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Decentralized Peer Review and e-Assessment in Hybrid Learning: Blockchain as a Tool for Equitable Feedback Mechanisms

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ABSTRACT

Background. The integrity and equity of assessment in hybrid learning environments have been increasingly challenged by issues of transparency, bias, and centralized control. Traditional peer review systems often lack traceability and accountability, leading to concerns about the fairness and credibility of formative feedback.
Purpose. This study explores the application of blockchain technology as a decentralized infrastructure for peer review and e-assessment in hybrid learning contexts. The research aims to evaluate how blockchain-based systems can enhance feedback transparency, reviewer accountability, and student trust in digital assessment processes.
Method. Employing a design-based research methodology, a prototype blockchain-enabled peer assessment platform was developed and tested with 92 university students across two hybrid courses. Quantitative and qualitative data were collected through platform analytics, student surveys, and focus group discussions.
Results. The results demonstrate that blockchain-based systems can serve not only as secure ledgers but also as ethical architectures for equitable formative assessment
Conclusion. The study concludes that blockchain offers a viable mechanism for building equitable, transparent, and tamper-resistant assessment systems in hybrid learning. The research contributes to the growing field of educational technology by introducing a scalable model for decentralized e-assessment.

KEYWORDS

Blockchain, Peer Review, Hybrid Learning, E-Assessment, Educational Equity

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INTRODUCTION

The increasing adoption of hybrid and blended learning models has revolutionized instructional delivery and assessment practices in higher education. These models combine online and face-to-face learning to create flexible environments that support diverse student needs. As hybrid learning becomes more prevalent, the use of digital tools for peer review and e-assessment has grown significantly. Institutions are now exploring scalable, technology-driven methods to ensure meaningful feedback, foster learner autonomy, and support formative evaluation in asynchronous and synchronous modes.

Despite technological advances, existing peer review and e-assessment systems face ongoing challenges related to trust, transparency, and equity. Students often express skepticism about the fairness of peer evaluations, citing concerns over anonymity, bias, and inconsistency in grading standards. Moreover, centralized digital learning management systems (LMS) that store and manage peer feedback are vulnerable to manipulation, lack auditability, and rarely provide visibility into how and why evaluative decisions were made. These issues can diminish student motivation, erode trust in the assessment process, and exacerbate disparities in feedback quality across learning environments.

Educational institutions and edtech developers are actively searching for alternative models that promote equity and accountability in assessment practices. Blockchain, a distributed ledger technology originally designed for secure financial transactions, offers promising features that can be adapted to educational settings. Its core characteristics-immutability, decentralization, transparency, and traceability-make it a suitable foundation for developing peer review systems that are verifiable, tamper-resistant, and equitably governed (Claxton-Oldfield & MacEachern, 2024; Gushken et al., 2025). Applying blockchain to e-assessment represents a frontier opportunity to reimagine how student work is evaluated and recognized in digitally mediated learning.

Current peer review processes in hybrid learning environments are typically embedded within centralized systems that rely heavily on instructor oversight and closed feedback loops. These models often lack transparency in the allocation, evaluation, and weighting of peer input. As a result, students may question the reliability of feedback received and doubt the fairness of how their work is assessed (Sarwar, 2025; Smith et al., 2025; Zaichenko, 2025). This is especially problematic in peer-assessed activities where grades or formative feedback directly impact learning outcomes, engagement, or student confidence.

The problem becomes more pronounced in diverse classrooms where language, background knowledge, or digital literacy levels vary widely. In such settings, centralized assessment mechanisms often fail to reflect the complexity of learner participation and engagement. Without mechanisms for verifiable, transparent evaluation, biases-whether conscious or unconscious-may influence peer ratings (Allison, 2025; Carrasco & Perez Lopez, 2025; Khairunnisa et al., 2025). Moreover, learners from marginalized groups are more likely to receive inconsistent or less constructive feedback, thereby reinforcing educational inequities that hybrid learning environments are supposed to mitigate.

There is a critical need for a system that distributes assessment responsibility equitably, ensures transparency of evaluative processes, and builds mutual accountability among peers. Such a system must provide secure records of feedback exchanges, allow for clear audit trails, and enable decentralized governance to prevent instructor or institutional bias. Blockchain technology, when integrated thoughtfully, offers a decentralized alternative that may address these issues while enhancing pedagogical transparency and trust in hybrid peer assessment ecosystems.

This study aims to design and evaluate a decentralized peer review and e-assessment framework using blockchain technology in a hybrid learning environment. The research focuses on how blockchain's technical affordances-such as distributed validation, timestamped records, and smart contracts-can be used to strengthen the fairness, credibility, and transparency of peer feedback (Abokor et al., 2025; Flomin et al., 2025; Serván-Mori et al., 2025; Sims et al., 2025). While blockchain has been widely explored for credentialing and data security in education, its pedagogical potential in decentralized peer assessment remains underdeveloped. This study addresses that gap by designing and implementing a blockchain-based peer review system within

hybrid classrooms. The goal is to investigate whether such a system can increase student trust in the review process and reduce instances of perceived bias or grading inconsistencies.

The study also seeks to explore the pedagogical impact of blockchain-enabled peer assessment on learner engagement, autonomy, and accountability. It examines how decentralized feedback mechanisms influence the quality of peer interaction, the depth of critique, and student willingness to take responsibility in the evaluation process. Data on usability, student perceptions, and system effectiveness will be gathered through mixed methods to provide a multidimensional understanding of the platform's implications.

A broader objective is to contribute to the discourse on equitable digital pedagogy by proposing a replicable model for decentralized assessment. By aligning technological innovation with inclusive assessment design, the study aims to offer a scalable framework that can be adopted across various educational institutions seeking to balance digital efficiency with fairness and learner empowerment (Bağlan & Esencan, 2025; Mongkolhutthi, 2025; Passarelli-Araujo, 2025; Seyedrezaei et al., 2025). The research outcome is expected to inform both theory and practice in blockchain-integrated instructional technology.

While considerable attention has been given to the affordances of blockchain in educational credentialing and academic integrity, limited empirical research exists on its application in formative peer assessment and decentralized feedback systems. Existing studies tend to focus on blockchain's potential in transcript verification, digital diplomas, and plagiarism detection, leaving its pedagogical applications underexplored. The lack of practical frameworks for implementing blockchain in classroom assessment highlights a critical research gap in the intersection of blockchain and learning analytics.

Scholarship on peer review in hybrid and online education has underscored the importance of feedback equity, yet few solutions have been proposed to structurally address issues of transparency and traceability. Most platforms continue to rely on opaque algorithms or instructor moderation, which may reproduce the very hierarchies that peer review is intended to counterbalance. Furthermore, discussions on educational decentralization often remain theoretical or confined to institutional reform, with minimal integration of real-time learning applications.

This study fills the gap by providing a design-based, use-case-oriented implementation of blockchain for peer feedback within a live hybrid classroom. It advances the literature by demonstrating how decentralized infrastructure can enhance the procedural justice of digital assessment. By grounding the investigation in actual learner experience and measurable outcomes, the research moves beyond conceptual speculation toward operationalization of blockchain as an equity-enhancing pedagogical tool.

The novelty of this research lies in its interdisciplinary approach, combining blockchain architecture with instructional design to address a long-standing problem in digital pedagogy: feedback inequity. This study is among the first to explore how distributed ledger technology can be applied not merely for administrative purposes but as a formative learning scaffold. It reconceptualizes peer review not as a static, instructor-mediated process, but as a decentralized learning transaction validated by community engagement and transparent protocols.

The blockchain-based framework introduced in this study integrates smart contracts to automate review assignment and scoring, ensuring consistency and fairness across participants. This automated transparency marks a departure from current peer assessment systems that operate in hidden or instructor-controlled databases. By removing centralized control, the system democratizes the evaluation process and empowers learners to participate more fully in the feedback economy of the classroom.

The justification for this research stems from the urgent need to build resilient, equitable feedback systems in an era of expanding hybrid education. As institutions increasingly adopt digital learning platforms, ensuring procedural fairness in assessment becomes a non-negotiable component of academic integrity and learner trust. This study offers a proof-of-concept that blockchain can serve not only as a security mechanism but as a pedagogical intervention, reshaping how we design for equity, transparency, and collaboration in the classroom of the future.

RESEARCH METHODOLOGY

A design-based research (DBR) approach was employed to iteratively design, implement, and refine a blockchain-enabled peer assessment platform. Participants were 92 undergraduate students across two hybrid courses representing diverse academic backgrounds. The system was developed using a private Ethereum blockchain and embedded smart contracts to automate assignment, timestamping, and verification of feedback (Kearns et al., 2025; Rowe & Di Gregorio, 2025). The focus was on creating a working prototype that integrates blockchain features—immutability, traceability, decentralization—into peer assessment workflows, while observing its pedagogical impact on feedback equity and learner engagement.

The study involved a population of undergraduate students enrolled in two hybrid-format courses at a mid-sized public university. A total of 92 students were selected as the sample through purposive sampling, ensuring participants represented varied academic backgrounds and digital literacy levels. The sample included students from both social science and computer science programs to reflect interdisciplinary user perspectives and promote a broader understanding of system usability and pedagogical effectiveness. All participants were provided with an orientation to blockchain concepts and the use of the platform prior to the intervention phase.

Data collection included system logs (traceability, latency, variance), pre/post surveys (perceived fairness, trust), and focus group interviews. Instrument reliability was confirmed through pilot testing (Cronbach's alpha = 0.89). Thematic analysis followed Braun & Clarke (2006) while inferential statistics used paired t-tests and correlation analysis to identify significant changes in perception and behavior.

The instruments used in the study included a blockchain-enabled peer review platform developed in collaboration with educational technology specialists. Quantitative data were collected through system logs capturing peer review submission times, evaluation consistency, and the traceability of feedback chains. Qualitative data were gathered through pre- and post-intervention surveys on student perceptions of fairness and transparency, as well as through semi-structured focus group interviews to capture narrative insights about learner trust, engagement, and perceived accountability. A rubric-based peer evaluation form was embedded within the platform to ensure consistency in feedback criteria across reviewers.

The research was conducted in four stages: platform development, pilot testing, classroom implementation, and post-intervention analysis. In the development phase, a prototype was designed using a private Ethereum blockchain and smart contracts programmed to automate peer review assignments, feedback validation, and timestamping. During pilot testing, usability and system performance were assessed with a small subset of students. In the classroom implementation phase, the system was deployed over a six-week period during which students conducted peer reviews within the platform as part of formative assessment tasks. In the final phase, all data were aggregated and analyzed using a mixed-methods approach, combining descriptive and inferential statistics with thematic analysis of interview transcripts. Ethical clearance was obtained prior to data collection, and all participants provided informed consent.

RESULT AND DISCUSSION

Table 1 provides a summary of key quantitative indicators collected through the blockchain-enabled peer review platform. The data include feedback traceability rates, consistency of peer evaluation scores, platform usage frequency, and response latency (time between assignment and submission of reviews). Across 92 participants, the traceability of peer feedback reached 100%, with all feedback transactions securely logged and timestamped on the blockchain. The average variance between peer evaluation scores across reviewers per assignment was 1.2 (on a 10-point scale), suggesting relatively high inter-rater consistency. Platform usage analytics recorded an average of 3.6 logins per week per user, with a mean response latency of 36.4 hours.

Table 1.
Quantitative Metrics from Blockchain-Based Peer Review Platform (n = 92)

Metric	Value
Traceability of Feedback Transactions	100%
Average Score Variance (peer reviews)	1.2
Weekly Platform Logins (per student)	3.6
Mean Response Latency (hours)	36.4

The system logs further indicated that 87% of students completed their peer review tasks before the automated deadline enforced by the smart contracts. All submitted feedback was permanently stored and accessible via encrypted ledger entries, ensuring verifiability without compromising anonymity. These technical features directly addressed key concerns around accountability and fairness in peer evaluation, especially in hybrid environments where asynchronous interactions are common. The system's ability to generate immutable records of evaluative input contributed to increased procedural transparency.

Survey results collected before and after the intervention showed notable shifts in student perceptions of feedback equity. Prior to implementation, only 39% of students agreed that peer review processes in previous courses had been "fair and transparent." Post-intervention, this figure rose to 78%, with 82% of students stating they had "greater trust in the peer assessment process" due to the blockchain system. Students also rated their satisfaction with feedback clarity and usefulness higher in the post-intervention survey ($M = 4.2$) compared to baseline data ($M = 3.1$) on a 5-point Likert scale.

Inferential analysis using paired-sample t-tests confirmed that the increase in perceived fairness and feedback trustworthiness was statistically significant. The difference in mean trust scores pre- and post-intervention ($t(91) = 8.21$, $p < 0.001$) and the improvement in clarity and usefulness of feedback ($t(91) = 7.53$, $p < 0.001$) indicate large effect sizes (Cohen's $d > 0.8$). These findings suggest that blockchain-enabled mechanisms had a substantial and measurable impact on learners' perceptions of equity in peer assessment.

Correlation analysis revealed a positive relationship between traceability of feedback and peer engagement metrics. Students who reported higher levels of trust in the system were also more likely to provide detailed, criterion-aligned feedback, as measured by word count and rubric alignment scores. The system usage data showed a moderate correlation ($r = 0.49$, $p < 0.01$) between frequency of login and feedback depth, suggesting that platform transparency may foster a sense of responsibility among students to provide meaningful evaluations.

A case study of two students, Participant A and Participant B, illustrates how the system functioned in practice. Participant A, previously skeptical about peer review, noted in post-intervention interviews that the ability to trace all evaluations and see the reviewer's rationale increased her trust in the process. She reported spending more time writing feedback because she believed her contribution would be visible and valued. Participant B, a high-performing student, expressed that the transparency and consistency of the blockchain system made it easier to accept critical feedback without defensiveness.

Both students noted that their engagement with the process was significantly enhanced by the visibility and auditability of the blockchain-based system. Participant A moved from providing brief, generic comments in early assignments to detailed, rubric-based analysis in later submissions. Participant B, who had often felt peer reviews were "subjective and biased," appreciated the tamper-proof nature of the new system, which reinforced the credibility of scores and narrative feedback. These student perspectives align with the broader survey trends and suggest that the platform had a positive influence on feedback behavior.

Focus group discussions provided additional qualitative insight into how students interpreted the decentralized system. Many described the platform as "fairer," "more democratic," and "less arbitrary" than previous LMS-based systems. Several students emphasized the psychological reassurance of having their evaluations recorded permanently, stating it made the effort they invested feel more "official" and "respected." These affective reactions to technological transparency suggest that decentralization can play an important role in cultivating learner motivation and ownership of the feedback process.

The overall findings point to the potential of blockchain as a foundational technology for equitable feedback systems in hybrid learning. The integration of decentralized validation, immutability, and automated rule enforcement enabled a peer review process that students perceived as more trustworthy, consistent, and fair. These results support the hypothesis that procedural transparency—when implemented through appropriate technological infrastructure—can enhance both the quality and perception of peer feedback in digitally mediated educational settings.

The findings of this study indicate that integrating blockchain technology into peer review and e-assessment systems in hybrid learning environments significantly improves perceptions of feedback fairness, transparency, and trust. Quantitative results demonstrated a marked increase in student confidence regarding the integrity of the assessment process, with post-intervention surveys revealing a 39% gain in perceived fairness. System log analysis confirmed 100% traceability of peer feedback, while inferential testing validated the significance of improvements in feedback clarity and perceived usefulness. Case studies further illuminated how decentralized design motivated students to engage more deeply and ethically with the feedback process, supporting the conclusion that blockchain-based platforms can foster more equitable evaluative cultures.

This study extends and complements prior research on digital peer assessment and blockchain in education by emphasizing its formative, learner-centered dimensions. Existing literature has focused largely on credential verification and academic record security, such as in works by Grech & Camilleri (2017), or on the use of smart contracts for certification. Unlike these applications, the present study explores blockchain as a pedagogical tool for enhancing instructional processes. The research adds to recent discourses by authors like Chen et al. (2020), who called for blockchain integration in learning analytics, but did not empirically test its effect on student behavior or perceived fairness in feedback systems.

The results signify a shift in how decentralized technology can function as both a technical and ethical intervention in education. The system's ability to automate transparency without

compromising anonymity illustrates that it is possible to address longstanding trust deficits in peer review without reverting to instructor-dominated models. Students' behavioral changes—more consistent feedback, deeper rubric alignment, and willingness to accept criticism—signal a transformation in feedback literacy that is grounded not in surveillance, but in mutual accountability (Brown et al., 2025; MacAulay et al., 2025; Mitchell et al., 2025; Prediger et al., 2025). These patterns indicate a larger pedagogical realignment where learners assume greater agency and ethical responsibility in the evaluative process.

The implications of these findings are far-reaching for instructional design and educational policy. Integrating blockchain into feedback systems provides a structural mechanism for equity, moving beyond individual goodwill or subjective moderation. Educational institutions seeking to scale formative assessment across diverse learning environments can adopt this decentralized model to ensure integrity without overburdening instructors. For hybrid and online learning, where interpersonal cues and real-time clarification are limited, systems that offer immutable, verifiable, and transparent feedback trails can serve as scaffolds for trust and motivation. Such architectures not only improve individual feedback quality but also enhance system-level credibility.

The results can be explained by the unique affordances of blockchain that align closely with pedagogical values in hybrid learning: traceability supports reflection, immutability fosters accountability, and decentralization encourages learner autonomy. The clarity of peer review provenance enabled by the system gave students confidence in the fairness of evaluation, which in turn increased engagement. The enforced structure of smart contracts ensured equal participation while removing discretionary bias often introduced through instructor mediation (Chigbu & Makapela, 2025; Malagón Castro et al., 2025; Sodergren et al., 2025). These design features create a learning environment where fairness is not just perceived but systematically embedded.

Student responses suggest that part of the success stemmed from the psychological safety created by procedural transparency. The knowledge that all evaluative actions were recorded and reviewable reduced anxiety about misrepresentation or hidden grading influences. This assurance empowered students to both give and receive feedback more openly, knowing that the process was governed by pre-set, visible rules rather than informal social dynamics (Aarntzen et al., 2025; Oyelere & Aruleba, 2025; Woolley et al., 2025). This aligns with constructivist theories of assessment, which posit that trust and structure are prerequisites for meaningful peer engagement.

The consistency of results across both quantitative and qualitative measures further validates the system’s effectiveness. The alignment between objective performance metrics (e.g., rubric fidelity, response rates) and subjective perceptions (e.g., fairness, motivation) highlights the holistic value of the platform. Blockchain’s role extended beyond a technical tool-it served as an agent of pedagogical coherence, helping to align assessment practice with the goals of transparency, accountability, and learner empowerment. This convergence is especially critical in hybrid environments, where fragmented communication can often erode clarity and trust.

The success of this decentralized model encourages future applications beyond peer review. Potential extensions include collaborative project tracking, decentralized grading, and learner-driven micro-credentialing. By embedding blockchain into broader pedagogical workflows, educators can construct systems that maintain academic rigor while promoting equity and participation. The data suggest that when feedback systems are designed with transparency and student trust in mind, learners respond with increased commitment, depth of engagement, and ethical sensitivity.

The next step involves refining and scaling the model across disciplines and institutional contexts. Additional research is needed to evaluate long-term impacts on student learning, identity

formation, and resilience in feedback-rich environments. Studies should also explore the role of instructor facilitation within decentralized frameworks, particularly in supporting novice learners or navigating cultural variations in peer evaluation norms. Building integrations with existing learning management systems will be essential for broad adoption.

Institutional policies must be adapted to support the infrastructural and pedagogical shift toward decentralized assessment models. This includes developing guidelines on ethical data use, platform interoperability, and feedback accountability. Faculty development initiatives should be launched to train educators in facilitating blockchain-based systems and designing tasks that benefit from peer validation. Emphasis should be placed not only on technical fluency, but on cultivating a pedagogical mindset that values transparency and learner agency.

Global education communities, particularly those advancing open and distributed learning models, may find this approach especially relevant. The application of blockchain in peer assessment complements movements toward open education, credential decentralization, and digital sovereignty. As educational systems continue to grapple with the demands of scale, equity, and personalization, blockchain offers not just a technological solution, but a reimagining of what trustworthy, democratic assessment can look like in the digital age. This study offers a foundational step toward realizing that vision.

CONCLUSION

This study confirms that a blockchain-enabled peer assessment platform significantly enhances fairness, transparency, and student trust in hybrid learning environments. Quantitative data revealed a 39% increase in perceived fairness and statistically significant gains in feedback clarity and confidence (Cohen's $d > 0.8$).

The most significant finding of this study is that the implementation of a blockchain-enabled peer review and e-assessment system in hybrid learning environments substantially enhanced students' perception of fairness, transparency, and trust in feedback processes. Unlike conventional peer assessment systems that rely on centralized moderation and limited auditability, the decentralized framework ensured 100% traceability and verifiability of evaluative interactions without compromising student anonymity. Students responded positively to the visibility and immutability of feedback records, which not only increased their confidence in the process but also encouraged greater responsibility in both giving and receiving critiques. This demonstrates that blockchain can serve as more than a technological infrastructure; it can function as an ethical architecture for equity in assessment.

The core contribution of this research lies in the operationalization of blockchain technology as a pedagogical tool for formative assessment, offering a replicable model for decentralized feedback systems that align technical affordances with inclusive instructional values. This study moves beyond conceptual discussions by presenting a design-based framework that incorporates smart contracts, distributed validation, and learner-centered transparency into real classroom use. It introduces a novel intersection between educational technology and feedback justice by framing blockchain not merely as a digital ledger, but as an active participant in shaping equitable learning cultures through structured peer interaction and procedural clarity.

The scope of the study was limited to a single institutional context and a relatively short intervention period, which restricts the generalizability of findings across broader educational systems and cultural settings. The study also did not explore long-term impacts on student learning outcomes or the role of instructor facilitation in decentralized assessment environments. Future research should investigate the scalability of this model across disciplines and educational levels,

and examine how blockchain-enabled feedback mechanisms influence learner autonomy, academic identity, and sustained engagement. Cross-cultural comparative studies and integrations with mainstream learning management systems would provide further insight into the institutional viability and pedagogical robustness of decentralized assessment infrastructures.

AUTHORS' CONTRIBUTION

Sevda Kara: Conceptualization; Project administration; Validation; Writing - review and editing; Conceptualization; Data curation; In-vestigation.

Charles Ndikumana: Data curation; Investigation; Formal analysis; Methodology; Writing - original draft.

Denise Mutoni: Supervision; Validation; Other contribution; Resources; Visuali-zation; Writing - original draft.

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