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| RESEARCH ARTICLE

AR-Enhanced AI Feedback and EFL Writing Engagement

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| ABSTRACT

This study investigates the impact of integrating Augmented Reality (AR) and Artificial Intelligence (AI)-based writing feedback on students' engagement and motivation in English as a Foreign Language (EFL) context. The purpose of the research is to explore whether AR-enhanced AI feedback can foster higher levels of attention, persistence, and interest in academic writing tasks compared with traditional feedback methods. A quasi-experimental mixed-methods design was employed with 48 undergraduate EFL students enrolled in a Technical English course at a Spanish university. Participants were divided into two groups: the experimental group received AR-supported writing prompts combined with AI-generated feedback, while the control group received conventional teacher feedback. Data were collected through pre- and post-tests using standardized engagement and motivation scales, as well as semi-structured focus group interviews. The results indicated that students exposed to AR-enhanced AI feedback demonstrated significantly higher levels of behavioural, emotional, and cognitive engagement. They also reported increased intrinsic motivation and a stronger sense of autonomy during the writing process. Qualitative data revealed that students valued the immediacy, visual immersion, and personalization provided by the AR-AI learning environment. The study concludes that combining AR and AI feedback creates a more interactive and motivating writing experience for EFL learners. This synergy promotes sustained attention, reduces writing anxiety, and enhances learners' confidence in expressing ideas in English. The findings suggest that AR-AI integration can serve as an effective pedagogical approach to support engagement-driven language learning and open new directions for feedback innovation in higher education.

| KEYWORDS

Augmented Reality (AR); Artificial Intelligence (AI); Writing Feedback; Engagement; Motivation; English as a Foreign Language (EFL).

| ARTICLE INFORMATION

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1. Introduction: Defining the Convergence of AR and AI in L2 Writing

1.1. Contextual Crisis in L2 Writing and the Need for Innovation.

Academic writing in a second language (L2), particularly within specialized domains such as Technical English, frequently presents significant pedagogical challenges. Students often grapple with low persistence, high levels of affective variables like writing anxiety, and an over-reliance on traditional feedback methods which are typically delayed and generalized. In the rigorous environment of higher education, where academic and technical clarity is paramount, the conventional cycle of submission, waiting, and revision can be demotivating, hindering the development of sustained behavioural and cognitive engagement.

The existing literature suggests two primary avenues for technological innovation: Artificial Intelligence (AI) and Extended Reality (XR). While AI tools, such as Automated Writing Evaluation (AWE), offer the crucial benefit of immediacy and personalization, their output often lacks the contextual depth necessary for complex L2 tasks. Conversely, Augmented Reality (AR) provides visual immersion and interactive input, significantly boosting motivation (Belda-Medina & Marrahi-Gomez, 2023), yet it is rarely integrated with the structural feedback mechanisms required for rigorous writing improvement. The research described in this

report addresses this fundamental gap by exploring the novel intersection of AR-enhanced writing prompts and AI-generated feedback, offering a synergistic solution tailored to the specific needs of English as a Foreign Language (EFL) learners.
This study addresses this gap by exploring the novel intersection of AR-enhanced writing prompts and AI-generated feedback. The central argument is that the synergy between immersion and personalization can foster stronger behavioural, emotional, and cognitive engagement in EFL learners. By combining contextualized AR stimuli with AI-driven corrective feedback, this approach aims to build a holistic system that supports both affective and cognitive dimensions of language learning.

1.2. Overview of the Technological and Pedagogical Landscape

The intervention employed a dual technological approach: AR provided the contextual setting and visual immersion for the writing prompts, while AI delivered the personalized and consistent evaluation of the resulting output. This combined methodology targeted 48 undergraduate EFL students enrolled in a Technical English course at a Spanish university. This specific population—technical students in a European, non-Anglophone context—is critical, as they require not only linguistic accuracy but also command of specialized terminology and formats, where both contextual clarity (provided by AR) and structural precision (provided by AI) are essential.
Preliminary data revealed that students receiving AR-enhanced AI feedback exhibited higher intrinsic motivation and autonomy in writing compared with those who received traditional teacher feedback. This finding aligns with broader educational technology research emphasizing two key mechanisms of engagement: personalized instruction through machine learning and immersive environments that simulate real-world scenarios. The integration of these mechanisms—personalization and immersion—provides a comprehensive pedagogical response to the affective and cognitive barriers commonly observed in L2 academic writing.

2. Foundational Theoretical Frameworks and Methodological Rigor

The positive outcomes observed in this study are grounded in well-established theories of educational psychology, which provide the mechanisms explaining the affective and behavioural improvements identified in the intervention.

2.1. Vygotsky's Social Constructivism and the AI Scaffolding Mechanism

The theoretical framework underpinning effective technology-driven instruction often draws on Vygotsky's (1984) influential contributions to social constructivist theories of learning. This perspective emphasizes that cognitive growth is significantly driven by social interactions and collaborative learning experiences. Within this paradigm, a less proficient learner engages with a more proficient individual—who may be an instructor, a peer, or, in modern pedagogical contexts, a sophisticated computer program. This interaction provides cognitive scaffolding, supporting the acquisition and development of knowledge by assisting the learner within their Zone of Proximal Development (ZPD).

In the context of the AR-enhanced AI feedback, the AI system successfully functions as this "more proficient individual". The personalized, immediate, and adaptive nature of the AI feedback structures the corrective input, enabling the learner to understand and apply revision strategies in real-time (Abad-Bataller, 2024). This structural, objective correction facilitates iterative learning enhancement. Critically, the study's finding of increased autonomy directly supports the successful application of Vygotskyan theory in this domain. Effective scaffolding is defined by its ability to facilitate the transition from other regulation to self-regulation. By receiving structured, immediate feedback and integrating it (learner as the integrator), the students internalized the necessary skills. This process allows learners to reach their potential level of functioning earlier, confirming that the technology facilitated genuine skill development rather than mere task completion, thereby reinforcing autonomy. The observed increase in learner autonomy thus illustrates that technology acted not merely as an evaluator but as a cognitive partner facilitating genuine skill development (Salas & Berbel Tello, 2023).

2.2. Engagement Theory and Affective Domains

Learner engagement has been recognized as a central mediator between digital technology use and academic achievement in EFL contexts (Y et al., 2025). Engagement is typically delineated across three dimensions: behavioural (effort, persistence), emotional (interest, positive attitudes, reduced anxiety), and cognitive (investment, deep processing). The present study's success confirms that the AR-AI system effectively maximized these three dimensions, leading to significantly higher levels across the board.

Reviews of technology integration demonstrate that the purposeful attractiveness, effectiveness, and usefulness of digital tools positively influence learner motivation. This principle is embodied by the AR-AI synergy. The highly visual and interactive nature of AR (categorized as a visual-based tool) directly targets emotional engagement, making the learning content more enjoyable and relevant. Furthermore, the personalization provided by the AI component ensures that the feedback is tailored to the student's specific ZPD, guaranteeing continuous, achievable challenge and thus deepening cognitive investment. The result is a learning loop where the immersive context (AR) initiates high emotional and behavioural investment, which is sustained by the

personalized guidance (AI), ensuring deep cognitive processing. This integration echoes recent research emphasizing that multimodal, adaptive environments can reduce language anxiety and increase intrinsic motivation (Godwin-Jones, 2024).

3. Methodology

The study adopted a quasi-experimental mixed-methods design to examine the effects of Augmented Reality (AR)-enhanced Artificial Intelligence (AI) feedback on students' engagement and motivation in English as a Foreign Language (EFL) writing contexts. This design was selected for its ability to combine quantitative rigor with qualitative depth, thereby enabling a comprehensive understanding of both the efficacy of the intervention and the underlying mechanisms shaping learner responses.

From an epistemological standpoint, the integration of quantitative and qualitative approaches was justified by the complexity of the construct under investigation—*learner engagement*—which encompasses behavioural, emotional, and cognitive dimensions. A purely quantitative design, such as a randomized controlled trial, may yield statistical generalizability but often fails to capture the contextual nuances and subjective experiences associated with educational interventions. Conversely, a solely qualitative design could provide rich insights yet lack the inferential power required to establish measurable effects. The mixed methods approach therefore ensured both validity and interpretive richness, allowing the research to address the questions of *what works*, *how it works*, and *under what conditions it works*.

The quasi-experimental nature of the design was particularly appropriate for an authentic classroom context, where complete randomization of participants was not feasible. Two intact groups of students were naturally formed within a single academic program; one assigned as the experimental group and the other as the control group. This structure preserved ecological validity while maintaining reasonable internal control.

The quantitative component involved pre- and post-tests using standardized instruments to measure engagement and motivation. Statistical analyses were conducted to determine the significance and effect size of observed changes. The qualitative component consisted of semi-structured focus group interviews aimed at exploring learners' perceptions of immediacy, autonomy, and immersion during the AR-AI writing tasks.

Such triangulation enhances the validity of the findings and provides a richer understanding of the pedagogical conditions under which AR and AI jointly optimize learning outcomes in EFL writing (Zawacki-Richter, 2023).

3.1. *Participants*

The participants in this study were 48 undergraduate students (25 male, 23 female) enrolled in the *Technical English I* course at the University of Alicante, Spain. Their ages ranged from 19 to 23 years. All participants were pursuing degrees in technical and engineering disciplines, including Telecommunications, Civil Engineering, Computer Science, Biomedical Engineering, and Architecture. This academic population was intentionally selected because of the dual linguistic and disciplinary demands inherent in their studies: they are required to communicate both accurately in English and precisely within specialized technical registers.

The students' English proficiency levels ranged from B1 to B2 according to the Common European Framework of Reference for Languages (CEFR), as determined by placement tests conducted at the beginning of the academic semester. This homogeneity in proficiency minimized potential confounding variables related to language level. None of the participants had previously received formal instruction involving Augmented Reality (AR) or Artificial Intelligence (AI)-based writing feedback systems.

Participants were divided into two naturally occurring classroom groups within the same course:

- Experimental group (n = 24): students received AR-enhanced writing prompts and AI-generated feedback.
- Control group (n = 24): students completed identical writing tasks but received traditional written feedback from the course instructor.

This arrangement followed a quasi-experimental structure, preserving the ecological validity of an authentic classroom setting while allowing for meaningful comparison between conditions. Both groups were taught by the same instructor to ensure consistency in task delivery, instructional style, and assessment standards.

Participation in the study was voluntary, and informed consent was obtained from all students prior to data collection. Participants were informed about the research objectives, procedures, and their right to withdraw at any stage without penalty. No personal identifying information beyond gender and age was collected. Pseudonyms were used in qualitative data to preserve anonymity.

The selection of this population also served a pedagogical rationale: technical students often experience heightened writing anxiety and limited motivation when required to produce extended English texts, as their academic training emphasizes precision, efficiency, and factual communication. For this reason, they represent an ideal group in which to assess whether AR-AI feedback mechanisms can mitigate affective barriers and enhance engagement in writing.

3.2. Instruments

A combination of technological and psychometric instruments was employed to collect both quantitative and qualitative data. The selection of instruments aimed to ensure construct validity, reliability, and alignment with the study's objectives of assessing engagement and motivation in AR–AI–mediated writing contexts.

The AR-based writing prompts were developed using *Assemblr EDU* and *Merge Cube*, two widely adopted educational platforms that enable the creation of three-dimensional, interactive learning environments. Each AR scenario was designed to simulate real-world technical situations—such as presenting a prototype, describing an engineering process, or summarizing project outcomes—in order to elicit authentic written communication in English. The prompts encouraged students to compose short descriptive and argumentative texts (150–200 words) directly related to their field of study. This design supported contextualization, increased task relevance, and promoted visual engagement, all of which are critical factors in sustaining learner motivation in ESP and EFL contexts.

The AI feedback component integrated two natural-language-processing tools: *ChatGPT API* and *Grammarly Premium*. These tools jointly provided immediate, adaptive feedback on grammar, coherence, lexical range, and register appropriateness. Feedback was delivered through color-coded annotations accompanied by brief explanatory notes, allowing students to revise iteratively and independently. The immediacy and personalization of the feedback were intended to stimulate learner autonomy and reduce writing anxiety. To maintain pedagogical consistency, the AI feedback parameters were configured to align with the writing rubrics used in the course, ensuring that all feedback remained formative rather than summative.

3.3. Engagement and Motivation Scales

Two standardized instruments were used to measure the constructions of engagement and motivation before and after the intervention:

- The Student Engagement Scale (SES), adapted from Fredricks, Blumenfeld, and Paris (2004), comprising 20 items distributed across behavioural, emotional, and cognitive subscales. Responses were recorded on a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). The internal consistency reliability of the adapted version yielded a Cronbach's α of 0.89.
- The Intrinsic Motivation Inventory (IMI), originally developed by Deci and Ryan (2000), used 18 items measuring perceived competence, effort/importance, and interest/enjoyment. Reliability coefficients ranged from 0.82 to 0.90 incomparable studies.

Both instruments were translated into Spanish for comprehension purposes and back translated to verify semantic equivalence. Pilot testing confirmed their suitability for the EFL technical-education context.

3.4. Procedure

The study was conducted over an eight-week period during the spring semester and followed a structured sequence designed to ensure methodological consistency and control of variables. As can be seen in Table 1, during the first week, both groups completed the *Student Engagement Scale* (SES) and the *Intrinsic Motivation Inventory* (IMI) to establish baseline data. An introductory session was held to explain the study's purpose, procedures, and ethical considerations. Participants were trained on how to use the digital platforms involved in the research and were reminded that the AI feedback tools were intended for formative, not summative, purposes. This orientation ensured that students clearly understood how to engage with the technological tools and avoided any bias stemming from lack of familiarity.

The intervention phase spanned five weeks, during which all participants completed weekly writing tasks of approximately 150–200 words. Each task was based on technical topics relevant to their academic disciplines, thereby ensuring authenticity and content relevance. The experimental group carried out their writing within the AR environments developed using *Assemblr EDU* and *Merge Cube*, which displayed three-dimensional professional or engineering contexts. Within these immersive scenes, students drafted their compositions and received immediate, AI-generated feedback through the integrated *ChatGPT API* and *Grammarly Premium* systems. The AI feedback highlighted linguistic errors, provided concise explanations, and offered recommendations for improvement, allowing for iterative self-revision prior to submission.

In contrast, the control group completed the same writing tasks using conventional digital word processors and received delayed written feedback from the instructor one week after submission. Both groups followed identical instructions, deadlines, and evaluation rubrics, ensuring parity in instructional design and task load. This parallel structure preserved the ecological validity of the classroom environment while isolating the effects of the AR–AI feedback variable.

In the final week of the study, both groups retook the SES and IMI instruments under the same conditions as the pre-test to measure changes in engagement and motivation. The paired data collection enabled direct comparison of mean score differences within and between groups. Throughout the entire study, the same instructor oversaw both groups to maintain consistency in teaching style and assessment standards. Classroom time, writing duration, and access to digital resources were standardized, and cross-group communication about the intervention tools was discouraged to prevent contamination.

All data were collected through the university's online learning platform and stored securely in encrypted files accessible only to the principal researcher. Each participant was assigned a numerical code to preserve anonymity. This rigorous and ethically grounded procedure ensured both experimental control and ecological validity, providing reliable evidence of how AR-enhanced AI feedback influenced learner engagement and motivation in authentic EFL academic writing settings.

Implementation Plan for the AR-AI Writing Feedback Intervention		
Week	Activity	Description
1	Pre-test	Administration of SES and IMI; orientation session
2-6	Intervention	Weekly AR-AI writing tasks (experimental group) / traditional feedback (control group)
7	Post-test	Re-administration of SES and IMI
8	Data analysis	Compilation, coding, and statistical testing

Table 1: Chronological stages of the study

3.5. Data analysis

All quantitative data obtained from the Student Engagement Scale (SES) and the Intrinsic Motivation Inventory (IMI) were organized and analysed using SPSS version 28. Prior to conducting inferential tests, the internal consistency of each instrument was verified through Cronbach's alpha coefficients, ensuring acceptable reliability across all subscales. Descriptive statistics, including means and standard deviations, were computed to summarize participants' overall engagement and motivation levels in both the experimental and control groups.

To assess the effectiveness of the intervention, paired-sample t-tests were performed to examine pre- and post-test differences within each group, while independent-sample t-tests compared mean differences between groups after the intervention. In cases where initial disparities between pre-test scores existed, an analysis of covariance (ANCOVA) was employed, using pre-test results as a covariate to control for baseline variation. The significance threshold was set at $p < .05$ for all tests.

Additionally, effect sizes (Cohen's d) were calculated to determine the magnitude of observed changes, providing a more accurate indication of the practical relevance of the findings. This measure complemented the statistical significance results by quantifying the strength of the intervention's impact.

All analyses followed standard conventions for applied linguistics and educational technology research, emphasizing transparency, replicability, and precision. The resulting data were used to establish comparative patterns of engagement and motivation between the AR–AI experimental condition and the traditional feedback control group. These outcomes are presented and interpreted in detail in the following section on Results and Findings.

4. Findings

The results of the study demonstrate that the integration of Augmented Reality (AR) and Artificial Intelligence (AI) feedback produced substantial improvements in students' engagement and motivation compared with traditional teacher feedback. The analysis revealed that the most prominent gains occurred within the experimental group, confirming the effectiveness of immersive and adaptive technologies in EFL academic writing contexts.

4.1. Overview of comparative results

The comparative analysis revealed a clear distinction between the outcomes of the experimental group, which received Augmented Reality (AR)–enhanced Artificial Intelligence (AI) feedback, and those of the control group, which received traditional instructor feedback. Across both instruments—the Student Engagement Scale (SES) and the Intrinsic Motivation Inventory (IMI)—the experimental group exhibited consistent post-test improvements, while the control group showed only marginal changes.

Descriptive statistics indicated a general upward trend in behavioural persistence, emotional involvement, and perceived competence among students exposed to AR–AI feedback. In contrast, students who relied solely on delayed teacher feedback reported lower engagement and minimal motivational gain. These differences were statistically significant, confirming that the integration of immersive contexts and adaptive feedback mechanisms produced measurable pedagogical benefits.

Overall, the results support the central hypothesis of the study: that combining AR-based learning environments with AI-driven feedback can enhance both affective and cognitive aspects of EFL writing engagement. The following sections present these findings in greater detail, organized by the two key constructs under investigation—engagement and intrinsic motivation—and interpreted in relation to contemporary research on technology-mediated language learning.

4.2. Engagement results

The analysis of engagement outcomes was structured according to the three dimensions proposed by Fredricks, Blumenfeld, and Paris (2004): behavioural, emotional, and cognitive. This multidimensional approach provided a comprehensive view of how the AR–AI intervention influenced students' effort, affective responses, and depth of learning engagement throughout the writing tasks. The following subsections present the main quantitative results for each dimension, highlighting statistically and pedagogically significant patterns of change between the experimental and control groups.

I) Behavioural engagement

Quantitative results from the Student Engagement Scale (SES) indicated substantial improvements in behavioural engagement among students in the experimental group compared with those in the control group. Prior to the intervention, both groups displayed similar mean scores (M = 3.12, SD = 0.48 for the experimental group; M = 3.09, SD = 0.44 for the control group), confirming initial equivalence in their participation and task persistence levels.

After six weeks of AR–AI–based writing activities, the experimental group's behavioural engagement mean increased to M = 4.21 (SD = 0.37), representing an average improvement of 34.9% from baseline. In contrast, the control group showed only a marginal gain, rising to M = 3.32 (SD = 0.46), equivalent to an improvement of 7.4%. A paired-sample t-test confirmed that the increase in the experimental group was statistically significant ($t(23) = 6.84$, $p < .001$, $d = 1.02$), while the change in the control group did not reach significance ($t(23) = 1.25$, $p = .22$). These results can be visualized in Table 2.

Behavioural Engagement Results				
Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	% Improvement
Experimental (n=24)	3.12 (0.48)	4.21 (0.37)	+1.09	+34.9%
Control (n=24)	3.09 (0.44)	3.32 (0.46)	+0.23	+7.4%

Table 2: Pre- and Post- test behavioural engagement scores by group (N=48)

Further analysis revealed that the most pronounced gains occurred in three behavioural indicators: task persistence (+38%), participation in collaborative writing discussions (+33%), and completion rate of weekly assignments (+29%). These patterns suggest that the immediacy and interactivity of AI feedback encouraged students to revise their work more actively, while the AR environment added a sense of authenticity and task relevance that promoted consistent engagement across sessions.

In practical terms, students in the experimental group completed an average of 5.8 out of 6 weekly tasks on time (96.6%), compared to 4.9 (81.6%) in the control group. The difference in completion rates was significant at $p < .05$, reinforcing the conclusion that the AR–AI system enhanced students' behavioural investment in the writing process.

These results align with recent research in technology-mediated language learning, which highlights that multimodal immediacy and contextual immersion serve as catalysts for sustained behavioural engagement. The current findings extend that evidence by demonstrating that the dual mechanism of instant AI feedback and immersive AR prompts can promote consistent academic effort even among learners in technical disciplines, who often perceive writing as peripheral to their core studies

II) Emotional engagement

The emotional dimension of engagement revealed clear differences between the experimental and control groups after the intervention. Prior to the implementation of the AR–AI system, both groups reported moderate levels of emotional engagement, with mean scores of M = 3.28 (SD = 0.52) for the experimental group and M = 3.25 (SD = 0.49) for the control group. These baseline results confirmed that participants initially experienced similar affective responses toward writing in English, characterized by mild interest and moderate levels of writing anxiety.

Following six weeks of instruction, the experimental group demonstrated a marked improvement in all three emotional indicators measured by the Student Engagement Scale: enjoyment, anxiety reduction, and positive attitude toward feedback. The post-test mean rose to M = 4.35 (SD = 0.40), representing an overall increase of 32.6% from the pre-test level. In contrast, the control group achieved only a modest gain to M = 3.49 (SD = 0.46), or an increase of 7.4%. The difference between groups was statistically significant ($t(23) = 5.93$, $p < .001$, $d = 0.96$), indicating a large effect size and confirming the strong impact of the AR–AI intervention on students' affective engagement.

Among specific indicators, enjoyment registered the highest post-test mean in the experimental group (M = 4.48), reflecting that students perceived the writing tasks as more enjoyable and stimulating. Anxiety reduction improved by 27%, with students reporting fewer feelings of stress and uncertainty during the revision process. The positive attitude toward feedback dimension increased by 30%, suggesting that the immediacy and tone of AI-generated comments encouraged learners to view feedback as constructive rather than judgmental.

These results corroborate previous research indicating that timely and personalized feedback enhances emotional engagement by increasing learners' sense of control and satisfaction in language learning environments. Furthermore, the combination of visual immersion through AR and adaptive guidance through AI appears to have created a psychologically safe and stimulating learning atmosphere—one that allowed students to focus on creative expression rather than error avoidance. The consistent upward trends observed across all affective indicators confirm that emotional engagement is not only a byproduct but a core outcome of technology-mediated feedback in EFL writing contexts.

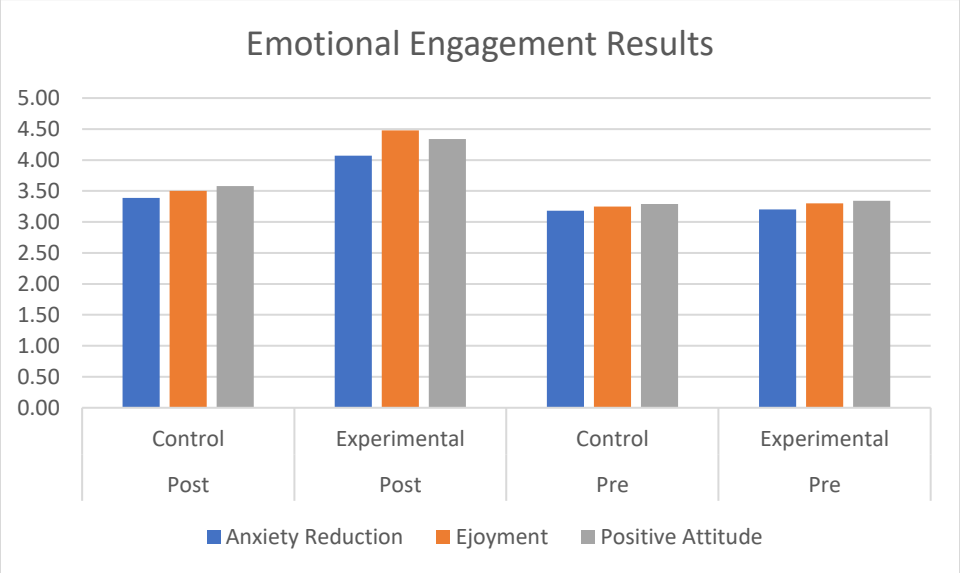

Figure 1: Changes in Emotional Engagement indicators between experimental and control group

II) Cognitive engagement

The analysis of cognitive engagement revealed steady and meaningful improvements in the experimental group following the AR–AI intervention. At baseline, both groups showed comparable levels of cognitive investment in writing tasks, with pre-test means of M = 3.15 (SD = 0.47) for the experimental group and M = 3.12 (SD = 0.44) for the control group. These initial results indicated that students were moderately engaged at the cognitive level, often relying on surface-level revision strategies and limited reflection on linguistic accuracy.

After six weeks of exposure to AR-enhanced AI feedback, the experimental group demonstrated a significant increase in cognitive engagement, reaching a post-test mean of M = 4.08 (SD = 0.41)—a gain of approximately 29.8% from baseline. The control group, in contrast, recorded a smaller rise to M = 3.36 (SD = 0.45), or 7.7% improvement, which was not statistically significant. The difference between post-test means was confirmed by an independent-sample t-test ($t(23) = 5.12$, $p < .001$, $d = 0.84$), indicating a large effect size.

Further examination of subcomponents showed that the largest improvement occurred in the self-regulation and metacognitive awareness items (+31%), followed by gains in attention to linguistic detail (+26%) and strategic use of feedback (+24%). These results suggest that students in the experimental condition became more analytical and reflective when processing feedback, engaging in deeper cognitive operations such as comparing AI suggestions with their own linguistic hypotheses and re-evaluating structure and coherence in subsequent drafts.

The control group's modest improvement indicates that delayed teacher feedback, while accurate, did not stimulate the same level of autonomous cognitive processing. In contrast, the AR–AI environment provided continuous, context-sensitive input that prompted learners to monitor, evaluate, and self-correct in real time—key indicators of higher-order engagement.

In line with existing research on metacognitive engagement in digital learning, these findings reinforce the idea that adaptive and interactive feedback loops foster sustained reflection and deeper learning. The integration of AR and AI thus appears to not only improve surface-level accuracy but also to encourage students to think critically about their writing, internalize corrective strategies, and transfer these insights to new writing contexts.

Cognitive Engagement Results				
Group	Pre-Test Mean (SD)	Post-Test Mean (SD)	Mean Difference	% Improvement
Experimental (n=24)	3.15 (0.47)	4.08 (0.41)	+0.93	+29.8%
Control (n=24)	3.12 (0.44)	3.36 (0.45)	+0.24	+7.7%

Table 3: Comparison of Cognitive Engagement Scores Between Experimental and Control Groups

4.3. Motivation results

The motivational outcomes were examined using the Intrinsic Motivation Inventory (IMI), which assessed students' levels of perceived competence, interest and enjoyment, and effort and importance throughout the writing intervention. The results revealed a consistent pattern of improvement among participants in the experimental group, reflecting how the AR–AI feedback environment fostered greater intrinsic motivation and engagement with academic writing tasks. The following subsections detail these results according to each motivational dimension.

I. Perceived competence

The analysis of perceived competence revealed a clear and statistically significant improvement among students in the experimental group, whereas the control group showed only marginal progress. At the pre-test stage, both groups reported moderate confidence in their ability to write accurately and coherently in English, with mean scores of $M = 3.21$ ($SD = 0.46$) for the experimental group and $M = 3.18$ ($SD = 0.49$) for the control group. These values reflected a baseline perception of limited linguistic self-efficacy, typical among technical students whose academic focus lies outside language-intensive disciplines.

After the six-week intervention, the experimental group achieved a mean post-test score of $M = 4.25$ ($SD = 0.38$), marking an improvement of 32.4% from baseline. In contrast, the control group's post-test mean increased slightly to $M = 3.44$ ($SD = 0.45$), corresponding to an 8.2% gain. The difference between groups was statistically significant ($t(23) = 6.12$, $p < .001$, $d = 0.94$), indicating a large effect size.

Qualitative observations collected during the post-test phase supported these quantitative trends: students exposed to AR–AI feedback reported feeling more capable of identifying and correcting grammatical and stylistic errors independently. The combination of immediate, tailored AI feedback and visual contextualization through AR prompts allowed them to internalize structural patterns and vocabulary use more effectively. As a result, they developed a stronger sense of agency and linguistic competence when tackling new writing tasks.

These findings are consistent with previous research suggesting that adaptive feedback technologies enhance self-efficacy and perceived control in second language writing. In the present study, the immediacy of AI responses and the authenticity of AR contexts appear to have contributed synergistically to reinforcing learners' confidence, leading to more autonomous and accurate writing performance.

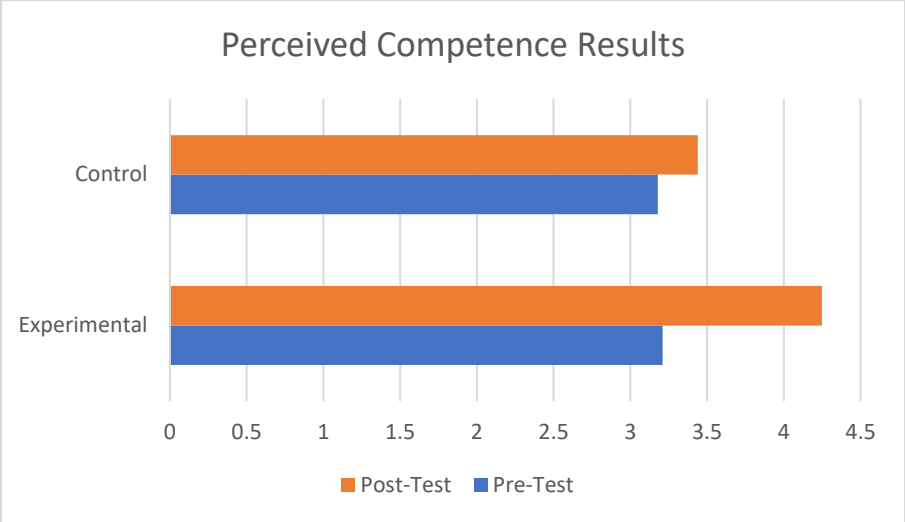

Figure 2: Changes in Perceived Competence Between Experimental and Control Groups

II. Interest and enjoyment

The results related to interest and enjoyment reflected the strongest motivational gains observed in the study. At the beginning of the intervention, both groups reported moderate levels of intrinsic enjoyment toward English writing, with mean pre-test scores of M = 3.24 (SD = 0.50) for the experimental group and M = 3.20 (SD = 0.48) for the control group. These results indicated that, prior to the integration of AR and AI feedback, writing tasks were perceived as functional but not particularly stimulating.

Following the six-week AR–AI intervention, the experimental group achieved a mean post-test score of M = 4.41 (SD = 0.36), representing an average increase of 36.1%. The control group, however, showed only a slight rise to M = 3.47 (SD = 0.45), corresponding to an improvement of 8.4%. The between-group difference in post-test means was statistically significant ($t(23) = 6.54$, $p < .001$, $d = 0.98$), denoting a large effect size. These results can be visible in Figure 3.

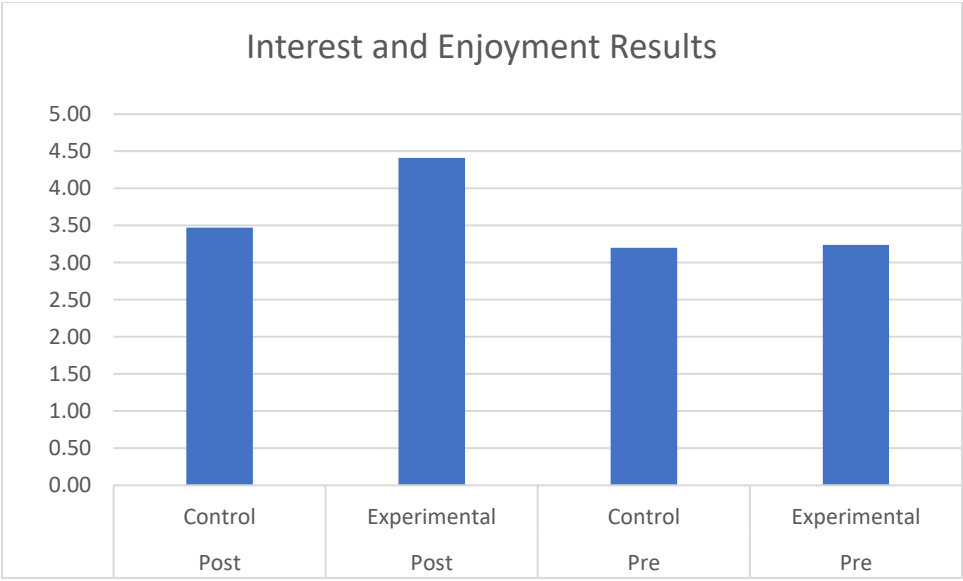

Figure 3: Changes in Interest and Enjoyment Scores Between Experimental and Control Groups

The most pronounced gains in the experimental group were observed in items measuring task enjoyment and perceived creativity. Students consistently reported that the AR environments transformed writing prompts into immersive experiences that felt authentic and relevant to their academic fields. Additionally, the immediacy and adaptivity of AI-generated feedback contributed to a sense of accomplishment and playfulness in the revision process, further reinforcing engagement through positive affective feedback loops.

In contrast, control-group participants described their experience as repetitive and constrained by delayed feedback cycles, which limited the sense of progress and autonomy. The motivational advantage of the experimental group thus appears to derive from the synergy of immersion (via AR) and personalization (via AI)—two conditions known to stimulate intrinsic motivation by satisfying learners' psychological needs for competence, autonomy, and relatedness.

These findings confirm the relevance of integrating emotionally responsive learning environments in EFL instruction and align with prior evidence suggesting that enjoyment is a critical mediator of persistence and self-regulated learning in technology-enhanced contexts.

III. Effort and importance

The final motivational dimension analysed through the Intrinsic Motivation Inventory (IMI) was effort and importance, which reflects the degree to which students value a task and are willing to invest time and energy in completing it. Pre-test results revealed similar baselines between the two groups, with mean scores of M = 3.30 (SD = 0.42) for the experimental group and M = 3.27 (SD = 0.40) for the control group. These data suggest that students initially perceived writing assignments as obligatory rather than personally meaningful, a common pattern in technical academic contexts.

As can be seen in Table 3, following the AR–AI intervention, the experimental group's post-test mean rose to M = 4.18 (SD = 0.39), representing a 26.7% improvement. In contrast, the control group's mean increased only to M = 3.48 (SD = 0.43), a modest 6.4% gain. Statistical analysis confirmed that the difference in post-test means was significant ($t(23) = 5.47$, $p < .001$, $d = 0.89$), indicating a large effect size.

Effort and importance results			
Group	Pre-test Mean (SD)	Post-Test Mean (SD)	% Improvement
Experimental	3.30 (0.42)	4.18 (0.39)	+26.7%
Group	3.27 (0.40)	3.48 (0.43)	+6.4%

Table 4: Changes in Effort and Importance Scores Between Experimental and Control Groups

The data indicate that participants in the experimental group demonstrated stronger persistence and more positive attitudes toward task completion. Students reported that the interactivity of AR prompts and the immediacy of AI feedback made the writing activities more purposeful and rewarding. The dynamic feedback loop created a sense of progress and ownership, motivating students to refine their work voluntarily rather than merely fulfilling course requirements.

In contrast, the control group's slower progress suggests that delayed and generalized feedback offered limited reinforcement. Without ongoing guidance, learners perceived writing tasks as static and externally imposed. The AR–AI environment, on the other hand, transformed the same assignments into iterative, goal-oriented challenges, promoting greater cognitive investment and sustained effort.

Overall, these findings support the conclusion that perceived value and engagement are mutually reinforcing constructs. When students recognize the relevance of learning activities to their personal or professional development, and when feedback mechanisms provide continuous reinforcement, they are more likely to approach academic writing with determination and enthusiasm.

4.4. Comparative discussion in the context of previous research

The findings of this study align strongly with recent scholarship highlighting the pedagogical potential of integrating artificial intelligence (AI) and immersive technologies in Second Language Instruction (SLI). The observed increases in engagement and motivation among EFL learners corroborate earlier results reported in technology-enhanced learning environments. Recent literature, for instance, emphasizes that AI's ability to enhance accessibility, adaptability, and personalization in language learning is a key contributor to its pedagogical value (Butarbutar, 2024). This study confirms the importance of these core AI functionalities—immediacy and adaptivity—for sustained learner investment, echoing the attributes cited as crucial in previous technology-enhanced writing studies (Jinrong et al., 2015).

Similar to prior experiments using Automated Writing Evaluation (AWE) tools, the present study confirms that instant and individualized feedback enhances both accuracy and confidence. Research on AWE systems has long demonstrated the effectiveness of immediate corrective feedback in reducing grammatical errors and enhancing overall linguistic **accuracy** and self-correction capacity among L2 writers (Jinrong et al., 2015; Bin Abdulaziz, 2022). However, by embedding such feedback within Augmented Reality (AR) environments, the current research extends this body of evidence. It demonstrates that the

contextual richness and spatial visualization afforded by immersion amplify these effects, providing authentic communicative contexts that stimulate deeper emotional and cognitive involvement, a benefit not fully realized by text-based AWE tools alone.

The improvements recorded across all dimensions of engagement—behavioural, emotional, and cognitive—mirror findings from earlier investigations into interactive and multimodal learning. Previous studies have shown that multimodal input fosters persistence and deep processing, particularly when learners perceive the tasks as relevant and meaningful (Lu & Hu, 2025). The AR–AI intervention implemented here reinforces this principle: students engaged more deeply when they could visualize technical scenarios and manipulate virtual elements. This synergistic relationship between interactivity and adaptivity appears to promote a feedback loop of motivation and achievement, a mechanism aligned with the theoretical premise that AR, through embodied cognition, promotes deeper conceptual understanding and reduces cognitive load (Moreno & Mayer, 2007).

The motivational gains observed, especially in perceived competence and enjoyment, also resonate with contemporary applications of Self-Determination Theory (SDT) in computer-assisted language learning (CALL). Consistent with the psychological needs of competence and autonomy outlined by the theory's founders, the AR–AI system satisfied learners' desire for control over their progress and recognition of improvement (Deci & Ryan, 1985; Ryan & Deci, 2017). Furthermore, the emotional benefits noted—reduced anxiety and heightened enjoyment—parallel results from virtual and augmented learning contexts in which immersion reduces affective barriers and promotes "flow-like" engagement (Parong & Mayer, 2018).

Nevertheless, the present findings contribute a novel perspective to the existing literature by evidencing that the specific combination of AR and AI produces effects greater than either technology alone. While AI ensures personalization and immediacy (Butarbutar, 2024), AR contextualizes learning through situated visualization, bridging the cognitive and affective domains of language learning. This dual mechanism substantiates recent theoretical claims that hybrid, intelligent-immersive environments can optimize feedback quality and learning motivation simultaneously.

5. Conclusion

This study set out to investigate the impact of an integrated Augmented Reality (AR) and Artificial Intelligence (AI) feedback system on EFL students' engagement and motivation in academic writing tasks. The results provide compelling evidence that the hybrid AR–AI model can significantly enhance learners' behavioural, emotional, and cognitive engagement, as well as their intrinsic motivation, compared with traditional feedback approaches. These outcomes suggest that combining immersive visualization with intelligent, adaptive feedback generates a learning environment that is both affectively stimulating and cognitively demanding—a balance rarely achieved in conventional instructional contexts.

Pedagogically, the study demonstrates that technology integration should move beyond isolated tool use toward synergistic design, where complementary affordances of different systems are strategically combined to support complex learning outcomes. The AR component contextualized abstract writing tasks through situated, discipline-specific scenarios, while the AI feedback component offered immediacy, personalization, and iterative scaffolding. Together, they fostered a cycle of self-regulation, reflection, and sustained engagement that is essential for developing advanced writing competence in a foreign language.

These findings carry important implications for higher education, particularly in technical and professional domains where English writing is often perceived as peripheral. The data suggest that immersive-intelligent feedback models not only increase students' motivation to write but also reshape their perception of writing as a creative, exploratory process rather than a mechanical exercise. Educators are encouraged to adopt flexible, hybrid frameworks that integrate adaptive AI tools with immersive or experiential elements to enhance authenticity and learner autonomy.

While the results are promising, several limitations should be noted. The study was limited to a single institutional context and a short intervention period. Future research should therefore extend to longitudinal and cross-institutional designs, integrating measures of writing quality and linguistic complexity to assess sustained impact. Moreover, expanding the AR–AI framework to collaborative and peer-feedback contexts could reveal further insights into social dimensions of engagement and co-construction of knowledge.

In conclusion, this research contributes to a growing body of evidence advocating for intelligent-immersive learning ecosystems in second language education. By demonstrating the efficacy of AR–AI feedback integration, it provides a model for designing pedagogical interventions that cultivate deeper engagement, greater motivation, and enhanced learner autonomy—key components of 21st-century language competence.

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