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Examining AI-Enhanced Bilingual Scaffolding in Educational Technology English: Evidence from a Quasi-Experimental Study

Andi Asrifan[1] ✉
Universitas Negeri Makassar, Makassar, Indonesia
La Sunra[2]
Universitas Negeri Makassar, Makassar, Indonesia
K. J. Vargheese[3]
Christ College Irinjalakuda, Kerala, India
Akhtem A. Dzhelilov[4]
V.I. Vernadsky Crimean Federal University, Crimea, Russia
Sajed S. Ingilan[5]
University of Southeastern Philippines, Davao City, Philippines

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ABSTRACT

This study examined AI-enhanced bilingual scaffolding in Educational Technology English within an ESP framework. It investigated whether strategic bilingual mediation and AI-assisted feedback were associated with higher student engagement and higher-order learning than traditional instruction. Using a quasi-experimental pretest-posttest non-equivalent control group design, the study involved 84 undergraduate students from an Indonesian Educational Technology program. Two intact classes were assigned as experimental and control groups. Data were collected through a student engagement scale, higher-order learning performance assessment, classroom observation checklists, and reflection logs. The data were analyzed using descriptive statistics, independent-samples t-tests, gain-score analysis, effect-size estimates, and thematic interpretation. The findings showed that the experimental group achieved greater gains in cognitive engagement (gain = 1.27; d = 1.46) and creation skills (gain = 18.7; d = 1.52), with significant between-group differences ($p < .001$). Qualitative findings suggested that AI functioned as a cognitive partner, supported bilingual conceptual transfer, reduced anxiety, and increased linguistic confidence. The study contributes to scaffolding and bilingual pedagogy by proposing an AI-enhanced bilingual co-scaffolding model for ESP curriculum design, AI literacy integration, and lecturer professional development.

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Corresponding Author: ✉andi.asrifan@unm.ac.id

INTRODUCTION

The swift incorporation of artificial intelligence (AI) into higher education has revolutionized the field of English language instruction, especially within English for Specific Purposes (ESP) areas that require disciplinary significance and cognitive complexity (Asrifan et al., 2025; Raj et al., 2026). In the realm of Educational Technology English, students are required to not only acquire specialized vocabulary and linguistic skills but also to critically engage with digital pedagogies, instructional frameworks, and novel AI-enhanced learning environments. Universities worldwide are progressively integrating AI-supported platforms into language education to enhance adaptive feedback, tailored learning pathways, and real-time learner assistance (Gutiĭrrez-Ujaque, 2024; Jalaluddin et al., 2025; Lie et al., 2023). In Indonesia and other multilingual environments, this transition coincides with another educational reality: the continued application of bilingual scaffolding to connect learners' first language resources with their academic achievement in the target language (Gazis & Vavouras, 2025; Khair, 2022; Sahiruddin, 2023). This issue is significant because many students in Educational Technology programs have a strong conceptual grasp of digital learning systems in Bahasa Indonesia but struggle to articulate these concepts clearly and critically in English. The integration of AI-enhanced tools with bilingual instructional support has proven to be an effective pedagogical strategy for enhancing engagement and advancing higher-order learning results (Juanda & Afandi, 2024; C. Li & Long, 2025; Nugraha & Syafei, 2025).

This study delineates three interrelated constructs to elucidate the educational framework. Scaffolding refers to temporary educational support that aids learners in completing tasks that may initially exceed their unaided linguistic or cognitive abilities. This support encompasses guided questioning, structured feedback, task modeling, and incremental help that progressively fosters learner autonomy. Bilingual mediation specifically refers to the strategic use of learners' first language (Bahasa Indonesia) to enhance conceptual clarity, mitigate cognitive overload, and support disciplinary meaning-making in English-medium education. This study employed multilingual mediation by providing selective Indonesian explanations of Educational Technology principles, clarifying terminology, and comparing concepts across languages. Third, AI support refers to the use of generative artificial intelligence systems that provide prompt and flexible assistance across educational tasks. This encompassed AI-assisted vocabulary enhancement, paragraph reorganization, reflective prompting, evaluation of argumentative coherence, and ideation enlargement during English academic assignments. This study defines AI-enhanced bilingual scaffolding as the combined instructional application of pedagogical scaffolding, bilingual mediation, and AI-supported feedback to promote engagement and advanced learning in Educational Technology English settings.

Previous studies on bilingual scaffolding in ESP contexts generally suggest that strategic first-language mediation can support comprehension, reduce linguistic anxiety, and facilitate disciplinary concept acquisition, particularly in cognitively demanding learning environments (Fan, 2025; Kanoksilapatham & Khamkhien, 2022; Mostafavi et al., 2021). These studies consistently indicate that bilingual support may help learners bridge the gap between conceptual understanding and target-language production. However, most of this research has focused primarily on comprehension outcomes and general language performance, with limited attention to how bilingual scaffolding influences higher-order learning processes in discipline-specific English contexts.

A related body of research has explored the role of AI-assisted feedback in academic English learning. Prior findings suggest that AI-supported writing and discussion tools may contribute to revision quality, learner confidence, and reflective engagement by providing immediate and adaptive feedback (Boudouaia et al., 2026; Mohammed & Khalid, 2025; Mujeeb et al., 2026).

At the same time, several scholars caution that AI-supported learning without adequate pedagogical mediation may encourage superficial task completion and passive dependency rather than deeper cognitive processing (Agostini et al., 2026; M. Li & Wilson, 2025; Mai, 2026). An experimental study on automated writing tools revealed enhancements in grammatical accuracy, yet minimal advancements in critical thinking and knowledge transfer, especially when students were devoid of metacognitive guidance (Deep & Chen, 2025; Elycheikh et al., 2024; Hyland, 2025). Taken together, existing studies suggest that both bilingual scaffolding and AI-mediated support may independently contribute to the quality of language learning. Nevertheless, relatively little research has examined how these two forms of support interact within a unified instructional framework, particularly in Educational Technology English courses that require both disciplinary reasoning and higher-order cognitive engagement.

Collectively, prior research indicates three overarching insights. Bilingual scaffolding regularly enhances understanding and confidence in cognitively challenging language activities. Secondly, AI tools are increasingly proficient at improving feedback quality, revision processes, and learner engagement. Third, higher-order learning—encompassing analysis, assessment, and synthesis—seems to be enhanced when technological support is integrated into organized educational frameworks. It is established that both bilingual mediation and AI-based help independently enhance the quality of language acquisition. The synergistic integration of both in discipline-specific ESP contexts is inadequately hypothesized and empirically examined (Mohamed et al., 2025; Praveena & Anupama, 2025; Yang, 2025).

Notwithstanding the growing interest in bilingual scaffolding and AI-assisted language acquisition, significant gaps remain inadequately addressed in the current literature. Prior research on bilingual scaffolding has predominantly focused on enhancing comprehension, vocabulary development, and overall English proficiency in EFL or ESP contexts.

Research on AI-assisted learning has mostly focused on automated feedback, writing support, and learner engagement in technology-enhanced classrooms. While these study strands offer useful insights individually, they have seldom been analyzed within a cohesive instructional framework. Limited studies have examined the simultaneous interaction of AI-mediated help and multilingual scaffolding on student engagement and higher-order learning outcomes in discipline-specific English courses. Current research predominantly focuses on general English learning environments rather than on Educational Technology English, which requires learners to engage in analytical reasoning, digital pedagogical assessment, and English-medium problem-solving. Furthermore, several prior studies predominantly focus on short-term performance metrics, neglecting the interconnectedness of multidimensional engagement and higher-order cognition as comprehensive learning outcomes. This study investigates the application of AI-enhanced bilingual scaffolding in an Educational Technology English course using a quasi-experimental design to address existing gaps. The study examines whether incorporating multilingual mediation and AI-assisted feedback correlates with enhanced student engagement and improved learning compared with traditional education.

This study seeks to evaluate the efficacy of AI-enhanced bilingual scaffolding in Educational Technology English courses in light of these limitations. This study specifically examines the following research question: (1) To what degree can AI-enhanced bilingual scaffolding boost student involvement in Educational Technology English learning? How does the intervention affect students' higher-order learning outcomes in comparison to traditional instruction? The study posits that students using AI-enhanced multilingual scaffolding will exhibit greater engagement and superior higher-order learning outcomes compared to the control group.

The study employs a quasi-experimental pretest–posttest control group design to systematically compare intervention and non-intervention classrooms in real educational contexts. This design is methodologically sound as it aims to assess causal educational impacts while maintaining the ecological validity of classroom training. Student engagement is anticipated to rise due to real-time AI feedback and bilingual conceptual clarity, while higher-order learning is projected to be enhanced through scaffolded analytical tasks, reflective prompting, and discipline-specific English creation.

This study's originality lies in the proposal and empirical evaluation of an integrated instructional approach that combines AI-mediated adaptive support with multilingual scaffolding in a disciplinary ESP context. Theoretically, the research expands the literature on scaffolding and cognitive engagement by demonstrating how AI can serve as a dynamic co-scaffold in tandem with strategic L1 mediation. The findings provide an evidence-based instructional paradigm for educators in Educational Technology and associated ESP programs aiming to enhance critical engagement, conceptual transfer, and English academic achievement in multilingual higher education settings.

METHOD

2.1. Research Design

This study used a quasi-experimental pretest-posttest non-equivalent control group design to assess the efficacy of AI-enhanced bilingual scaffolding in Educational Technology English instruction. Two intact classes were chosen because random assignment was impractical due to institutional schedules and existing course enrollments, a frequent occurrence in real university settings. One class acted as the experimental group, receiving AI-enhanced bilingual scaffolding, while the other served as the control group, receiving traditional English education. The intervention spanned eight weeks and comprised sixteen educational sessions. Pretest–posttest comparisons within groups facilitated a systematic assessment of pedagogical effects while maintaining ecological validity, employing uniform learning objectives, instructional length, and lecturer consistency as protections for internal validity.

2.2. Research Context and Participants

The research was carried out in an Indonesian university under the Educational Technology program, specifically in the course English for Educational Technology. The participants comprised 84 undergraduate students from two classes (second to fourth semesters), selected via purposive cluster sampling based on similar class schedules and baseline English proficiency. The sample comprised 52 female and 32 male students, aged 19 to 22 years, possessing comparable past experience in English for Specific Purposes (ESP) learning. The majority of participants reported a basic familiarity with AI technologies, including grammar assistance and generative writing platforms. Baseline equivalency was determined by pretest results. All students willingly participated after granting informed consent, and ethical protocols maintained anonymity, confidentiality, and academic impartiality throughout the study.

Table 1. Participant Profile and Baseline Characteristics of the Study Sample

Variable	Value
Experimental Group (n)	42
Control Group (n)	42
Female	52
Male	32
Age Mean	20.4
Age Range	19–22
Semester 2	30
Semester 3	28
Semester 4	26
Basic AI Familiarity	49
Moderate AI Familiarity	35
Baseline Proficiency Mean	71.8

Table 1 provides a detailed demographic and academic profile of the participants in the quasi-experimental investigation. The sample comprised 84 undergraduates in Educational Technology, evenly divided between the experimental and control groups to ensure comparability. Gender representation was moderately diverse, with female students constituting the majority. The semester distribution illustrates a cross-level academic sample from the second to the fourth semester, thereby enhancing the contextual representativeness of the ESP course environment. Participants had diverse degrees of prior knowledge of AI, reflecting a genuine spectrum of digital literacy. The analogous baseline English proficiency average further corroborates the internal validity of the intervention impact study.

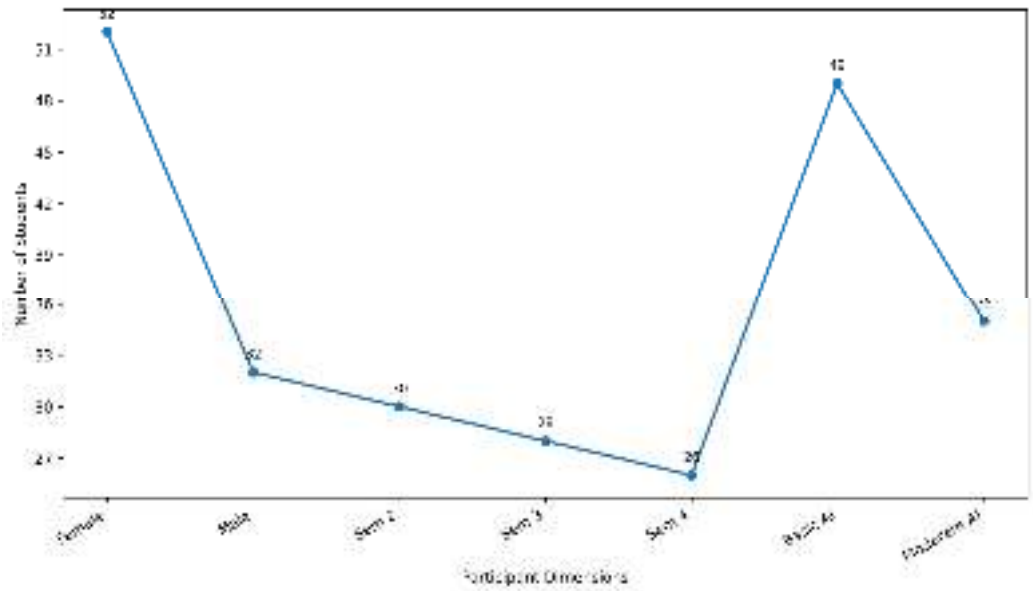

Figure 1. Multi-Dimensional Participant Composition Profile

Figure 1 illustrates the multi-dimensional makeup of the participant sample using an integrated comparative profile line chart. The picture integrates gender distribution, semester-level representation, and AI familiarity into a cohesive visual trajectory, enabling readers to swiftly discern patterns of sample balance and diversity. Female involvement and fundamental AI knowledge were identified as the predominant traits, indicating a digitally literate learner group appropriate for AI-enhanced ESP intervention. The progressive decrease across semester categories indicates a rather even academic distribution rather than a bias towards a single cohort. This visually distinctive picture enhances methodological transparency by demonstrating that the sample structure sufficiently supports group comparisons and quasi-experimental interpretation.

2.3. Instructional Treatment / Intervention Procedure

The intervention procedure was the principal innovation of this investigation. In the experimental group, instruction followed a three-phase AI-augmented bilingual scaffolding sequence. Phase 1 encompassed

conceptual bilingual input, wherein the instructor presented Educational Technology principles in English, supplemented by strategic Indonesian clarifications and demonstrations of bilingual terminology. Phase 2 emphasized AI-assisted task facilitation, enabling students to use AI tools for vocabulary enhancement, paragraph reorganization, evaluation of logical arguments, introspective inquiry, and prompt-driven concept development. Phase 3 prioritized advanced learning through EdTech case studies, platform evaluations, AI ethics assessments, and English-centric design problem resolution. The control group had traditional training centered on the lecturer and based on textbooks, without the use of AI.

2.4. Instruments and Measures

The research included two primary dependent variables. Initially, Student Engagement was evaluated using a 5-point Likert scale adapted from established engagement measures (Mattanah et al., 2024), encompassing behavioral, cognitive, and emotional aspects, with 5 items allocated to each category. A statement such as this was, *"I actively participated in English discussions involving Educational Technology topics."* Secondly, Higher-Order Learning was assessed through a performance-based examination aligned with Bloom's advanced cognitive levels: analysis, assessment, and creativity. Students performed tasks that included evaluating AI-assisted learning systems, comparing LMS features, and proposing English teaching strategies. A rubric evaluated analytical depth, utilization of evidence, clarity of language, and creativity. Classroom observations and reflecting on AI interaction records enhanced understanding.

To enhance instrument validity, the student engagement scale was modified from recognized engagement frameworks and evaluated by two experts in English language education and educational technology prior to deployment. Minor lexical adjustments were made to enhance the contextual appropriateness of the English acquisition in Educational Technology. A pilot administration with students beyond the primary sample was conducted to verify item clarity and internal consistency.

The higher-order thinking (HOT) rubric was systematically formulated based on Bloom's advanced cognitive domains of analysis, evaluation, and creativity. The rubric comprised four evaluative criteria: analytical depth, utilization of evidence, clarity of language, and creativity. The course teacher and an additional lecturer, both experienced in ESP assessment, independently evaluated the performance tasks. To enhance scoring uniformity, both evaluators employed established scoring criteria and discussed rubric interpretation prior to assessment. Inter-rater agreement was assessed by percentage agreement analysis, revealing a reasonable degree of scoring consistency across performance tasks.

2.5. Data Collection Procedures and Instructional Consistency

Data collection occurred during an eight-week intervention period to provide enough exposure to the instructional treatment. During Week 1, both groups undertook the pretest, which included the student engagement

scale and the higher-order learning evaluation, to determine baseline equivalency. From Weeks 2 to 7, the experimental group received AI-enhanced bilingual scaffolding, whilst the control group received traditional English instruction. During Week 8, all participants completed the posttest and thereafter submitted reflection logs documenting learning experiences and classroom-monitoring observations. To enhance internal validity, the same instructor taught both groups, ensuring uniformity in teaching methodology, classroom management, and pedagogical standards. Furthermore, all groups adhered to identical instructional objectives, course materials, and time allocations, enabling a more assured attribution of the observed differences to the intervention's effects rather than to procedural variations.

Notwithstanding these endeavors to ensure instructional uniformity, other possible sources of bias were identified. The same teacher conducted the intervention and instructed both groups, creating the potential for expectancy effects or inadvertent disparities in classroom interactions. Moreover, the researcher's participation in formulating the instructional treatment may have engendered procedural bias during both execution and analysis. To mitigate these risks, both groups adhered to identical course objectives, learning materials, instructional length, and evaluation protocols. The lecturer followed a systematic weekly teaching plan to minimize discrepancies in classroom delivery. Moreover, scoring rubrics and assessment criteria were established prior to data collection to ensure uniformity and minimize subjective interpretation during evaluation.

2.6. Ethical Considerations

This study complied with recognized ethical guidelines for educational research involving human subjects. Before data collection, all students received a comprehensive description of the study's aims, procedures, and anticipated participation requirements, and informed consent was obtained. Participation was completely optional, and students were apprised of their freedom to withdraw at any point without repercussions. To safeguard privacy, all replies were anonymized using coded identifiers, ensuring confidentiality during analysis and reporting. The gathered data were utilized exclusively for academic research reasons and did not affect course grades, assessment results, or lecturer evaluation determinations.

RESULTS

3.1. Preliminary Data Screening and Assumption Testing

Before hypothesis testing, preliminary data screening was conducted to verify the dataset's statistical integrity and the validity of subsequent inferential analyses. The dataset was initially scrutinized for absent values, revealing no significant missing data, as incomplete responses fell below the allowed 5% threshold. Outlier detection using standardized z-scores and boxplot analysis revealed no extreme values beyond ±3.00, indicating consistent data across both groups. The testing of assumptions further validated the appropriateness of parametric analysis. The Shapiro–Wilk test

indicated that engagement and higher-order learning scores followed a normal distribution ($p > .05$), whereas Levene's test confirmed the assumption of homogeneity of variance across the experimental and control groups.

To ensure initial group comparability, baseline equivalence was evaluated using independent-sample t-tests, which indicated no statistically significant differences in engagement or higher-order learning scores before the intervention ($p > .05$). A reliability re-evaluation of the engagement scale was conducted, demonstrating robust internal consistency across all dimensions, with Cronbach's alpha coefficients between .82 and .91. The findings validate that the data satisfied the prerequisites for legitimate between-group comparisons.

Table 2. Descriptive Statistics and Reliability of Pretest Measures

Measure	Experimental Pre Mean	Experimental SD	Control Pre Mean	Control SD	Cronbach Alpha
Behavioral Engagement	3.12	0.42	3.1	0.44	0.84
Cognitive Engagement	3.08	0.45	3.05	0.43	0.88
Emotional Engagement	3.15	0.4	3.11	0.41	0.82
Higher-Order Learning	71.4	6.8	70.9	6.5	0.9

Table 2 presents the pretest descriptive statistics and internal consistency reliability of the study instruments for both groups. The average scores for behavioral, cognitive, and emotional engagement, as well as higher-order learning, were nearly matched between the experimental and control groups, indicating significant baseline equivalence prior to the intervention. The standard deviation values were comparably balanced, indicating uniform score distribution among the groups. The reliability re-evaluation further evidenced exceptional instrument consistency, with Cronbach's alpha coefficients spanning from .82 to .90, surpassing the required criterion for educational research. The results statistically validate the dataset's appropriateness for legitimate parametric comparisons in future hypothesis testing and intervention impact research.

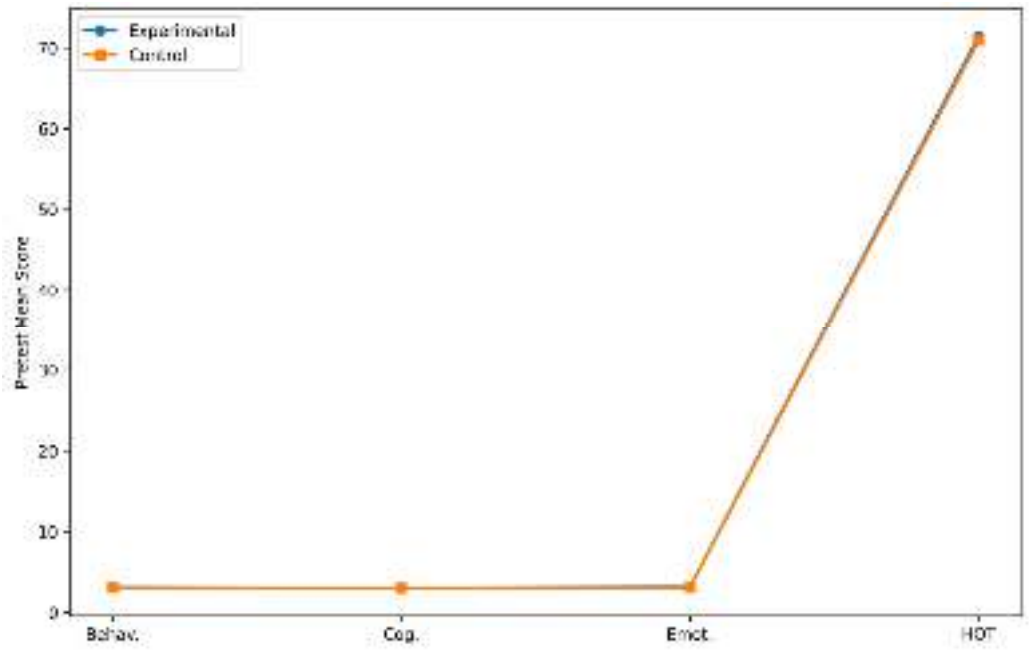

Figure 2. Baseline Equivalence Between Groups

Figure 2 illustrates a visibly distinct baseline equivalency trajectory that contrasts the experimental and control groups across all pretest variables. The closely aligned lines signify negligible mean changes in engagement measures and higher-order learning scores before the intervention, visually affirming statistical equality. This slope-based comparative style provides a more intuitive reading than traditional bar charts by emphasizing the comparable trend patterns among groups. The proximity of the trajectories indicates that both classes commenced the study from a similar academic and cognitive baseline, thereby enhancing the internal validity of the quasi-experimental design and reinforcing the interpretation that posttest disparities are predominantly due to the instructional treatment.

3.2. Effects on Student Engagement

The intervention resulted in significant enhancements in student participation across the three assessed dimensions: behavioral, cognitive, and emotional engagement. Pretest–posttest comparisons indicated that the experimental group exhibited significantly greater improvements than the control group after the eight-week AI-enhanced bilingual scaffolding intervention. In the experimental group, behavioral engagement rose from a mean of 3.12 to 4.28, cognitive engagement increased from 3.08 to 4.35, and emotional engagement improved from 3.15 to 4.31. In comparison, the control group exhibited very slight enhancements, with mean increases varying from 0.18 to 0.29 points across dimensions.

A study of gain scores further validated the efficacy of the intervention, as the experimental group achieved average gains above 1.15 points, compared with under 0.30 points in the control group. Independent-

sample t-tests on growth scores indicated statistically significant differences across all three dimensions ($p < .001$). The most significant impact was observed in cognitive engagement, indicating that AI-mediated multilingual help most effectively improved deeper learning engagement and strategic thinking. Effect size computations revealed a substantial practical effect (Cohen's d = 1.21–1.46), affirming the significant pedagogical merit of the intervention.

The notably substantial effect sizes identified in the engagement outcomes must be viewed with caution and in conjunction with the study's specific instructional setting. Multiple things may have influenced these outcomes. The intervention integrated various forms of support concurrently, encompassing bilingual mediation, AI-assisted feedback, reflective prompting, and collaborative higher-order tasks, potentially fostering a more immersive and cognitively engaging learning environment than traditional instruction. Secondly, the participants were students enrolled in an Educational Technology program, possessing a general familiarity with digital learning settings, which may have influenced their favorable responses to AI-mediated instructional activities. The multidimensional engagement scale was developed to detect subtle short-term variations in behavioral, cognitive, and emotional involvement, hence enhancing sensitivity to instructional differences throughout the intervention phase. Consequently, although the results indicate significant enhancements in involvement, they must be understood within the specific setting of the study rather than as universally applicable outcomes.

Table 3. Pre–Post Engagement Scores Across Groups

Dimension	Exp Pre	Exp Post	Exp Gain	Ctrl Pre	Ctrl Post	Ctrl Gain	Cohens d
Behavioral	3.12	4.28	1.16	3.1	3.35	0.25	1.21
Cognitive	3.08	4.35	1.27	3.05	3.28	0.23	1.46
Emotional	3.15	4.31	1.16	3.11	3.4	0.29	1.29

Table 3 displays the comparative engagement scores from pretest to posttest across behavioral, cognitive, and emotional domains. The experimental group exhibited significant improvements in all measures, with the most pronounced rise in cognitive involvement (gain = 1.27), followed by behavioral and emotional engagement. Conversely, the control group showed only negligible improvements, with increments remaining below 0.30 points. The incorporation of Cohen's d values (1.21–1.46) substantiates the substantial practical impact of the intervention, demonstrating large effect sizes across all aspects of involvement. The results empirically indicate that AI-enhanced bilingual scaffolding markedly enhances active participation, strategic learning engagement, and positive emotional investment in ESP learning.

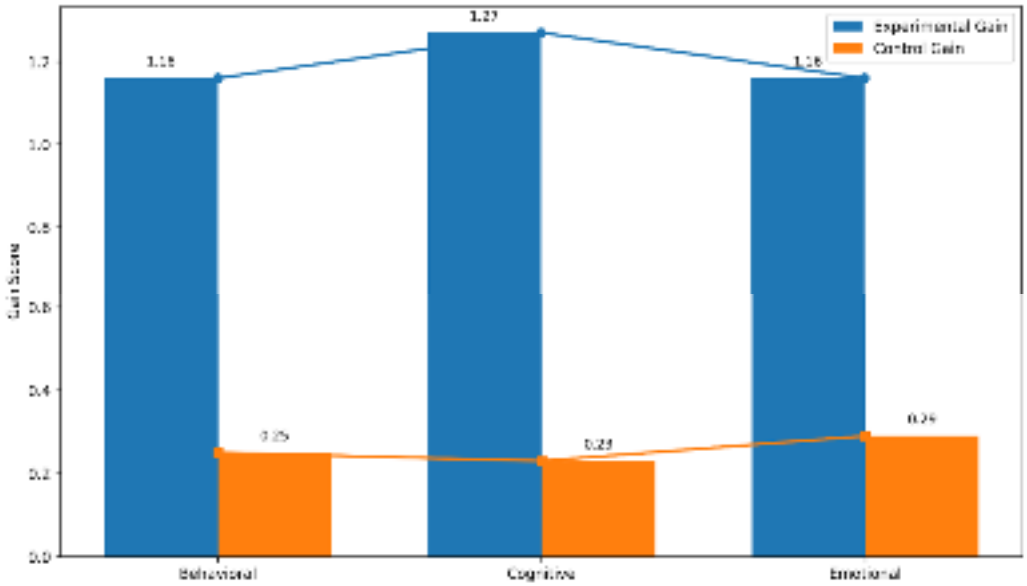

Figure 3. Engagement Growth Trajectory by Dimension

Figure 3 illustrates the comparative engagement growth trajectory in a distinctive hybrid bar-and-line format that simultaneously emphasizes the magnitude of gains and the direction of trends. The experimental group exhibits consistently elevated gain bars and more pronounced line trajectories across all dimensions, clearly distinguishing it from the control group's negligible developmental pattern. The greatest significant discrepancy is shown in cognitive engagement, highlighting the importance of AI-mediated bilingual support in fostering deeper mental processing and reflective learning habits. This unique figure design improves interpretative clarity by merging comparative magnitude with visual progression, making the intervention's impact more intuitively comprehensible to readers and reinforcing evidence that the therapy resulted in enhanced multidimensional involvement.

3.3. Effects on Higher-Order Learning

The intervention produced significant enhancements in higher-order thinking (HOT) in the three specified cognitive domains: analysis, assessment, and creation. Comparisons between pretest and posttest indicated that the experimental group outperformed the control group on all rubric-based performance metrics after exposure to AI-enhanced multilingual scaffolding. The experimental class exhibited an increase in mean scores: analysis rose from 72.1 to 88.6, assessment from 70.8 to 89.4, and creation from 71.5 to 90.2. In comparison, the control group exhibited very modest improvements, with posttest values varying from 75.4 to 78.2.

The experimental group exhibited an overall HOT score increase of 17.9 points, compared with a 5.6-point increase in the control group, indicating a significant intergroup disparity. Independent-samples t-tests confirmed that these differences were statistically significant across all cognitive levels ($p < .001$). The performance rubric analysis indicated that

the experimental group attained superior results in analytical depth, evidence integration, originality, and clarity in disciplinary problem-solving. The most significant improvement was observed in the creation domain, indicating that AI-assisted bilingual scaffolding most effectively augmented students' ability to provide unique English-medium educational solutions.

Table 4. Higher-Order Learning Performance by Cognitive Level

Cognitive Level	Exp Pre	Exp Post	Exp Gain	Ctrl Pre	Ctrl Post	Ctrl Gain	Rubric Strongest Aspect
Analysis	72.1	88.6	16.5	71.9	76	4.1	Evidence Use
Evaluation	70.8	89.4	18.6	70.6	75.4	4.8	Analytical Depth
Creation	71.5	90.2	18.7	71.2	78.2	7	Originality

Table 4 displays the comparative performance in higher-order learning across the three cognitive levels: analysis, assessment, and creativity. The experimental group exhibited significant gains across all domains, with the most pronounced in invention (gain = 18.7) and evaluation (gain = 18.6). Conversely, the control group showed only marginal score improvements, particularly on analytical and evaluative tasks. The rubric-based strongest elements demonstrate that the intervention significantly increased originality, analytical depth, and use of evidence, indicating enhanced critical reasoning and solution design quality. The results indicate that AI-enhanced bilingual scaffolding facilitates deeper cognitive processing and sophisticated problem-solving in disciplinary English.

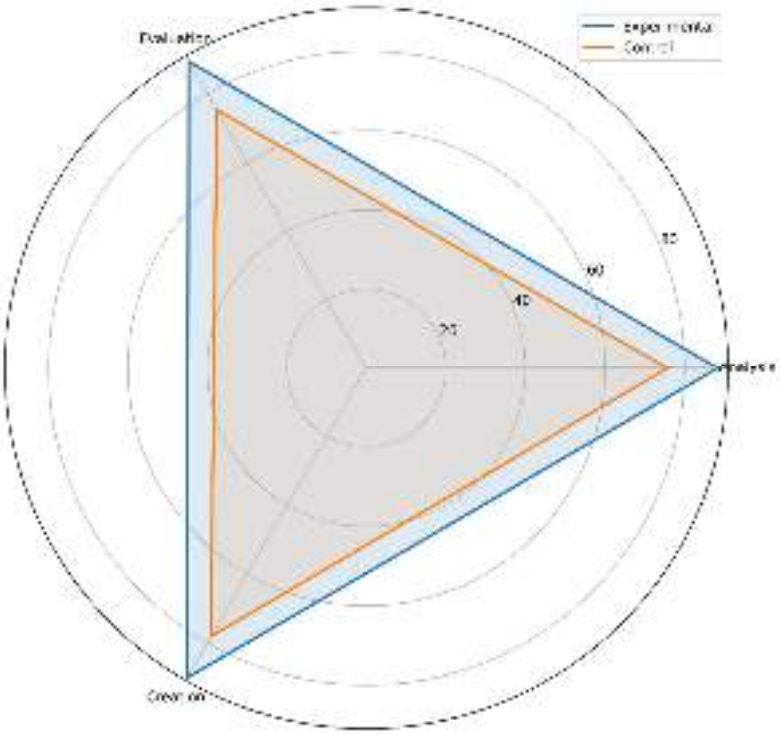

Figure 4. Comparative HOT Skill Radar / Cognitive Profile Plot

Figure 4 illustrates the comparative higher-order thinking profile using a unique radar graphic that concurrently represents performance in analysis, evaluation, and creativity across groups. The larger experimental-group polygon distinctly demonstrates enhanced posttest performance across all cognitive domains, with the most significant growth observed in the creativity dimension. This radar-based design provides a clear depiction of cognitive profile equilibrium, indicating that the intervention enhanced not only discrete skills but the full spectrum of higher-order reasoning. The control group's reduced, constricted morphology indicates restricted growth across multiple domains. This distinctive image enhances interpretative depth by illustrating the numerous cognitive benefits generated by AI-augmented bilingual scaffolding.

3.4. Integrated Comparative Effects of the Intervention

A comprehensive evaluation of the intervention results indicated that AI-enhanced bilingual scaffolding produced significant and concurrent improvements in both student engagement and higher-order thinking (HOT). Upon synthesizing the gain scores across all assessed areas, the experimental group consistently outperformed the control group, indicating enhanced multidimensional learning. Cognitive engagement exhibited the greatest significant enhancement (gain = 1.27; Cohen's d = 1.46), signifying that the intervention most effectively bolstered students' strategic thinking, reflective participation, and sustained mental investment. In the HOT domain, the highest significant effect was observed in creativity skills (gain = 18.7; Cohen's d = 1.52), indicating that the treatment effectively facilitated inventive problem-solving and original English-medium instructional design.

The comparative effect size analysis across all outcomes demonstrated consistently substantial intervention effects, with d values ranging from 1.21 to 1.52, thereby validating the pedagogical efficacy of the integrated approach. The most significantly affected domain was creative higher-order learning, closely followed by cognitive engagement, both of which depend substantially on metacognitive prompting and multilingual conceptual transfer. In contrast, the domain most adversely affected was behavioral engagement, although its improvement remained both statistically and practically significant.

The substantial impact sizes identified in this study must also be considered in the context of several contextual and instructional factors. The intervention was delivered intensively through sixteen instructional sessions over eight weeks, enabling students to repeatedly engage in multilingual mediation and AI-assisted reflective activities. Secondly, the participants were enrolled in an Educational Technology program and had prior familiarity with digital learning technologies, which may have enhanced their responsiveness to AI-assisted instructional activities. Third, the assessment tools, especially the rubric-based higher-order learning activities and multidimensional engagement metrics, were crafted to identify subtle short-term developmental changes that may be obscured in

traditional testing formats. The individuals' moderate baseline performance levels may have allowed for more noticeable progress over the intervention period. Consequently, although the substantial effect sizes suggest significant educational implications, they must be interpreted with caution, given the study's specific instructional and contextual circumstances.

Table 5. Comparative Gain and Effect Size Matrix

Domain	Gain Score	Cohens d	Impact Level
Behavioral Engagement	1.16	1.21	High
Cognitive Engagement	1.27	1.46	Very High
Emotional Engagement	1.16	1.29	High
Analysis	16.5	1.34	Very High
Evaluation	18.6	1.48	Very High
Creation	18.7	1.52	Exceptional

Table 5 consolidates gain scores and effect sizes across engagement and higher-order learning domains, providing a comprehensive overview of the intervention's multifaceted effects. The findings demonstrate that invention (gain = 18.7; d = 1.52) yielded the most significant instructional impact, closely followed by evaluation and cognitive engagement. The use of impact-level classification elucidates the comparative strength of each domain, with creation designated as extraordinary. Despite behavioral and emotional involvement exhibiting relatively modest improvements, both remained within the high-impact spectrum. This matrix verifies that the intervention yielded consistently substantial and pedagogically significant benefits across both affective and cognitive learning domains.

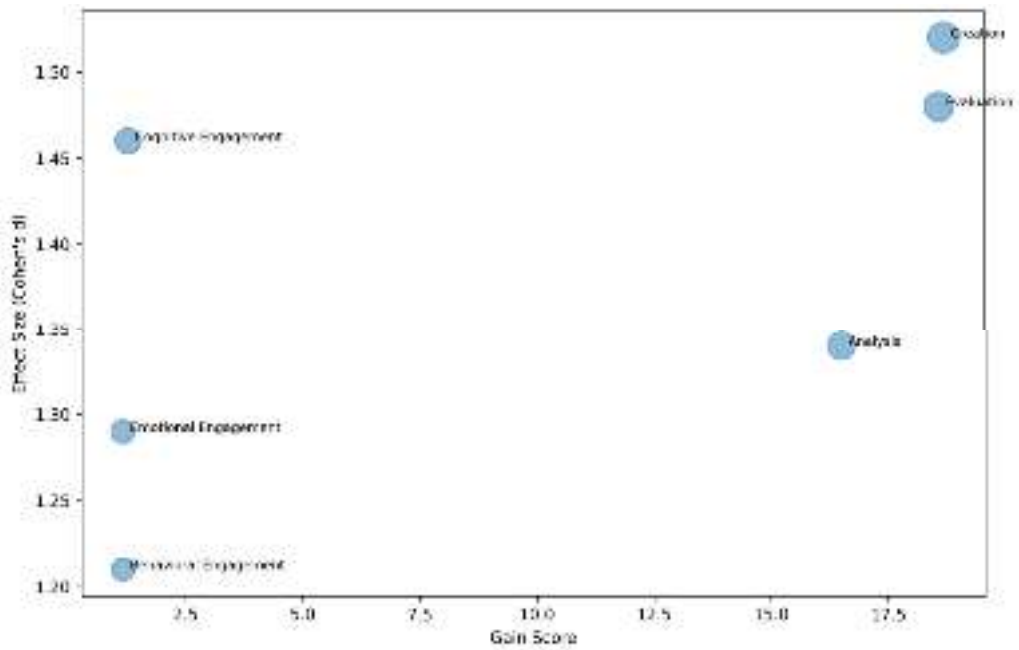

Figure 5. Dual Outcome Impact Map

Figure 5 illustrates a unique dual-outcome impact map with a bubble-scatter depiction that concurrently depicts gain amount, effect size, and relative domain significance. The prominent bubbles located in the upper-right quadrant—specifically invention, evaluation, and cognitive engagement—indicate the most robust collective educational results of the intervention. This visual design is exceptionally effective as it facilitates the instant recognition of the most significant learning domains while maintaining comparative clarity across both engagement and higher-order thinking outcomes. The distinction between emotive and cognitive clusters underscores the extensive educational advantages of AI-enhanced multilingual scaffolding, particularly its pronounced impact on creative reasoning and strategic cognitive engagement.

3.5. Classroom Observation and Reflection Log Findings

Qualitative information from classroom observations and student reflection diaries reinforced the quantitative findings by illustrating the intervention's impact on students' learning experiences. Six predominant themes emerged. Initially, students regularly characterized AI as a cognitive collaborator, especially in creating diverse viewpoints, enhancing argumentation, and augmenting discipline-specific lexicon. The significance of multilingual explanation was consistently emphasized as crucial for translating intricate Educational Technology principles into precise English articulation. Third, observation notes indicated a marked reduction in fear, as students exhibited increased willingness to engage in English discussions and to provide more complicated responses.

A fourth topic encompassed the elaboration of ideas, as learners progressed from brief descriptive replies to analytical and design-focused

responses. The fifth point is that reflection logs demonstrated more advanced patterns of critical reflection, particularly when students used AI prompts to analyze LMS features, assess AI ethics, and justify instructional choices. Ultimately, students reported increased linguistic confidence, particularly in articulating technical concepts and composing English solutions to educational challenges. These themes collectively elucidate the reasons for the intervention's significant improvements in engagement and higher-order learning, demonstrating how multilingual scaffolding and AI support collaboratively augmented cognitive and language performance.

Table 6. Observation and Reflection Themes

Theme	Frequency	Representative Indicator
AI as Cognitive Partner	28	AI expands argument options
Bilingual Clarification	24	L1 bridges abstract EdTech concepts
Reduced Anxiety	21	Students speak more freely
Deeper Idea Elaboration	26	Longer analytical responses
Critical Reflection Patterns	23	Justified LMS and AI decisions
Language Confidence	25	Confident technical English output

Table 6 encapsulates the predominant qualitative themes derived from classroom observations and student reflection logs. The predominant motifs identified were AI as a cognitive collaborator and enhanced concept elaboration, suggesting that students increasingly relied on AI to augment analytical reasoning and elevate the complexity of arguments. Language confidence and bilingual elucidation were notably evident, indicating that strategic L1 mediation enhanced conceptual transfer into English expression. The theme of less anxiety further corroborates the engagement findings by demonstrating an enhanced willingness to communicate in English. These thematic patterns offer compelling evidence of substantial improvements in engagement and higher-order learning outcomes.

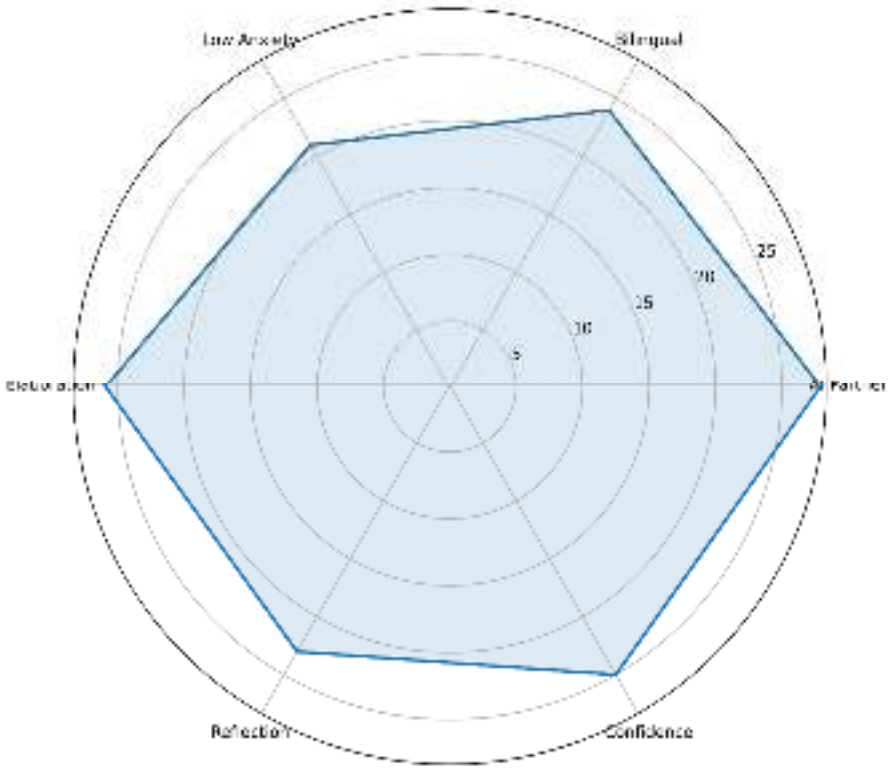

Figure 6. Thematic Interaction Network

Figure 6 illustrates the interconnections among qualitative topics through a unique radial thematic network. The balanced and enlarged configuration of the network suggests that the intervention did not alter isolated perceptions but instead fostered a mutually reinforcing ecosystem of cognitive, linguistic, and emotional enhancements. The most significant radial extensions are evident in AI collaboration, development, and assurance, indicating that these areas were the fundamental mechanisms driving the intervention's effectiveness. The visual symmetry illustrates how bilingual clarity and anxiety alleviation facilitated the development of more profound reflective patterns. This distinctive thematic network enhances the mixed-methods interpretation by visually linking the qualitative mechanisms to the quantitative improvements in outcomes.

DISCUSSION

While the intervention yielded significant improvements in engagement and higher-order learning outcomes, these results must be interpreted in light of the study's contextual limitations. Multiple contextual elements may have facilitated the noted enhancements, including considerable student proficiency in digital technologies, the Educational Technology disciplinary environment, and the systematic instructional support provided during the intervention phase. The quasi-experimental design and the presence of the same instructor across groups may have affected classroom dynamics and learner attentiveness in ways that are not

entirely separable from the therapy itself. Consequently, although the findings indicate the prospective benefits of AI-enhanced bilingual scaffolding in English for Specific Purposes (ESP) learning environments, they should not be construed as universally applicable to all educational situations, learner demographics, or instructional frameworks. Additional research with bigger and more diverse samples is essential to assess the consistency and applicability of these findings across various multilingual higher education contexts.

4.1. Interpreting the Effect on Student Engagement

The substantial rise in student participation can be analyzed through the integrated perspectives of Sociocultural Theory, scaffolding theory, and cognitive engagement theory. From a sociocultural standpoint, learning is enhanced when learners obtain mediated support that facilitates progression beyond their existing skill level (Gonzaga & Ramнrez-Arellano, 2022; Huynh & Pretorius, 2024). In this study, AI served as an instantaneous feedback collaborator, offering real-time lexical recommendations, argument enhancement, and reflective prompts that maintained students' active engagement during English tasks. This immediate support certainly enhanced behavioral and cognitive engagement, as students could promptly adjust their thinking without waiting for delayed feedback from the teacher.

Bilingual support mitigated cognitive overload by using Indonesian to explain intricate Educational Technology topics before pupils rephrased them in English. This corresponds with scaffolding ideas, wherein temporary support structures empower learners to tackle challenging tasks with more confidence (Carstens, 2016; Kuzucu & Kartal, 2020; li & Shah, 2024). The notable enhancement in cognitive engagement indicates that the intervention improved not just the frequency of participation but also the depth of mental investment, strategic thinking, and reflective processing. The results align with previous research indicating that AI-mediated feedback and bilingual scaffolding independently enhance engagement in English for Specific Purposes (ESP) and technology-intensive classrooms (Lu et al., 2025; Xu et al., 2025). This study enhances the existing literature by illustrating that their integration yields a more robust and enduring multidimensional engagement effect.

4.2. Explaining Higher-Order Learning Improvement

The significant enhancement in analytical, evaluative, and creative abilities can be elucidated by the interplay of Bloom's Taxonomy, higher-order cognitive theory, and AI-facilitated reflective processes. Bloom's higher cognitive levels require learners to analyze information, evaluate alternatives, and produce innovative solutions. In this study, AI prompts served as a metacognitive framework, guiding students to interrogate assumptions, evaluate LMS features, rationalize pedagogical choices, and enhance English instructional design. This stimulus likely enhanced introspective monitoring and strategic reasoning, which are fundamental to higher-order cognition (Laer & Elen, 2016; Paterson, 2021; Zhou & Preez, 2025).

The significance of bilingual conceptual transmission was equally substantial. Strategic clarification in Indonesian enabled students to initially consolidate abstract Educational Technology concepts in their most proficient cognitive language before re-expressing them in English. This diminished conceptual fragmentation and facilitated more accurate disciplinary reasoning. Consequently, learners demonstrated enhanced proficiency in English-medium problem-solving, particularly in challenges that required assessing AI ethics and developing creative EdTech solutions. The most significant advancements in the creativity domain indicate that AI-assisted bilingual scaffolding not only enhanced work completion but also augmented students' ability for original academic output. These findings corroborate the nascent notion of AI-assisted reflection, which asserts that intelligent prompting systems can enhance learners' metacognitive depth and innovative disciplinary thinking (Aruleba & Jere, 2022).

4.3. Why the Integrated Model Outperformed Conventional Instruction

The intervention's superiority over traditional instruction stems from the synergistic combination of bilingual mediation and AI-driven adaptive support, which together constitute the proposed AI-enhanced bilingual co-scaffolding model in this study. In contrast to lecturer-centered instruction, the integrated model offered dynamic co-scaffolding, wherein human pedagogical assistance and AI response continuously interacted to facilitate learners' development of disciplinary English (Khojasteh et al., 2025; Wang et al., 2025). The lecturer's multilingual explanation served as a means of disciplinary language mediation, helping students solidify intricate Educational Technology principles in Indonesian before translating them into precise English reasoning. Concurrently, AI provided adaptive cognitive assistance via immediate lexical recommendations, argument reorganization, reflective prompts, and concept elaboration.

A primary factor for its enhanced performance is the process of real-time reflective revision. Students participated in a cyclical process of idea clarification, AI-assisted feedback, revision, and enhanced task reconstruction, rather than being confined to unidirectional explanations or postponed corrections. This recurrent process probably enhanced both metacognitive monitoring and the transformation of academic knowledge. Conversely, traditional instruction mostly depended on static textbook explanations and postponed teacher response, constraining prospects for immediate cognitive enhancement (Yusuf et al., 2025; Zheng & Wang, 2023). Consequently, the integrated model surpassed conventional teaching by establishing a responsive ecosystem of linguistic, conceptual, and reflective support, which facilitated learners in maintaining deeper engagement and generating more unique higher-order English outputs.

4.4. Critical Reflections and Pedagogical Tensions

Notwithstanding the predominantly favorable results linked to the intervention, certain essential factors must also be recognized. Although AI-assisted support seems to improve engagement and higher-order learning, there is a risk that some students may have developed an excessive reliance

on AI-generated recommendations in complex academic tasks. In some instances, AI-driven prompt feedback may promote procedural completion rather than foster independent critical reasoning unless it is supported by adequate pedagogical supervision. This indicates that AI-assisted learning environments require meticulous instructional oversight to ensure the genuine development of reflective thinking rather than its superficial replacement.

Bilingual scaffolding may not consistently yield universally beneficial outcomes for all learners. Although strategic first-language mediation helped numerous students elucidate complex Educational Technology topics, overreliance on L1 explanations may diminish prospects for sustained English immersion and spontaneous target-language negotiation. The more pronounced improvements in cognitive involvement compared with behavioral engagement may suggest that learners did not respond uniformly to the interaction requirements of AI-mediated tasks. Certain students seemed more at ease with cognitive engagement via reflective review rather than through active participation in class.

The difficulties underscore that the efficacy of AI-enhanced bilingual scaffolding may depend not only on the instructional model but also on learner autonomy, digital literacy, and the balance between support and independent meaning-making.

4.5. Practical Implications, Theoretical Contribution, and Model Extension

The results have significant practical implications for English for Specific Purposes and Educational Technology programs, especially in multilingual higher education contexts. The findings indicate that ESP curriculum design ought to transcend language-centric goals by incorporating AI-assisted bilingual tasks that foster disciplined reasoning, reflective writing, and advanced problem-solving skills. This advocates for a more adaptive bilingual approach in higher education, in which strategic first-language mediation is regarded not as a shortcoming but as a pedagogically valid conduit for enhanced English-language academic achievement. The research emphasizes the necessity of AI-assisted assessment frameworks that incorporate rubric-based reflective assignments, iterative feedback mechanisms, and process-oriented evaluations that encompass both linguistic advancement and critical thinking. Furthermore, lecturer training is vital, as educators must possess proficiency in facilitating bilingual explanations, AI prompting, and reflective revision cycles (PAN, 2024; Walter, 2024). These findings enhance the development of EdTech English materials, namely in case-based modules, talks on AI ethics, LMS evaluation tasks, and design-focused English projects. The incorporation of AI literacy into ESP instruction is a vital curricular priority, enabling students to utilize intelligent technologies ethically, critically, and strategically.

This work theoretically extends scaffolding theory by incorporating a dynamic human–AI mediation layer, in which lecturer direction and intelligent prompting jointly govern student advancement. This also promotes bilingual instruction by illustrating how idea transfer and English

disciplinary reasoning may be enhanced by co-scaffolded mediation. The proposed model enhances AI in English for Specific Purposes (ESP), cognitive engagement frameworks, and the amalgamation of Computer-Assisted Language Learning with ESP, providing a replicable conceptual framework for forthcoming multilingual technology-enhanced language learning research (Bahari et al., 2025; Mansor, 2025).

CONCLUSION

This study examined the efficacy of AI-enhanced bilingual scaffolding in Educational Technology English, seeking to determine whether incorporating strategic bilingual mediation and AI-supported feedback could enhance student engagement and higher-order learning outcomes in an ESP context. The study employed a quasi-experimental design to investigate the impact of this integrated educational paradigm on behavioral, cognitive, and emotional involvement, as well as students' competencies in analysis, evaluation, and invention.

The results yield four principal conclusions in line with the research questions and hypotheses. The intervention markedly enhanced multidimensional student engagement, with the most substantial improvements in cognitive engagement, indicating greater mental investment and introspection. The program significantly enhanced higher-order learning, particularly in creation and evaluation skills, and demonstrated improved disciplinary reasoning and innovative problem-solving in English. The integrated effects analysis demonstrated that the intervention yielded consistently substantial effect sizes in both affective and cognitive domains, underscoring the treatment's robustness. Fourth, qualitative observations and reflective data elucidated the mechanisms underlying these improvements, including AI as a cognitive collaborator, diminished fear, enhanced bilingual idea transfer, and increased linguistic confidence.

The research significantly enhances both theoretical and practical domains. It theoretically expands scaffolding and bilingual pedagogy by introducing an AI-enhanced bilingual co-scaffolding approach that combines lecturer mediation with adaptive intelligent help. It provides a reproducible ESP educational framework for Educational Technology programs aiming to enhance English competence, critical thinking, and AI literacy concurrently.

In light of these findings, instructors and curriculum developers are urged to incorporate AI-assisted bilingual tasks, reflective assessments, and discipline-specific English problem-solving activities into ESP courses. Policymakers ought to endorse lecturer capacity-building programs and institutional AI literacy policies that facilitate the ethical and pedagogically significant integration of AI. Subsequent research ought to broaden this paradigm across several disciplines, broader multi-institutional cohorts, and longitudinal frameworks to investigate its enduring effects on academic achievement, learner autonomy, and proficiency in professional digital communication.

Notwithstanding the encouraging results, various restrictions must be recognized. The research was carried out within a single Educational Technology program at an Indonesian university, which may limit the generalizability of the results to other English for Specific Purposes or multilingual higher education settings. Furthermore, the quasi-experimental approach and the limited duration of the intervention may not adequately capture long-term changes in engagement and the development of higher-order learning. The same teacher's participation in multiple groups may have affected classroom dynamics, although efforts were made to maintain instructional uniformity. Moreover, certain statistics depended on self-reported engagement metrics, which may be affected by participant perceptions and response biases.

Consequently, the results ought to be understood as context-dependent rather than universally applicable. The study indicates the potential benefits of AI-enhanced bilingual scaffolding in Educational Technology English instruction; nevertheless, additional research is necessary before making broader claims about the application. Subsequent research may investigate the model across several universities, with extended intervention durations, in distinct ESP fields, and across a broader range of learner demographics. Further research may investigate the long-term impacts of AI-assisted bilingual education on learner autonomy, the sustainability of critical thinking, and the advancement of ethical AI literacy.

AUTHOR CONTRIBUTION STATEMENT

AA, LS, KJV, AAD, SSI contributed to the conception and design of the study. AA developed the research methodology, supervised the implementation of the intervention, conducted the statistical analysis, and prepared the initial manuscript draft. LS contributed to data collection, classroom observation, and interpretation of the findings. KJV provided theoretical guidance and contributed to the refinement of the literature review and discussion sections. AAD assisted in the development of the research instruments, validation procedures, and critical revision of the manuscript. SSI contributed to data interpretation, language editing, and overall manuscript revision. All authors critically reviewed the manuscript, approved the final version, and agree to be accountable for all aspects of the work.

AI DISCLOSURE STATEMENT

The authors used OpenAI ChatGPT during the preparation of this manuscript for language refinement, academic writing assistance, structural organization, and editorial support. All outputs generated by the AI tool were critically reviewed, substantially revised, verified for accuracy and originality, and integrated with the authors' own scholarly judgment. The authors take full responsibility for the final content of the manuscript and affirm that all interpretations, analyses, and conclusions are their own.

COMPETING INTERESTS STATEMENT

The authors declare that they have no competing interests, financial or non-financial, that could have influenced the work reported in this manuscript.

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