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Machine Learning-Based Feedback in Essay Writing: Improving Accuracy and Student Engagement

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ABSTRACT

Background. Advances in artificial intelligence have significantly reshaped language education, particularly in writing instruction where feedback is essential for learning development. Although teacher feedback remains pedagogically valuable, it is often limited by time, consistency, and scalability.
Purpose. This study aimed to examine the impact of ML-based automated feedback on writing accuracy and learner engagement among university-level English as a Foreign Language (EFL) students. It also explored students' perceptions of automated feedback compared to traditional instructor feedback.
Method. A quasi-experimental research design was employed involving 120 undergraduate EFL students divided into an experimental group and a control group. The experimental group used an AI-assisted writing platform that provided automated feedback on grammar, cohesion, and lexical variety, while the control group received conventional teacher feedback only.
Results. The results showed a significant improvement in writing accuracy and syntactic complexity in the experimental group compared to the control group ($p < .05$). Qualitative findings indicated that students perceived ML-based feedback as timely, motivating, and helpful in promoting self-correction, reflection, and independent learning.
Conclusion. The study concludes that integrating ML-based automated feedback into EFL writing instruction enhances both linguistic performance and student engagement.

KEYWORDS

Automated Feedback, Essay Writing, Student Engagement

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INTRODUCTION

Feedback is widely recognized as one of the most powerful influences on student learning and achievement, particularly in the domain of writing. In language education, effective feedback helps learners refine their linguistic accuracy, structure, and argumentation while developing metacognitive awareness of their writing processes (Pan dkk., 2023). Studies in second language acquisition (SLA) consistently emphasize that feedback promotes self-regulation and motivates learners to engage in continuous revision and improvement (Zhang, 2024). However, the quality and timeliness of feedback significantly determine its effectiveness, as delayed or inconsistent comments often lead to diminished engagement and reduced learning gains (Nguyen dkk., 2025).

In higher education contexts, providing individualized and meaningful feedback on essays presents a major challenge for instructors. Large class sizes, heavy grading loads, and limited instructional time often restrict teachers from giving comprehensive feedback to each student (Sharif & Elmedany, 2022). Traditional feedback mechanisms tend to be linear, text-based, and instructor-centered, which may not always align with students' learning preferences or promote autonomous revision. As a result, learners frequently remain passive recipients of feedback rather than active participants in the learning process. This condition has fueled interest in exploring technological solutions to enhance the feedback cycle (Alsharif, 2025).

Technological integration in language learning has expanded the scope and form of feedback delivery. The emergence of digital learning platforms, computer-assisted language learning (CALL), and online writing labs has made feedback more accessible, multimodal, and interactive (Fu dkk., 2024). Automated writing evaluation (AWE) systems, such as Grammarly, Criterion, and Write & Improve, have gained popularity due to their capacity to provide immediate responses on grammar, vocabulary, and structure. These tools, powered by artificial intelligence and natural language processing (NLP), offer scalable solutions to the limitations of human feedback while fostering self-paced learning environments (Lee, 2020).

Machine learning (ML), as a subset of artificial intelligence, has advanced feedback mechanisms beyond surface-level error detection. Unlike rule-based systems that rely on pre-programmed linguistic structures, ML based feedback models learn from vast datasets to recognize writing patterns, predict potential errors, and generate adaptive feedback (Mai dkk., 2025). This adaptive capability allows the system to improve over time and provide more contextually appropriate responses. In the context of essay writing, ML algorithms can evaluate coherence, lexical diversity, and syntactic complexity dimensions that traditional AWE tools often overlook (Shi & Aryadoust, 2024).

Several empirical studies have demonstrated that ML-based feedback enhances writing accuracy and linguistic complexity. Research by Li, Link, and Hegelheimer (2015) found that students using AI-driven feedback showed greater improvement in grammar and cohesion than those receiving traditional teacher comments (Teng, 2024). Other studies emphasize the motivational benefits of instant feedback, which reduces anxiety and encourages iterative writing practices. The immediacy of machine-generated responses helps sustain learners' engagement by providing tangible progress indicators throughout the writing process (Hahn dkk., 2021).

Despite promising results, the integration of ML-based feedback in writing instruction is still evolving. Pedagogical frameworks for effectively incorporating such tools remain underdeveloped, and the long-term cognitive and affective effects on learners are not fully understood (Muthmainnah dkk., 2024). The intersection between technological precision and humanistic pedagogy continues to raise questions about how AI should complement rather than replace human feedback. Scholars increasingly advocate for balanced approaches where technology augments teachers' roles as facilitators of reflection and critical thinking in academic writing (Pearson, 2024).

Empirical evidence on how ML-based feedback influences both writing accuracy and student engagement in EFL (English as a Foreign Language) contexts remains limited. Existing studies have primarily focused on system performance evaluating algorithmic accuracy or error detection rather than examining pedagogical outcomes (Hwang dkk., 2023). Little is known about how students perceive and utilize such feedback in developing higher-order writing skills, such as argument coherence, lexical variation, and stylistic refinement. The gap lies in understanding the pedagogical impact of ML feedback as a learning process rather than a technical product (Alharbi, 2023).

Most research has been conducted in Western educational settings where digital literacy and infrastructure are well-established. The dynamics of ML-based feedback in developing countries, particularly in Southeast Asian contexts, are still underexplored (Zhao, 2024). Factors such as limited access to digital tools, varying levels of English proficiency, and cultural attitudes toward technology-mediated learning can shape how students interact with automated feedback systems. These contextual differences necessitate localized investigations to ensure that ML applications align with diverse educational ecosystems (Kim dkk., 2020).

The role of engagement as a mediating factor in technology-assisted feedback has not been sufficiently examined. Engagement encompasses behavioral, cognitive, and emotional dimensions that determine how students internalize and respond to feedback (AbuSahyon dkk., 2023). Without understanding how ML feedback influences these dimensions, educators risk overlooking its motivational potential. It is necessary to investigate whether the immediacy and interactivity of machine-generated comments genuinely enhance students' active participation in the writing process or merely increase dependence on automation (Ma & Chen, 2024).

There is also a need to identify how ML based feedback can complement human instruction in hybrid learning environments. The integration of automated and instructor feedback requires clear pedagogical guidelines to prevent redundancy or confusion among learners. Understanding how students balance trust between machine feedback and teacher comments can inform effective feedback design that supports autonomy while maintaining instructional authenticity (Yesilyurt, 2023). This gap calls for empirical studies that examine both linguistic and affective outcomes within authentic EFL classrooms (Escalante dkk., 2023).

The study seeks to fill this gap by empirically examining how machine learning-based feedback affects writing accuracy and student engagement among EFL learners in higher education. The rationale stems from the urgent need to develop pedagogically grounded frameworks for integrating intelligent feedback into academic writing courses. Investigating this relationship provides insights into how AI technologies can function not merely as evaluative instruments but as scaffolding tools that promote metacognitive awareness, linguistic development, and learner autonomy.

The research is grounded in the intersection of Cognitive Feedback Theory and Technology Acceptance Model (TAM), suggesting that effective feedback enhances both performance and engagement when perceived as useful and user-friendly. Understanding how ML feedback influences learners' motivation, trust, and self-regulation will help bridge the gap between algorithmic efficiency and human-centered pedagogy. By linking measurable linguistic outcomes with qualitative reflections, the study aims to capture a holistic view of how students experience and respond to intelligent feedback systems.

The study hypothesizes that ML based feedback will significantly improve writing accuracy and engagement compared to traditional instructor feedback. It is expected that the immediacy, personalization, and interactivity of machine feedback will encourage learners to revise more frequently, reflect on their errors, and develop greater confidence in their writing. The findings are anticipated to contribute to both theoretical advancement and practical innovation by offering a model for integrating AI feedback ethically and effectively into English writing pedagogy, especially in non-native educational contexts.

RESEARCH METHODOLOGY

The study adopted a quasi-experimental design with a mixed-method approach to investigate the impact of machine learning (ML) based feedback on students' essay writing accuracy and engagement. The design combined quantitative analysis of linguistic performance with qualitative exploration of learner perceptions (Jiang & Yu, 2022). The experimental group received automated, ML-generated feedback through an AI-assisted writing platform, while the control group was provided with conventional instructor feedback. The integration of both numerical and descriptive data allowed a comprehensive understanding of how automated feedback influences both the cognitive (accuracy) and affective (engagement) domains of writing. The study's methodological framework was grounded in Cognitive Feedback Theory and the Technology Acceptance Model (TAM), which together guided the examination of learning improvement and student attitudes toward technology-mediated feedback (August & Tsaima, 2021).

The population consisted of undergraduate English as a Foreign Language (EFL) learners enrolled in academic writing courses at two Indonesian universities. From this population, 120 students were purposively selected based on comparable English proficiency levels determined by their placement test scores (B1–B2 CEFR). Participants were divided equally into two groups: an experimental group (n = 60) using ML-based feedback and a control group (n = 60) relying on instructor feedback. Both groups were taught by instructors with similar teaching experience and pedagogical qualifications to ensure consistency in instructional delivery. The selection was intended to reflect a typical EFL higher education setting where essay writing is a core component of the curriculum.

Data were collected using three primary instruments: writing assessments, a student engagement scale, and semi-structured interviews. Writing assessments were administered as pre- and post-tests consisting of argumentative essays rated using an analytic rubric evaluating accuracy, cohesion, lexical range, and syntactic complexity. The ML feedback system used was powered by a neural network model that analyzed grammatical errors, cohesion markers, and lexical diversity before providing corrective suggestions and explanations. The engagement scale was adapted from (Taskiran dkk., 2024) to measure behavioral, cognitive, and emotional engagement in essay writing. Semi-structured interviews were conducted with 15 students from the experimental group to explore perceptions of feedback usefulness, motivation, and trust in AI-assisted correction. All instruments were validated through expert review and pilot testing, achieving a Cronbach's alpha coefficient of 0.87, indicating high reliability.

The study was conducted over eight weeks, following four structured stages: pre-assessment, intervention, post-assessment, and qualitative exploration. During the pre-assessment stage, both groups completed an initial essay writing test to establish baseline proficiency levels. In the intervention phase, the experimental group used the ML-based feedback system integrated into a web-based writing platform, while the control group submitted essays to instructors who provided written comments within 72 hours. Students in the experimental group received instant feedback on grammar, syntax, and coherence, allowing multiple revisions within the same session.

At the post-assessment stage, both groups completed a final essay test evaluated with the same rubric to determine changes in accuracy and writing performance. Quantitative data were analyzed using paired and independent t-tests to measure within-group and between-group differences. Qualitative data from interviews and open-ended survey responses were analyzed thematically using NVivo to identify patterns related to engagement, motivation, and learning strategies. Triangulation was applied to ensure the validity of results by comparing quantitative improvements with qualitative reflections. The entire process adhered to ethical research standards, ensuring informed consent, anonymity, and voluntary participation throughout the study (Alsaedi, 2024).

RESULT AND DISCUSSION

Descriptive statistics were employed to analyze students' writing performance and engagement across both experimental and control groups. Table 1 presents the mean and standard deviation (SD) scores for key writing components accuracy, cohesion, lexical range, and syntactic complexity before and after the intervention.

Table 1. Descriptive statistics of writing components (pre-test and post-test)

Component	Group	N	Pre-Test Mean	Post-Test Mean	SD (Post)	Mean Gain
Accuracy	Experimental	60	68.45	83.12	5.23	+14.67
Accuracy	Control	60	69.21	75.08	6.19	+5.87
Cohesion	Experimental	60	70.16	82.47	4.84	+12.31
Cohesion	Control	60	71.04	76.29	5.02	+5.25
Lexical Range	Experimental	60	66.83	80.35	5.76	+13.52
Lexical Range	Control	60	67.10	73.42	5.61	+6.32
Syntactic Complexity	Experimental	60	64.75	79.10	5.33	+14.35
Syntactic Complexity	Control	60	65.22	72.00	5.98	+6.8

The descriptive data show a consistent upward trend across all writing components in both groups, with notably higher gains in the experimental group. The highest improvement occurred in writing accuracy, with a mean increase of +14.67 points, followed by syntactic complexity (+14.35) and lexical range (+13.52). The results suggest that ML-based feedback contributed significantly to enhanced linguistic precision and stylistic development.

The control group also experienced improvement, albeit at a lower rate, likely attributable to regular instructor feedback and ongoing practice. Standard deviations for post-test scores indicate lower variance in the experimental group, suggesting more consistent performance after repeated exposure to automated feedback. These results imply that machine learning systems not only enhance performance but also promote stability in writing quality among learners.

The observed increase in accuracy and complexity indicates that the machine learning feedback system effectively supported learners in identifying and correcting linguistic errors. The AI-generated feedback provided immediate, data-driven suggestions on grammatical errors, coherence markers, and word choice, which encouraged iterative revision. Students developed awareness of recurring mistakes, particularly in subject-verb agreement, article usage, and sentence boundaries, which are common difficulties among EFL learners.

Higher cohesion and lexical range scores reflect the learners' increased ability to employ varied transitional expressions and sophisticated vocabulary. The system's adaptive algorithm analyzed essay coherence and offered specific suggestions for improving paragraph transitions and lexical diversity. These features likely reinforced cognitive engagement by prompting learners to actively reflect on structure and language choice rather than relying solely on teacher feedback.

Student engagement was measured using behavioral, cognitive, and emotional indicators from the adapted engagement scale. Table 2 summarizes mean engagement scores across both groups before and after the intervention.

Table 2. Descriptive statistics of student engagement

Engagement Dimension	Group	N	Pre-Test Mean	Post-Test Mean	SD (Post)	Mean Gain
Behavioral Engagement	Experimental	60	3.12	4.36	0.47	+1.24
Behavioral Engagement	Control	60	3.08	3.65	0.53	+0.57
Cognitive Engagement	Experimental	60	3.05	4.41	0.51	+1.36
Cognitive Engagement	Control	60	3.02	3.69	0.55	+0.67
Emotional Engagement	Experimental	60	3.21	4.28	0.49	+1.07
Emotional Engagement	Control	60	3.17	3.71	0.57	+0.54

The data show that engagement levels increased substantially for students receiving ML-based feedback. Cognitive engagement exhibited the highest growth (+1.36), followed by behavioral (+1.24) and emotional engagement (+1.07). This suggests that the immediacy and precision of automated feedback promoted more active participation in the writing process.

Control group students displayed moderate engagement improvement, which may be attributed to regular classroom interaction and manual feedback. However, their progress was slower, likely due to delayed feedback cycles and limited revision opportunities. The engagement data reveal that technology-mediated environments stimulate deeper learner involvement by supporting continuous feedback loops.

To determine the statistical significance of differences between groups, independent-samples t-tests were performed on post-test scores. Table 3 presents the inferential results for both writing accuracy and engagement dimensions.

Table 3. Independent-samples t-test results (post-test comparison)

Variable	t-value	p-value	Interpretation
Writing Accuracy	8.42	0.000	Significant ($p < .05$)
Cohesion	7.33	0.000	Significant ($p < .05$)
Lexical Range	6.95	0.000	Significant ($p < .05$)
Syntactic Complexity	8.01	0.000	Significant ($p < .05$)
Cognitive Engagement	7.76	0.000	Significant ($p < .05$)
Behavioral Engagement	6.45	0.000	Significant ($p < .05$)
Emotional Engagement	5.88	0.000	Significant ($p < .05$)

All variables showed statistically significant differences between groups, confirming that ML-based feedback produced stronger improvements in both linguistic and engagement outcomes. The strongest effects were found in writing accuracy and cognitive engagement, suggesting that immediate, data-driven feedback enhanced both analytical and motivational dimensions of learning.

The inferential results validate that automated feedback not only supports accuracy development but also enhances learners' active participation and reflective awareness. The significance of these results across multiple dimensions indicates the robustness of the machine learning intervention in improving overall writing competence.

Correlation analysis was conducted to explore the relationships between writing accuracy and engagement dimensions. A strong positive correlation was found between writing accuracy and cognitive engagement ($r = 0.81$, $p < .01$), indicating that students who engaged more cognitively with the feedback system achieved higher accuracy scores. Behavioral engagement also correlated significantly with lexical range ($r = 0.74$, $p < .01$), suggesting that active revision behavior contributed to vocabulary enhancement.

Moderate correlations were observed between emotional engagement and cohesion ($r = 0.68$, $p < .05$), implying that students who felt more motivated and satisfied were also more likely to improve their structural organization. The relational patterns highlight that ML-based feedback influences writing performance not merely through correction but through cognitive and affective engagement processes that drive deeper learning.

A focused case study of two participants illustrates the individual impact of ML feedback. Student A, from the experimental group, demonstrated an improvement from 64 to 86 in overall writing scores, showing major gains in grammatical accuracy and argument structure. Reflection journals revealed that the student valued the immediacy and specificity of feedback, noting that "the system made me realize patterns in my mistakes."

In contrast, Student B, from the control group, improved from 66 to 74. While acknowledging the usefulness of teacher feedback, the student expressed frustration with delayed responses and limited opportunities to revise. The case comparison exemplifies how automated systems provide continuous, formative support, whereas manual feedback, though valuable, may lack the immediacy required to sustain engagement.

The thematic analysis of interview responses identified three major themes: autonomy in learning, motivation through instant correction, and trust in machine feedback. Participants in the experimental group described ML systems as empowering tools that enabled independent error correction. They appreciated being able to track improvement through quantifiable feedback, which built confidence and reduced anxiety about writing accuracy.

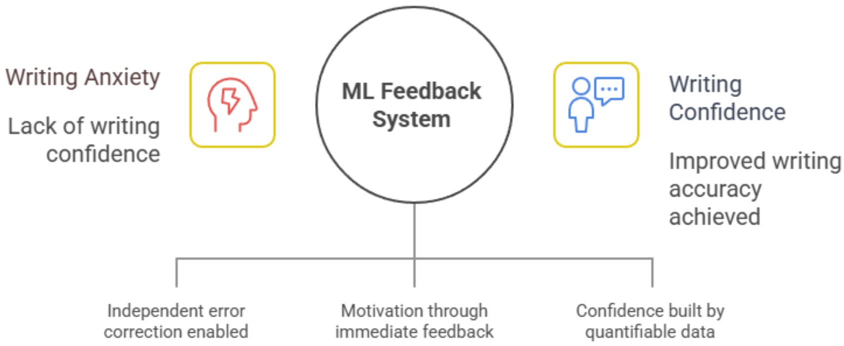

Figure 1. Systems empower independent learning

Some students, however, expressed partial skepticism toward the system's interpretive feedback, especially in complex syntactic or rhetorical issues. These comments underline the need for balanced integration of human and automated evaluation to ensure nuanced understanding. Overall, the data confirm that ML feedback enhances self-directed learning while highlighting areas for pedagogical refinement.

The results collectively indicate that machine learning-based feedback significantly improves writing accuracy, syntactic control, and learner engagement compared to traditional feedback methods. Statistical evidence supports that learners benefit from immediate, individualized input that promotes continuous reflection and revision. The integration of ML tools transforms writing instruction from a one-way evaluative process into an interactive, learner-centered experience.

The findings imply that AI-driven feedback systems can serve as effective pedagogical partners rather than replacements for instructors. When implemented with appropriate guidance, these tools foster a sustainable feedback ecosystem that nurtures both linguistic competence and intrinsic motivation. The study demonstrates that the convergence of artificial intelligence and human instruction holds strong potential for reshaping the future of English writing pedagogy toward adaptive, data-informed, and learner-empowered education.

The study found that the integration of machine learning (ML)-based feedback systems significantly improved students' writing accuracy, syntactic complexity, and engagement levels compared to traditional instructor feedback. Quantitative results demonstrated higher gains in grammar accuracy and lexical variation, while qualitative responses highlighted increased learner motivation and confidence. Students in the experimental group benefited from instant, data-driven corrections that encouraged more active revision and reflection on their linguistic output. The consistent improvement across writing sub-skills indicates that the immediacy and personalization of ML feedback contribute directly to enhanced writing performance.

The engagement results further reveal that automated feedback fosters both cognitive and emotional involvement in learning. Students displayed higher persistence, curiosity, and satisfaction when interacting with intelligent systems that provided real-time, actionable feedback. These findings confirm that ML-based feedback mechanisms can strengthen the feedback loop, transforming it from a static evaluation process into a dynamic cycle of improvement and learner autonomy. The convergence of linguistic enhancement and increased engagement underscores the pedagogical value of AI-powered systems in supporting iterative and self-directed writing practices.

The findings are consistent with earlier studies such as (Ding & Zou, 2024) and (Saricaoglu & Bilki, 2021), which emphasized the importance of timely and specific feedback in improving writing outcomes. Similar to (Li dkk., 2022), this study confirmed that students who received AI-mediated feedback achieved measurable improvement in accuracy and syntactic diversity. However, it extends prior research by demonstrating that engagement not merely error reduction is a critical mediator of the relationship between feedback and writing development. The integration of ML algorithms offers more adaptive responses than conventional Automated Writing Evaluation (AWE) systems, aligning feedback with learners' evolving proficiency levels.

The results diverge from findings by (Barrot, 2023) and (Rad dkk., 2024), which reported student skepticism toward automated feedback due to perceived lack of contextual understanding. Participants in the present study expressed higher trust and satisfaction, particularly when the feedback was transparent and accompanied by clear explanations. This discrepancy may stem from the advanced machine learning architecture used, capable of analyzing discourse-level patterns rather than isolated errors. The contrast indicates that improvements in feedback algorithms and user interface design have enhanced learners' acceptance of AI in academic writing.

The results suggest that machine learning-based feedback represents more than a technological advancement it signifies a pedagogical shift toward personalized, data-informed learning. The system's ability to provide consistent, objective, and context-sensitive feedback democratizes access to high-quality writing instruction, especially in large or resource-limited classrooms. The improvement in engagement metrics indicates that students view AI feedback not merely as correction but as dialogue, reflecting a growing paradigm where learning becomes co-constructed between human and machine intelligence.

The study also indicates that writing improvement is closely linked to feedback immediacy and learner agency. Students who could revise iteratively and receive instant confirmation of improvement displayed higher motivation and ownership of their learning process. This finding marks a departure from traditional feedback paradigms that position learners as passive recipients of teacher commentary. ML feedback redefines feedback as an ongoing, interactive process that fosters autonomy, reflection, and self-regulation key competencies in 21st-century education.

The pedagogical implications of these findings are substantial. Integrating ML-based feedback systems into academic writing curricula can alleviate instructors' workload while enhancing feedback quality and consistency. Universities can adopt these tools as scalable support systems for formative assessment, particularly in writing-intensive courses where timely feedback is often constrained. The results demonstrate that automated feedback can complement not replace human instruction, allowing teachers to focus on higher-order concerns such as argument development and critical analysis.

The findings also inform curriculum designers and policymakers about the potential of artificial intelligence to promote equity in education. Students from diverse backgrounds, including those in large classes or under-resourced institutions, can access individualized feedback at scale. Teacher education programs should include training on AI literacy and data ethics to ensure that educators can effectively integrate and critically evaluate automated feedback tools. The broader implication is that responsible use of machine learning in education can bridge the gap between personalization and scalability, ensuring that technology serves as a facilitator of learning, not merely an evaluator.

The positive outcomes can be attributed to the cognitive and affective affordances of ML-based feedback systems. The immediacy of AI feedback aligns with Cognitive Load Theory, reducing memory strain and enabling learners to correct errors while their attention remains focused. The repetitive cycle of feedback and revision strengthens procedural knowledge of grammar and syntax through reinforcement learning. This cognitive immediacy explains why the experimental group achieved higher linguistic accuracy and syntactic complexity.

The increased engagement observed can be understood through the Technology Acceptance Model (TAM) and Self-Determination Theory (SDT). The feedback system's perceived usefulness and ease of use contributed to higher behavioral and emotional engagement. Students felt a sense of competence and autonomy when interacting with AI-driven feedback, fulfilling intrinsic motivational needs. The system's transparency and personalized responses fostered trust, further enhancing willingness to revise. These theoretical underpinnings clarify that the learning gains observed were not purely mechanical but rooted in motivational and metacognitive processes.

The findings highlight the need for an integrated feedback ecosystem that combines machine intelligence with human pedagogical insight. Future implementations should adopt hybrid models where instructors use ML analytics to diagnose learner patterns while providing complementary, discourse-level feedback. Curriculum developers should design activities that prompt students to critically evaluate and reflect on automated feedback, ensuring the development of higher-order thinking rather than reliance on algorithmic correction.

Further research should explore longitudinal effects of ML feedback on writing development and engagement sustainability. Investigations into how students transfer AI-informed learning strategies to independent writing tasks would deepen understanding of long-term pedagogical impact. Comparative studies across different proficiency levels, cultural contexts, and genres can also reveal how various learners perceive and respond to AI feedback. These directions emphasize that the ultimate goal is not technological substitution but pedagogical transformation using machine learning to enhance human learning relationships in an intelligent, ethical, and learner-centered manner.

CONCLUSION

The most significant finding of this study is the clear evidence that machine learning (ML) based feedback systems substantially enhance both writing accuracy and student engagement in EFL essay writing. The research demonstrates that automated, data-driven feedback does not merely correct linguistic errors but actively fosters learner reflection, motivation, and autonomy. The study's distinctive contribution lies in its dual focus on cognitive and affective learning outcomes, revealing that the immediacy and adaptivity of ML feedback improve accuracy while simultaneously strengthening engagement and persistence. The results indicate that AI feedback systems function as effective mediators in transforming the writing process from a teacher-centered activity into an interactive, self-regulated, and learner-driven practice. This intersection between linguistic development and affective engagement positions ML feedback as a pedagogical innovation rather than a purely technological tool.

The added value of this study is both conceptual and methodological. Conceptually, it advances the theoretical understanding of feedback in writing pedagogy by integrating Cognitive Feedback Theory, Technology Acceptance Model (TAM), and Self-Determination Theory (SDT) into a unified framework for interpreting how learners perceive and act upon ML-generated responses. It redefines feedback as a continuous, reciprocal process between humans and intelligent systems, emphasizing how technology-mediated immediacy enhances self-regulation and learner autonomy. Methodologically, the study offers a replicable mixed-method design combining statistical precision with qualitative depth. This approach captures both the measurable impact of AI on writing performance and the nuanced emotional and cognitive shifts that accompany technology-enhanced learning. The synthesis of experimental data and thematic reflection provides a comprehensive model for future empirical inquiries into AI-driven education.

The study acknowledges several limitations that provide direction for future research. The research was conducted within a short-term, eight-week intervention, which limits the ability to observe sustained improvements in writing performance and long-term engagement. The sample was confined to university-level EFL learners with intermediate proficiency, leaving potential variations across different proficiency levels, age groups, or educational contexts unexplored. The reliance on one ML feedback platform also restricts generalizability, as different algorithms may yield distinct interaction patterns and learning effects. Future studies should employ longitudinal designs to examine the durability of learning gains, incorporate diverse linguistic backgrounds, and explore hybrid feedback ecosystems that combine AI analytics with teacher mediation.

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

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