and accountability.	Saves institutions time and money.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in smart contract-based credentialing.
Learning analytics	Blockchain can be used to track learner progress and performance data in a secure and decentralized way.	Enables institutions to collect and analyze data on learner performance.	May be difficult to ensure data accuracy and privacy.	Highly secure and tamper-proof.	High level of transparency and accountability.	Improves decision-making by providing more accurate and comprehensive data.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is growing as institutions look for more comprehensive ways to track learner performance.
Funding and donations	Blockchain can be used to track funding and donations for educational projects and initiatives.	Increases transparency and accountability in funding and donation processes.	May be difficult to ensure data accuracy and privacy.	Highly secure and tamper-proof.	High level of transparency and accountability.	Increases efficiency in tracking funding and donations.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in blockchain-based funding and donations.
Intellectual property	Blockchain can be used to secure and manage intellectual property rights for educational content and resources.	Increases security and reduces infringement risks.	May be difficult to ensure enforcement of intellectual property rights.	Highly secure and tamper-proof.	High level of transparency and accountability.	Provides an efficient way to manage intellectual property rights.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is interest in blockchain-based intellectual property management solutions.
Identity management	Blockchain can be used to manage and verify learner identities in a secure and decentralized way.	Increases security and reduces fraud risks.	May be difficult to ensure data accuracy and privacy.	Highly secure and tamper-proof.	High level of transparency and accountability.	Simplifies identity verification processes.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in blockchain-based identity management solutions.
Data sharing	Blockchain can be used to enable secure and decentralized sharing of educational data between institutions and learners.	Increases data security and reduces data silos.	May be difficult to ensure data accuracy and privacy.	Highly secure and tamper-proof.	High level of transparency and accountability.	Enables more efficient sharing of educational data.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in blockchain-based data sharing solutions.
Student record management	Blockchain can be used to securely store and manage student records in a decentralized way.	Increases security and reduces data loss risks.	May be difficult to ensure data accuracy and privacy.	Highly secure and tamper-proof.	High level of transparency and accountability.	Improves efficiency in managing student records.	High initial cost of implementation.	Can be difficult to scale across multiple institutions.	Adoption is still growing, but there is increasing interest in blockchain-based student record management solutions.

instructors. Each composition is timestamped, hashed, and stored on the blockchain, establishing a permanent record of its creation.
2. Secure licensing and royalty distribution: When students or instructors want to license their compositions for commercial use within the platform or even outside of it, smart contracts are used to automate licensing agreements. These smart contracts specify the terms, conditions, and royalty distribution for each usage. Payments are made directly to the copyright holders through the blockchain, ensuring transparency and eliminating intermediaries.
3. Immutable ownership and attribution: As compositions are shared and used within the Harmony Academy community, the blockchain provides an immutable record of ownership and attribution. This ensures that the original creators receive proper credit for their work and allows for transparent tracking of derivative works.
4. Collaboration and remixing: Blockchain enables secure collaboration and remixing of musical compositions. Students and instructors can collaborate on projects by granting temporary access to their compositions on the blockchain while retaining control over their intellectual property.
5. Transparent usage tracking: The blockchain tracks the usage of compositions within the Harmony Academy platform, providing transparent and auditable records of how compositions are utilized. This helps in enforcing licensing agreements and ensuring fair compensation for copyright holders.

By implementing blockchain technology in this manner, Harmony Academy enhances trust, transparency, and accountability within the online music education ecosystem. It empowers students and instructors with greater control over their intellectual property while simplifying licensing processes and ensuring fair compensation for creators.

This example demonstrates how blockchain can disrupt and reform traditional educational processes, specifically in the field of online music education. It showcases the potential of blockchain technology to address copyright-related challenges, encourage collaboration, and create a fair and transparent environment for creators and learners alike.

11.3. Example 3: blockchain in credential verification for higher education

In the field of higher education, the verification of academic credentials is a critical process that often relies on time-consuming and paper-based methods. Blockchain technology offers a transformative solution by providing a decentralized and immutable ledger that can securely store and verify educational records.

Let us consider a scenario where blockchain is implemented to reform the traditional credential verification process for a university. In this example, the university adopts a blockchain-based system called "EduBlock" to streamline and enhance the verification of student degrees.

1. Student enrollment: When a student enrolls in the university, their educational records, including courses taken and grades earned, are securely entered into the blockchain. Each record is cryptographically signed and timestamped, ensuring its integrity and immutability.
2. Degree issuance: Upon completion of their studies, the student's degree is digitally issued and recorded on the blockchain. The degree information includes details such as the program of study, specialization, and honors received.
3. Blockchain verification: To verify a student's degree, third-party entities, such as potential employers or other educational institutions, can access the blockchain-based system. They can independently verify the authenticity and accuracy of the student's credentials by verifying the records on the blockchain.
4. Increased trust and efficiency: By leveraging blockchain, the credential verification process becomes more transparent, efficient, and tamper-proof. Institutions can eliminate the need for manual verification processes, reducing administrative burdens and potential errors. Moreover, students have greater control over their digital credentials, allowing them to easily share verified records with employers or other educational institutions.
5. Data privacy and security: Blockchain technology ensures the privacy and security of educational records. Students have ownership of their data and can grant permission for specific entities to access their records, maintaining control over their personal information.

By implementing blockchain technology in this illustrative example, the university revolutionizes the traditional credential verification process. The adoption of EduBlock enhances transparency, efficiency, and data security, benefiting both students and institutions. This example showcases how blockchain can reform educational processes, paving the way for a more reliable and streamlined credential verification system in higher education.

Note: This example focuses on credential verification, but blockchain technology has the potential to impact various other aspects of education, such as digital content ownership, secure voting systems, and transparent allocation of educational resources.

11.4. Example 4: blockchain in language learning and certification

In the realm of language learning and certification, traditional methods often face challenges in verifying language proficiency and ensuring the credibility of certificates. Blockchain technology can offer a transformative solution by introducing decentralized and transparent mechanisms for language learning and certification.

Let us consider a scenario where blockchain is applied to reform the traditional language learning and certification processes for a language institute called "LinguaTech".

1. Language learning on the blockchain: LinguaTech develops a blockchain-based language learning platform that offers interactive lessons, practice exercises, and assessments. Each student's learning progress, including completed lessons, scores, and achievements, is recorded on the blockchain in an immutable and transparent manner.
2. Peer-to-Peer verification: To enhance the credibility of language proficiency certifications, LinguaTech leverages blockchain's decentralized nature. After completing a course or demonstrating language proficiency, students' achievements are cryptographically recorded on the blockchain. These achievements can be verified by other language institutes, employers, or individuals through a peer-to-peer verification process.
3. Smart contracts for certification: LinguaTech utilizes smart contracts, self-executing agreements on the blockchain, to issue digital language proficiency certificates. When a student achieves a certain level of proficiency, the smart contract automatically generates a digital certificate with relevant details and stores it on the blockchain. These certificates are tamper-proof, easily verifiable, and accessible to authorized parties.
4. Blockchain-based credential portfolios: LinguaTech develops a decentralized credential portfolio system on the blockchain. Students can securely store their language proficiency certificates, achievements, and other educational records in their personal blockchain-based portfolios. They have control over who can access their credentials and can easily share them with employers, educational institutions, or other relevant parties.
5. Global language passport: LinguaTech collaborates with other language institutes worldwide to create a global language passport initiative. This initiative utilizes blockchain technology to ensure the interoperability of language proficiency certificates issued by different institutions. Students can have a unified, verifiable

language passport that showcases their language skills across multiple educational contexts.

By incorporating blockchain technology into language learning and certification, LinguaTech revolutionizes traditional processes. The adoption of blockchain provides transparency, credibility, and security in verifying language proficiency. Students benefit from verifiable certificates, secure credential storage, and enhanced portability of their language skills. Employers and educational institutions gain access to reliable and tamper-proof language proficiency records, facilitating efficient recruitment and admission processes.

This example demonstrates how blockchain can reform traditional language learning and certification processes, creating a more trustworthy and globally recognized framework for assessing language proficiency in the educational landscape.

11.5. Example 5: blockchain in environmental science education

In the field of environmental science education, traditional methods often face challenges in data integrity, collaboration, and transparency. Blockchain technology can offer a transformative solution by introducing decentralized and immutable records that enhance environmental research, foster collaboration, and ensure data accuracy.

Let us consider a scenario where blockchain is applied to reform the traditional environmental science education processes for a university program called "EcoChainX".

1. Decentralized data collection: EcoChainX leverages blockchain technology to facilitate decentralized data collection in environmental science research. Students and researchers can record environmental data, such as air quality measurements, water samples, and biodiversity observations, directly onto the blockchain. This ensures the integrity and authenticity of the data, making it tamper-proof and transparent.
2. Immutable research findings: Research findings and conclusions are stored on the blockchain as immutable records. This enables students and researchers to publish their work securely and transparently, fostering collaboration and peer review. The blockchain-based system allows for efficient dissemination of research, increasing the visibility and impact of environmental science studies.
3. Collaborative data sharing: EcoChainX creates a decentralized data-sharing platform on the blockchain. Students and researchers can securely share their environmental datasets with peers, other educational institutions, or government agencies. The transparent and auditable nature of blockchain ensures data integrity and builds trust among stakeholders, facilitating collaboration for environmental research initiatives.
4. Smart contracts for environmental campaigns: EcoChainX utilizes smart contracts on the blockchain to automate and transparently manage environmental campaigns. Students can propose and execute campaigns to address environmental issues, such as reforestation or waste reduction. Smart contracts automatically track campaign progress, fund allocation, and impact metrics, ensuring transparency and accountability throughout the campaign lifecycle.
5. Blockchain for climate change mitigation: EcoChainX collaborates with climate change initiatives and utilizes blockchain to track and verify carbon credits. Students can learn about carbon offset mechanisms and engage in projects that reduce greenhouse gas emissions. The blockchain ensures transparent and auditable tracking of carbon credits, enhancing the credibility and impact of climate change mitigation efforts.

By incorporating blockchain technology into environmental science education, EcoChainX revolutionizes traditional processes. The adoption of blockchain provides transparency, data integrity, and collaboration in environmental research. It empowers students to contribute to real-world environmental initiatives, engage in data-driven decision-making, and explore innovative solutions to pressing environmental challenges.

This example demonstrates how blockchain can reform traditional environmental science education processes, enrich students' learning experiences and foster collaboration for sustainable environmental practices. It equips students with the skills and knowledge needed to address complex environmental issues and contribute to a more sustainable future.

12. Discussion

While the technology is still in its early stages of adoption in the education sector, the potential benefits are significant, and there is a growing body of research that supports its use in education. One of the most significant advantages is improving the efficiency, security, and credibility of the educational process. Here are some examples of how blockchain technology can achieve this:

Secure and transparent platforms for tracking and verifying academic achievements: Blockchain technology can create secure and transparent platforms for tracking and verifying students' academic achievements. This can help to ensure that educational records are accurate, tamper-proof, and easily accessible to relevant stakeholders. For instance, some universities and educational institutions are already using blockchain to issue digital certificates and badges to their graduates. These digital credentials can be easily verified by potential employers, eliminating the need for time-consuming background checks.

Reduced administrative burden: The use of blockchain technology in education can also reduce the administrative burden on educational institutions. For instance, by creating a decentralized platform for storing and sharing educational records, blockchain can eliminate the need for intermediaries such as third-party verification agencies. This can save time, reduce costs, and improve the overall efficiency of the educational process.

Improved accessibility: Blockchain technology can also improve the accessibility of education by creating a more inclusive and equitable system. For instance, by using blockchain-based platforms to issue and verify digital credentials, educational institutions can reach out to learners who may not have access to traditional educational channels. This can help to bridge the digital divide and create more opportunities for learners from marginalized communities.

Enhanced credibility: Blockchain technology can also enhance the credibility of the educational process by providing an immutable and transparent record of educational achievements. This can help to address the issue of diploma mills and fake degrees, which have become a significant problem in some parts of the world. By using blockchain to verify educational credentials, educational institutions can ensure that their graduates are qualified and competent, thereby enhancing their reputation and credibility in the eyes of potential employers.

One challenge is the technical knowledge required to implement and use blockchain technology. Blockchain is a complex and rapidly evolving technology, and educators and administrators may not have the necessary technical expertise to implement and manage it. This can lead to implementation issues, such as problems with data integrity, interoperability with existing systems, and user adoption. Another challenge is data privacy and security. As with any digital technology, blockchain can be vulnerable to cyber-attacks and data breaches, which can compromise sensitive information such as student records and credentials. In addition, there are concerns about the use of blockchain for the surveillance and monitoring of students and the potential for data misuse or abuse.

Regulation and governance are also important challenges to consider. As blockchain adoption increases in education, there will be a need for clear and consistent regulation and governance frameworks to ensure the responsible and ethical use of the technology. This includes addressing concerns about data privacy and security, and ensuring that

blockchain systems are interoperable with existing educational systems.

Despite these challenges, the potential implications of blockchain technology in education are significant. By providing a secure, transparent, and decentralized platform for storing and sharing educational data, blockchain can help to improve trust, accountability, and accessibility in education. For example, blockchain can be used to create secure and transparent platforms for tracking and verifying students' academic achievements, making it easier for students to showcase their skills and knowledge to potential employers.

There is strong evidence to suggest that blockchain technology has the potential to greatly improve the efficiency, security, and credibility of the educational process by creating secure and transparent platforms for tracking and verifying students' academic achievements. As the adoption and implementation of this technology continues to grow, we can expect to see significant improvements in the way that academic records are stored, managed, and shared. First, secure and tamper-proof records: With blockchain technology, educational institutions can create secure and tamper-proof records of students' academic achievements. These records can be stored on a decentralized blockchain network, which makes it extremely difficult for anyone to alter or manipulate them. This ensures that students' academic achievements are accurately recorded and cannot be forged or manipulated. Second, increased efficiency by which traditional academic record-keeping is often slow and time-consuming, involving multiple parties and manual processes. With blockchain technology, records can be stored and updated in real-time, reducing the need for manual processes and improving the efficiency of the academic record-keeping process [75]. This can also help to reduce administrative costs associated with record-keeping. Third, greater transparency and trust such that the transparent and decentralized nature of blockchain technology can help to increase trust in the academic record-keeping process. Students, employers, and other parties can access and verify academic records on the blockchain network, ensuring that records are accurate and trustworthy. Fourth, the improved credentialing by which blockchain technology can also be used to improve the credentialing process makes it easier for students to prove their qualifications and skills to potential employers [76]. By creating a secure and transparent platform for tracking academic achievements, blockchain technology can help to ensure that student's skills and qualifications are accurately represented and recognized. Fifth, the pilot projects and adoption which there are already several pilot projects and initiatives that are exploring the use of blockchain technology in education. For example, the University of Melbourne in Australia is developing a blockchain-based platform for recording and sharing academic credentials. The MIT has also developed a blockchain-based platform for issuing and verifying digital credentials [77].

This paper presents a compelling case for the potential benefits of blockchain technology in education. However, there are several weaknesses in the study that need to be addressed for the technology to be implemented effectively.

One of the most significant challenges is the technical knowledge required to implement and use blockchain technology. Educators and administrators may not have the necessary technical expertise to implement and manage it. This can lead to implementation issues, such as problems with data integrity, interoperability with existing systems, and user adoption. There is a need for training and support to enable educators to understand and implement the technology effectively.

Another major challenge is data privacy and security. As with any digital technology, blockchain can be vulnerable to cyber-attacks and data breaches, which can compromise sensitive information such as student records and credentials. It is essential to ensure that blockchain systems are designed with data privacy and security in mind, and to implement robust security measures to protect sensitive information.

Regulation and governance are also important challenges to consider. As blockchain adoption increases in education, there will be a need for clear and consistent regulation and governance frameworks to ensure the responsible and ethical use of the technology. This includes addressing concerns about data privacy and security and ensuring that blockchain systems are interoperable with existing educational systems.

In addition, there are concerns about the use of blockchain for the surveillance and monitoring of students, and the potential for data misuse or abuse. It is essential to ensure that the use of blockchain technology in education is transparent and accountable, and respects students' privacy and rights.

Despite these challenges, there are several possible ways to project and develop the use of blockchain technology in education. First, there is a need for more research and development to address the technical challenges and to design blockchain systems that are secure, transparent, and user-friendly. Second, there is a need for training and support to enable educators and administrators to implement and use the technology effectively. Third, there is a need for collaboration and partnerships between educational institutions, technology companies, and regulatory bodies to ensure the responsible and ethical use of the technology. Finally, there is a need for clear and consistent regulation and governance frameworks to ensure that blockchain systems are interoperable with existing educational systems and respect students' privacy and rights.

13. Conclusion and future directions

The study has explored the impact of blockchain technology on the education sector, with a particular focus on promoting sustainability in education and securing data and certification. It has identified the challenges and potential benefits of implementing blockchain technology in education and evaluated the suitability of the five major blockchain platforms for enhancing educational sustainability. The study has also analyzed the initiatives of universities that have implemented blockchain technology in education. The findings of the study highlight the importance of carefully considering the hardware, software, devices, and security solutions required for the successful implementation of blockchain technology in education. The study also emphasizes the need to address the challenges of data privacy and security, trust and reliability, verification and validation, data management, adoption, technical knowledge, regulation, cost, education, and training. It is equally essential to recognize the potential benefits and unique attributes that this technology can offer to the education sector. By addressing these challenges and leveraging the benefits of blockchain technology, educational institutions can enhance educational sustainability and secure their data and certification. There is a need for further research to explore the potential of blockchain technology in education in greater depth. Future studies could investigate the potential of blockchain technology to improve educational access and equity, enhance student engagement and collaboration, and promote the use of open educational resources. Additionally, more research is needed to evaluate the potential of blockchain technology to address the challenges of data privacy and security, trust and reliability, verification and validation, data management, adoption, technical knowledge, regulation, cost, education, and training. Finally, future studies could examine the legal and ethical implications of implementing blockchain technology in education and explore the potential of blockchain technology to promote sustainability in other sectors.

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The author declares that he have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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