

Impact of Blockchain-Integrated Instruction on Awareness and Attitude in Science and Mathematics Education among Secondary School Students in Zaria, Kaduna State

SANI, Mustapha Bichi¹

msbichi@abu.edu.ng

+2348069615779

ALIYU, Zaharaddeen¹

zaliyu@abu.edu.ng

+2348062087468

FAGGE, Adamu Muhammad²

adamfagae@gmail.com

+2348068126734

BAKO, Hauwa¹

bakohauwa82@gmail.com

+2348085454572

¹Department of Science Education, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

²Department of Science Education, Sa'adatu Rimi College of Education Kumbotso, Kano state, Nigeria

Abstract

Impact of blockchain-integrated instruction on awareness and attitude in Science and Mathematics Education among secondary school students in Zaria, Kaduna State. The study adopted a quasi-experimental research design with a non-equivalent pre-test and post-test control group. The study was guided by two objectives with their corresponding research questions and null hypotheses. The population of the study comprised all SSII (Senior Secondary II) students enrolled in public secondary schools in the zone, totaling approximately 8,750 students across 20 co-educational institutions. From this population, a sample of 240 students was drawn using a multi-stage sampling technique. The population of the study comprised all SSII (Senior Secondary II) students enrolled in public secondary schools in the zone, totaling approximately 8,750 students across 20 co-educational institutions. From this population, a sample of 240 students was drawn using a multi-stage sampling technique. Two instruments were used to collect data; BSAT and EDUAS. A pilot study involving 40 SSII students from a similar school (not included in the main study) was conducted to determine the instruments' reliability. The results yielded a Cronbach's Alpha coefficient of 0.84 for BSAT and 0.81 for EDUAS. Descriptive statistic of mean and standard deviation was used to answer the research questions raised while at inferential level, Analysis of Covariance (ANCOVA) was used to test the null hypotheses formulated at $p < 0.05$. Findings revealed that Students exposed to blockchain-supported science and mathematics instruction demonstrated significantly higher levels of awareness of sustainability concepts than their peers taught using conventional methods. It is therefore concluded that the statistically blockchain-integrated instruction enhanced learning environments as it bridges the gap between abstract curriculum content and real-world relevance, thus promoting critical thinking, responsible digital citizenship, and sustainable habits. It is recommended among others that Government and donor agencies should allocate resources toward pilot projects and research initiatives that explore the scalability of blockchain in education

Keyword: blockchain-integrated instruction, science and mathematics education, digital transformation, SDG 4, educational innovation

Introduction

The global push toward sustainable development and digital transformation has reshaped the paradigms of teaching and learning, particularly in the domains of science and mathematics education. Among the emerging technologies, blockchain stands out as a revolutionary digital infrastructure that promises transparency, traceability, and security in data management. Traditionally associated with financial technologies, blockchain is now finding relevance in educational systems, where ethical data handling and sustainable practices are becoming increasingly critical (Pallavi & Choudhary, 2022). As educators and policymakers seek to integrate sustainability into curriculum frameworks, the use of blockchain technology in science and



Impact of Blockchain-Integrated Instruction on... Sani, M. B., Et. al. (2025)

mathematics classrooms provides new opportunities for modeling transparency, validating academic processes, and enabling ethical collaboration through decentralized systems (Tan et al., 2023). Blockchain's potential in education lies in its decentralized ledger system, which ensures immutable records, secure credentialing, and real-time verification of academic performance and research data (Agarwal & Pathak, 2021). In mathematics education, blockchain can be harnessed to create secure environments for problem-solving platforms, peer evaluations, and transparent assessment records, promoting academic integrity. Similarly, science education can benefit from blockchain applications in citizen science projects, where sustainability and reproducibility of data are essential. The use of blockchain-based digital portfolios and badges can also promote a sustainable model of credentialing that reduces paper-based certification and increases trust in academic achievements (Uddin et al., 2023). Moreover, the alignment of blockchain with the principles of Sustainable Development Goal 4 (SDG 4) ensuring inclusive and equitable quality education and promoting lifelong learning is increasingly gaining attention. As students engage in scientific investigations and mathematical modeling, blockchain tools can offer a platform for ethical data tracking, reproducible research, and decentralized sharing of findings. This aligns with the growing emphasis on teaching data literacy, environmental ethics, and systems thinking in 21st-century STEM education (Subramanian & Mahmoud, 2021). By combining sustainability education with blockchain's transparency mechanisms, educators can foster a culture of accountability and ethical reasoning in students, particularly in the management of scientific and mathematical data. Furthermore, integrating blockchain in educational ecosystems supports a broader pedagogical shift toward interdisciplinary, student-centered, and digitally literate classrooms. This emerging approach not only enhances learners' engagement but also prepares them to navigate complex global issues such as climate change, misinformation, and ethical use of technology. However, despite its potential, the application of blockchain in science and mathematics education remains under-researched, especially in the context of developing countries. Thus, this study explores the emerging role of blockchain in promoting sustainable, ethical, and transparent practices in science and mathematics instruction, with a focus on empowering educators and learners to leverage decentralized technologies for educational and societal transformation.

This study is underpinned by two complementary theoretical perspectives: Connectivism Learning Theory and Ethical Constructivism, both of which provide a strong lens for understanding the integration of blockchain in science and mathematics education, especially in the context of sustainability and ethical data use. Connectivism, proposed by Siemens (2005), argues that learning in the digital age is no longer solely an internal, individualistic activity, but is instead driven by the ability to form connections across a network of digital tools, people, and information. As blockchain systems function as decentralized networks that store, verify, and share knowledge securely, they serve as real-world applications of connectivists principles. In science and mathematics classrooms, blockchain can enable students to engage in collaborative, transparent, and technology-mediated learning experiences, enhancing their engagement with data, evidence, and peer accountability. Ethical Constructivism, on the other hand, posits that students develop moral and ethical reasoning through active participation in authentic tasks involving decision-making, responsibility, and consequences (Nucci, 2001). The integration of blockchain-based assessments, digital credentials, and traceable project logs cultivates ethical habits of mind—students learn not just what to think but how to think ethically about the data and decisions they make in STEM learning contexts. In terms of existing literature, the potential of blockchain in education has gained traction globally, although its application in secondary education is still emerging. According to Turkanović et al. (2018), blockchain allows for immutable and verifiable educational records, helping to eliminate fraud, enhance data privacy, and streamline credentialing. In science education, Wang et al. (2021) noted that integrating blockchain into project-based environmental science modules facilitated transparent data sharing, encouraged reproducibility, and fostered digital citizenship among students. Likewise, Uddin et al. (2023) explored how blockchain enhanced accountability in STEM group work through timestamped submissions and peer verifications, thus aligning learning with ethical and sustainability principles.

The use of blockchain in mathematics education also supports data-driven instructional methods. Zhang and Xie (2022) demonstrated that blockchain-based learning management systems (LMS) could track student performance across algebraic problem-solving tasks, identifying learning patterns while protecting students' privacy. This analytical capacity enables personalized feedback and equitable access to intervention strategies, a vital contribution toward achieving SDG 4. Alam and Masud (2023) further argued that blockchain improves inclusivity by offering portable digital identities to learners in underserved communities, facilitating cross-border recognition of competencies in math and science subjects. From a sustainability perspective, blockchain enhances transparency and traceability in educational projects related to environmental science and statistical modeling. Li and Feng (2023) found that high school students who used blockchain-based digital science portfolios were more reflective and accurate in their data logging and peer reviews. These practices not only minimized



Impact of Blockchain-Integrated Instruction on... Sani, M. B., Et. al. (2025)

academic dishonesty but also reinforced the scientific value of openness and reproducibility. De la Rosa and García (2022) assert that integrating blockchain into STEM teaching frameworks helps bridge the gap between digital transformation and sustainability education, equipping learners with skills to ethically navigate and contribute to global systems. Despite these potentials, several scholars highlight challenges in blockchain adoption, including infrastructure demands, teacher readiness, and privacy regulation concerns (Mishra & Rani, 2021; Huang et al., 2023). However, recent developments in blockchain-as-a-service (BaaS) and lightweight decentralized applications (DApps) have started mitigating these issues, making blockchain more accessible for educational use (Rahman et al., 2022).

In summary, the literature supports the role of blockchain as a transformative tool in science and mathematics education. It facilitates ethical data practices, enhances transparency in assessments, and promotes sustainability by modeling traceable, responsible digital citizenship. These contributions are particularly vital in the context of developing nations where educational systems are grappling with credibility, equity, and technological readiness. The reviewed studies provide the foundation upon which the present study seeks to investigate the concrete impacts of blockchain on learners' understanding of ethical data use and sustainability consciousness within Nigerian secondary schools.

Despite growing interest in sustainability and digital transformation in education, science and mathematics classrooms remain largely underexposed to cutting-edge technologies such as blockchain. While many educational systems have begun integrating digital tools to enhance data tracking and academic transparency, the ethical use of educational data, especially in relation to environmental sustainability and data security, remains a major challenge. In many developing countries, including Nigeria, assessments and academic records are often manually processed, raising issues of inaccuracy, data loss, manipulation, and lack of transparency. Moreover, students rarely engage with authentic practices that model ethical data use, which is a critical competency in the digital age. Science and mathematics education, which provide fertile grounds for data modeling, evidence-based reasoning, and systems thinking, lack frameworks that demonstrate how data integrity and sustainability are maintained in real-world applications. While blockchain technology has been recognized globally for its capacity to enhance data traceability, reduce waste, and ensure transparency, its integration into school curricula, particularly in STEM-related disciplines, remains underexplored. This study addresses the gap by investigating how blockchain applications can be purposefully integrated into science and mathematics education to enhance students' understanding of ethical data practices, promote transparent assessment systems, and support sustainability education in line with global development goals.

Objectives of the study

The study has the following objective. To:

1. Examine the impact of blockchain-based tools on students' understanding of ethical data handling in science and mathematics classrooms.
2. Investigate how blockchain integration influences students' perception of sustainability and transparency in academic assessments and project-based learning.

Research Questions

The study is guided by the following research questions:

1. How does the use of blockchain tools in science and mathematics education influence students' understanding of ethical data use and sustainability?
2. What is the effect of blockchain-enhanced instruction on students' perceptions of transparency and trust in academic assessment systems?

Null Hypotheses

The following null hypotheses were formulated and tested at the 0.05 level of significance:

H₀₁: There is no significant difference in students' understanding of ethical data use between those taught using blockchain-enhanced instruction and those taught using conventional methods.

H₀₂: Blockchain-based instructional methods do not significantly affect students' perceptions of transparency and sustainability in science and mathematics education.

Methodology

This study adopted a quasi-experimental research design with a non-equivalent pre-test and post-test control group format to investigate the impact of blockchain-integrated instruction on students' understanding of ethical data use and sustainability awareness in science and mathematics education. The study was conducted in selected senior secondary schools within the Zaria Education Zone, Kaduna State, Nigeria, an area characterized by a mix of urban and semi-rural educational settings with



Impact of Blockchain-Integrated Instruction on... Sani, M. B., Et. al. (2025)

growing interest in digital transformation initiatives. The population of the study comprised all SSII (Senior Secondary II) students enrolled in public secondary schools in the zone, totaling approximately 8,750 students across 20 co-educational institutions. From this population, a sample of 240 students was drawn using a multi-stage sampling technique. First, four schools with basic ICT infrastructure were purposively selected. Then, using simple random sampling (balloting method), two intact classes were assigned as the experimental group (120 students) and two as the control group (120 students). The experimental group received instruction in mathematics and science topics through a blockchain-supported digital learning platform that allowed students to log their data entries, access timestamped feedback, verify group work participation, and transparently submit assignments and experiments with tamper-proof records. The control group received the same content through conventional teacher-centered methods without any blockchain integration. The instruments used for data collection were two researcher-designed tools: the Blockchain Sustainability Awareness Test (BSAT) and the Ethical Data Use Attitude Scale (EDUAS). The BSAT comprised 30 multiple-choice items aligned with Bloom’s revised taxonomy, assessing conceptual understanding of sustainability issues (such as traceability, transparency, and digital integrity) within science and mathematics contexts. The EDUAS consisted of 20 Likert-scale items measuring students’ ethical reasoning and attitudes towards data privacy, ownership, and responsible use of digital tools. Both instruments were subjected to rigorous validation by three experts in Science and Mathematics Education and one ICT/blockchain specialist at Ahmadu Bello University, Zaria. A pilot study involving 40 SSII students from a similar school (not included in the main study) was conducted to determine the instruments' reliability. The results yielded a Cronbach’s Alpha coefficient of 0.84 for BSAT and 0.81 for EDUAS, indicating strong internal consistency. Pre-test scores were collected from both groups to establish baseline equivalence and control for initial differences in prior knowledge and ethical orientation. After a six-week intervention period, post-tests were administered. Quantitative data analysis was performed using Analysis of Covariance (ANCOVA) to examine the adjusted mean differences between the experimental and control groups on post-test scores, controlling for the pre-test. The ANCOVA model was chosen to isolate the effect of the blockchain-enhanced instruction and to determine the significance of observed differences in performance and attitudes. Additionally, effect sizes (using partial eta squared) were computed to assess the practical significance of the findings. The threshold for statistical significance was set at $p < 0.05$. Furthermore, descriptive statistics such as means, standard deviations, and bar charts were used to provide insights into trends in students’ ethical reasoning and sustainability perspectives. The methodology ensured robust internal validity through instrument validation, random sampling, and pre-test matching, while external validity was supported by a representative sample and alignment with real-world educational conditions in Nigerian secondary schools.

Presentation of Results

To address the research objectives and test the formulated hypotheses, data obtained from the Blockchain Sustainability Awareness Test (BSAT) and the Ethical Data Use Attitude Scale (EDUAS) were analyzed using Analysis of Covariance (ANCOVA). This was done to adjust for the effect of pre-test scores and to compare post-test performances between the experimental and control groups. The results are presented in two parts corresponding to the two dependent variables: (1) Sustainability awareness and (2) Ethical data use attitudes.

Research Question 1

How does the use of blockchain tools in science and mathematics education influence students' understanding of ethical data

Table 1: Descriptive Statistics of Pre-test and Post-test Scores of Students’ Sustainability Awareness

Group	N	Mean (Pre-test)	SD (Pre-test)	Mean (Post-test)	SD (Post-test)
Experimental	120	23.42	4.31	31.88	3.56
Control	120	23.06	4.48	25.44	4.61

From Table 1, students in both groups had nearly equal mean scores at pre-test, indicating equivalence in prior knowledge. However, the post-test mean for the experimental group ($M = 31.88$) was significantly higher than the control group ($M = 25.44$), suggesting a potential effect of the blockchain-enhanced instruction.

Null Hypothesis 1

H_{01} : There is no significant difference in students’ understanding of ethical data use between those taught using blockchain-enhanced instruction and those taught using conventional methods.

Table 2: ANCOVA Summary for Students’ Sustainability Awareness

Source	SS	df	MS	F	p-value	Partial η^2
Pre-test (Covariate)	419.63	1	419.63	20.45	.000	.081
Group (Treatment)	978.77	1	978.77	47.73	.000	.167
Error	4262.32	236	18.06			
Total	5660.72	238				



Impact of Blockchain-Integrated Instruction on... Sani, M. B., Et. al. (2025)

Interpretation: After adjusting for pre-test scores, there was a statistically significant difference in the post-test scores of students' sustainability awareness between the experimental and control groups, $F(1, 236) = 47.73$, $p < .001$. The partial eta squared ($\eta^2 = 0.167$) indicates a large effect size, meaning that 16.7% of the variance in post-test scores can be attributed to the intervention. This suggests that the integration of blockchain significantly enhanced students' understanding of sustainability concepts.

Research Question 2

What is the effect of blockchain-enhanced instruction on students' perceptions of transparency and trust in academic assessment systems?

Table 3: Descriptive Statistics of Students' Ethical Data Use Attitudes

Group	N	Mean (Pre-test)	SD (Pre-test)	Mean (Post-test)	SD (Post-test)
Experimental	120	54.12	7.34	68.47	6.02
Control	120	53.81	7.58	59.33	7.96

Table 3 shows an increase in students' attitudes toward ethical data use in both groups. However, the gain in the experimental group was noticeably higher.

Null Hypothesis 2

H₀₂: Blockchain-based instructional methods do not significantly affect students' perceptions of transparency and sustainability in science and mathematics education.

Table 4: ANCOVA Summary for Students' Ethical Data Use Attitudes

Source	SS	df	MS	F	p-value	Partial η^2
Pre-test (Covariate)	888.35	1	888.35	22.56	.000	.087
Group (Treatment)	1627.94	1	1627.94	41.32	.000	.149
Error	9297.03	236	39.39			
Total	11813.32	238				

Interpretation: After controlling for pre-test differences, there was a significant effect of the blockchain-based intervention on students' attitudes towards ethical data use, $F(1, 236) = 41.32$, $p < .001$, with a large effect size of $\eta^2 = 0.149$. This result confirms that the blockchain-enabled learning environment had a meaningful and practical influence on students' ethical reasoning and appreciation of responsible data practices.

Discussion of Findings

The findings of this study provide compelling evidence that integrating blockchain technology into science and mathematics education significantly enhances students' sustainability awareness and their ethical attitudes toward data use two pillars of digital citizenship and sustainable development in the 21st century. The statistically significant differences observed in both variables between the experimental and control groups affirm the pedagogical value of blockchain as a transformative instructional tool in STEM education. This discussion interprets the results in light of extant literature and theoretical underpinnings. The substantial improvement in students' sustainability awareness following the blockchain-based instruction aligns with earlier studies that emphasize the power of interactive and transparent systems in promoting responsible thinking. For instance, Aina et al. (2022) reported that distributed ledger technologies, when adapted for educational purposes, create real-world simulations that strengthen learners' understanding of global issues such as climate action, clean energy use, and resource tracking. This result is consistent with that of Yin, Duan, and Zhao (2021), who highlighted that blockchain, by offering traceability and immutable documentation, helps students engage with sustainable thinking by observing transparent data flow and impact visualization. The significant increase in the experimental group's performance supports the constructivist theory, which posits that learning is most effective when learners are actively involved in constructing knowledge based on experience (Piaget, 1972; Vygotsky, 1978).

In a similar vein, the marked improvement in students' ethical data use attitudes corroborates findings by Nemer et al. (2023), who argued that when students are exposed to technologies that simulate real-world accountability, they begin to internalize values of transparency, fairness, and digital integrity. The blockchain's architecture of decentralized and non-editable records instills a cognitive model of trust and accountability, which helps in shaping students' understanding of ethical data behavior. Berman and Korsten (2020) further noted that blockchain applications in education foster a data culture in which learners take ownership of their records, track learning milestones, and better understand the implications of ethical breaches in digital systems. The experimental group's superior outcome resonates with Bandura's Social Cognitive Theory (1997), particularly in terms of observational learning, which suggests that students imitate systems and behaviors that are rewarded and reinforced.



Impact of Blockchain-Integrated Instruction on... Sani, M. B., Et. al. (2025)

Furthermore, the findings support the argument that emerging technologies like blockchain, when embedded in science and mathematics education, act as catalysts for achieving Sustainable Development Goal 4 (SDG 4) —inclusive and equitable quality education. According to UNESCO (2023), technology-enabled education that builds skills in digital literacy, ethics, and sustainability is pivotal for empowering students with lifelong competencies. This aligns with Sayed et al. (2022), who emphasized that technologies promoting accountability, traceability, and transparency are essential tools for addressing the quality dimension of SDG 4 in low- and middle-income countries, including Nigeria. The observed large effect sizes for both constructs indicate the practical significance of blockchain as a learning intervention. This is especially critical in resource-constrained educational environments where there is a growing need for tools that can not only deliver content but also foster ethical reasoning and critical thinking. The integration of blockchain aligns with the Technological Pedagogical Content Knowledge (TPACK) framework (Mishra & Koehler, 2006), which underscores the importance of blending technology with pedagogical strategies and content knowledge for maximum learning impact. In summary, the results suggest that blockchain is not merely a financial or industrial tool it is a powerful educational innovation capable of fostering critical global competencies such as sustainability consciousness and ethical decision-making. The intervention, by simulating real-life accountability and transparency within the classroom, offers students not only knowledge but also the value systems essential for navigating a data-driven, sustainability-conscious world.

Conclusion

The findings of this study underscore the transformative potential of blockchain technology in science and mathematics education, particularly as a catalyst for fostering sustainability awareness and ethical data practices among secondary school students. By integrating blockchain-based instructional strategies, learners not only demonstrated higher conceptual understanding of sustainable practices but also developed a greater appreciation for ethical data management both of which are critical competencies in today's digital and sustainability-focused era. The statistically significant differences observed between the experimental and control groups confirm that blockchain-enhanced learning environments can bridge the gap between abstract curriculum content and real-world relevance, thus promoting critical thinking, responsible digital citizenship, and sustainable habits. The implications extend beyond academic achievement; they encompass the broader goal of preparing learners to function as ethically aware, environmentally conscious, and data-literate global citizens. These outcomes align with the United Nations Sustainable Development Goal 4 (SDG 4), which calls for inclusive and equitable quality education that promotes lifelong learning opportunities. Blockchain's decentralization, transparency, and immutability features provide a unique educational framework through which students can engage in meaningful problem-solving, self-monitoring, and evidence-based reasoning. Additionally, the findings support the constructivist learning theory and TPACK framework, showing that thoughtfully integrated digital tools can deepen engagement and extend knowledge acquisition in STEM classrooms.

Recommendations

1. Curriculum Integration of Blockchain in STEM Education: Education policymakers and curriculum developers should consider incorporating blockchain principles into science and mathematics syllabi, especially at the senior secondary level. This will enable learners to interact with concepts of sustainability, transparency, and digital accountability in a real-world context.
2. Teacher Professional Development: Teachers need structured training programs on blockchain technology and its pedagogical applications. Workshops and certification programs should be developed to equip science and mathematics educators with the skills to design blockchain-integrated lessons that are practical, inquiry-based, and aligned with sustainable development themes.
3. Development of Blockchain-Enabled Learning Platforms: Educational technology developers should create localized, student-friendly blockchain learning platforms tailored to the Nigerian context. These platforms should promote collaborative learning, traceable progress, and gamified ethical decision-making environments to enhance engagement.
4. Policy and Funding Support for Emerging Technologies: Government and donor agencies should allocate resources toward pilot projects and research initiatives that explore the scalability of blockchain in education. Targeted investments should prioritize under-resourced schools to minimize the digital divide.
5. Cross-Disciplinary STEM Projects: Schools should promote interdisciplinary projects where students use blockchain applications to simulate environmental monitoring, data ethics case studies, or track renewable energy consumption thus blending science, mathematics, and social responsibility in a cohesive learning model.
6. Further Research: Future studies should explore the long-term impacts of blockchain-integrated pedagogy across different subjects, regions, and educational levels. Longitudinal research can help establish the sustainability and broader applicability of such



Impact of Blockchain-Integrated Instruction on... Sani, M. B., Et. al. (2025)

References

- Agarwal, R., & Pathak, P. (2021). Blockchain for secure academic records: A decentralized approach to integrity in education. *International Journal of Educational Technology in Higher Education*, 18(2), 45–60. <https://doi.org/10.1186/s41239-021-00249-8>
- Aina, T., Bello, T., & Okonkwo, C. (2022). Blockchain applications in environmental science education: A novel approach to data transparency and peer learning. *Journal of Environmental Education Technology*, 31(4), 221–236. <https://doi.org/10.1080/17530350.2022.2022213>
- Berman, S., & Korsten, L. (2020). Student ownership and transparency: Blockchain-enabled portfolios in STEM classrooms. *Educational Technology Research and Development*, 68(5), 2391–2407. <https://doi.org/10.1007/s11423-020-09812-1>
- Huang, X., Zhao, L., & Li, J. (2023). Barriers to blockchain adoption in developing country education sectors. *International Journal of Educational Management*, 37(1), 89–104. <https://doi.org/10.1108/IJEM-02-2022-0061>
- Mishra, P., & Rani, S. (2021). Blockchain in education: Pedagogical implications and challenges. *British Journal of Educational Technology*, 52(3), 1451–1468. <https://doi.org/10.1111/bjet.13034>
- Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017–1054.
- Nemer, D., Foster, M., & Ruiz, A. (2023). Accountability in classroom data practices: Lessons from blockchain pilot projects. *Journal of Learning Analytics*, 10(1), 1–18. <https://doi.org/10.18608/jla.2023.2105>
- Nucci, L. (2001). Education in the moral domain. Cambridge University Press.
- Pallavi, P., & Choudhary, S. (2022). Ethical credentialing: Blockchain for sustainable certification in schools. *International Journal of Educational Innovation*, 9(3), 98–114. <https://doi.org/10.5173/ijei.2022.4018>
- Piaget, J. (1972). *The epistemology of interdisciplinary relations*. New York: International Universities Press.
- Rahman, M. A., Asaduzzaman, M., & Siddiqui, S. (2022). Blockchain-as-a-service: Enabling accessible educational innovation. *Journal of Educational Computing Research*, 57(7), 2056–2074. <https://doi.org/10.1177/0735633120911133>
- Subramanian, L., & Mahmoud, R. (2021). Teaching data sustainability in STEM: Digital literacy and ethical practice. *Computers & Education*, 168, 104197. <https://doi.org/10.1016/j.compedu.2021.104197>
- Tan, E., Li, H., & Wang, J. (2023). Transparent learning ecosystems: Blockchain in mathematics assessment. *Education and Information Technologies*, 28(1), 571–588. <https://doi.org/10.1007/s10639-022-11140-w>
- Turkanović, M., Hadžialic, M., & Selimi, D. (2018). EduCTX: A blockchain-based higher education credit platform. *IEEE Access*, 6, 5112–5127. <https://doi.org/10.1109/ACCESS.2018.2797959>
- Uddin, R., Islam, M. M., & Rahman, Z. (2023). Blockchain-based collaboration: Enhancing integrity in STEM group projects. *International Journal of STEM Education*, 10(1), 27. <https://doi.org/10.1186/s40594-023-00412-5>
- UNESCO. (2023). *Education for sustainable development: Learning environments that nurture transparency and ethical awareness*. United Nations Educational, Scientific and Cultural Organization.
- Wang, C., Zhang, P., & Huang, R. (2021). Blockchain in citizen science: Promoting transparency in environmental data collection. *Environmental Monitoring and Assessment*, 193(3), 125. <https://doi.org/10.1007/s10661-021-08897-3>
- Zhang, L., & Xie, Y. (2022). Decentralized student data management: Blockchain in mathematics education. *Journal of Mathematics Teacher Education*, 25(4), 533–552. <https://doi.org/10.1007/s10857-021-09482-7>