Empowering Critical Thinking in EFL Learners' Writing Through AIGC: A Model Based on the "Questioning-Dialectic-Reconstruction" Cyclical Framework

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ABSTRACT The rise of generative artificial intelligence presents unprecedented challenges and opportunities for EFL learners' writing instruction, especially when students are required to express technical concepts, experimental processes, and research arguments in advanced engineering fields such as electromagnetic waves, antennas, propagation, and radiofrequency systems. This technological shift enables students to organize engineering information with professional linguistic structures more effectively, fostering the specialized communicative competence required in academic and technical writing contexts. Traditional teaching models centered on language correction and model essay imitation have seen their efficacy diminish in the face of AIGC, potentially fostering intellectual passivity in students. This study aims to construct an AIGC-enabled teaching model for EFL learners' writing, centered on a "Questioning-Dialectic- Reconstructing" cycle. This model positions AIGC as a "thinking partner" and "dialectical opponent", systematically integrating it into the pre-writing, drafting, and revision stages of the writing process. It guides students in transforming from passive content consumers into active and discerning knowledge constructors. The paper elaborates on the theoretical foundation, three-stage operational procedure, and supportive assessment system of the model, demonstrating its application through concrete instructional cases involving engineering-oriented writing tasks. The goal is to provide a theoretical model and practical guidelines for transforming writing pedagogy toward critical thinking in the AIGC era.

INDEX TERMS aigc, EFL learners' writing, critical thinking, teaching model, engineering discourse

I. INTRODUCTION

THE proliferation of Generative AI technologies like ChatGPT, DeepSeek, and Ernie Bot has brought English as a Foreign Language (EFL) learners' writing instruction to a historic crossroads. On one hand, students can effortlessly use AIGC to produce grammatically correct essays regarding engineering processes and technical systems, rendering traditional teaching methods focused on basic model emulation largely ineffective.

This accessibility shifts the instructional focus toward verifying the technical accuracy of engineering terminology and the logical depth of technical analysis in student writing. On the other hand, this technological convenience harbors a deeper crisis: if students merely settle for AIGC's output without engaging in independent thinking and creation, the cultivation of their critical thinking, logical reasoning, and creative expression abilities faces severe threat. Such intellectual passivity may not constitute an inherent consequence of AIGC itself, but rather could demonstrate that the observed phenomenon appears to emerge from unstructured or uncritical use patterns. When embedded within carefully designed pedagogical frameworks, AIGC can shift from merely functioning as a tool for cognitive outsourcing to becoming a catalyst for active inquiry. Through systematic questioning and evaluation of AI-generated responses, students are required to justify claims and examine alternative perspectives, thereby transforming the technological application into a mechanism that stimulates deeper cognitive engagement.

However, simply viewing AIGC as a menace and prohibiting it is not a wise strategy. A more proactive approach is to explore how this disruptive technology can be transformed into a catalyst for pedagogical innovation. Writing, by its very nature, is the externalization and materialization of

thought, making it an ideal pathway for cultivating critical thinking. Accordingly, the central research question is: How can AIGC be organically integrated into EFL learners' writing instruction so that it becomes an enabler, rather than a substitute, for critical thinking?

To address this question, this study constructs a cyclical teaching model—"Questioning-Dialectic-Reconstructing" ("Q-D-R"), based on constructivism and the process writing approach. This model aims, through a carefully designed instructional procedure, to guide students in questioning and evaluating AI-generated content regarding engineering material properties and advanced manufacturing techniques, thereby systematically forging their critical thinking skills while enhancing their English writing proficiency. By engaging in a continuous dialogue with AIGC about the complexities of engineering systems, learners refine their ability to articulate professional insights and create high-quality technical discourse relevant to the advanced engineering fields.

II. RESEARCH BACKGROUND

A. AIGC-EMPOWERED EFL LEARNERS' WRITING INSTRUCTION: A PARADIGM SHIFT FROM TOOL TO ECOSYSTEM

With the rapid advancement of generative artificial intelligence, AIGC is being integrated into the educational field with unprecedented depth and breadth. In the specific context of EFL learners' writing instruction, its empowering pathways and research foci are mainly reflected in the following three levels.

1) As a High-Efficiency Tool: Enhancing Writing Efficiency and Personalized Feedback

Early and much current research positions AIGC as a powerful auxiliary tool. Researchers generally agree that AIGC can instantly generate writing examples, provide multi-angle writing inspiration, and assist with language polishing and grammar correction [1], thereby significantly reducing students' cognitive load [2] and allowing them to shift attention from basic language encoding to higher-level text structure and idea expression [3]. In the feedback stage, AIGC can provide 24/7, highly personalized formative assessment, compensating for the lag and limited coverage of teacher feedback in traditional large-class teaching [4,5]. However, this tool perspective also raises concerns, such as students potentially becoming over-reliant on AIGC, leading to intellectual laziness, or even directly submitting generated content as their own, raising issues of academic integrity [6,7].

2) As an Interactive Collaborator: Reconstructing the Writing Teaching Process

Further research begins to view AIGC as an intelligent collaborator in the teaching process. It is no longer a one-way output tool but a partner that can engage in multiple rounds of dialogue with students and guide their deeper thinking. For instance, students can ask questions and follow-ups, requiring AIGC to provide arguments for and against a specific point, or examine the same topic from different cultural perspectives. This interactive model transforms writing from a solitary product-output activity into a dynamic, inquiry-based dialogic process [8]. From this perspective, the core of instructional design shifts from focusing on how to use the tool to designing effective human-AI dialogue tasks that stimulate students' deep cognitive activities [9].

3) As a Builder of a New Teaching Ecosystem: Opportunities and Challenges

Macro-level research points out that the integration of AIGC is reshaping the entire ecosystem of English writing teaching. It challenges traditional teacher roles, assessment methods, and course objectives. Teachers need to transition from being authoritative transmitters of knowledge to designers of learning tasks, guides for human-AI collaboration, and cultivators of critical thinking [10]. Simultaneously, the black-box nature and potential biases of AIGC-generated content require both teachers and students to possess the ability to critically evaluate information sources [11]. While current research recognizes these macro changes [12,13], there is still a lack of operational specific pathways and stable models for systematically embedding the core literacy of critical thinking into the entire process of writing instruction.

Existing research clearly outlines the empowering trajectory of AIGC from tool, to collaborator, to ecosystem builder. However, the focus is often on efficiency gains and model innovation at the technical application level, or remains at the ethical level of risk warning. There is a lack of an integrated theoretical framework and practical guide that systematically channels the potential of AIGC towards cultivating students' higher-order thinking, particularly critical thinking, throughout the instructional process.

B. CULTIVATING CRITICAL THINKING IN EFL LEARNERS' WRITING INSTRUCTION: GOALS, DILEMMAS, AND EXISTING PATHWAYS

The importance of critical thinking as a core objective of higher education is widely recognized. A review of the literature shows that related research and practice mainly focus on the following aspects:

1) The Intrinsic Unity of Critical Thinking and Writing

It is widely recognized that writing is essentially the externalization process of critical thinking [14]. An excellent argumentative or analytical essay necessarily reflects the author's abilities in analysis, evaluation, inference, and argumentation. Consequently, the English writing classroom is regarded as a natural field for cultivating critical thinking [15]. Traditional cultivation paths mainly include using brainstorming to stimulate ideas, using logic maps to structure essays, and using peer review and teacher feedback to examine and revise arguments.

2) The Practical Dilemmas of Traditional Cultivation Models

Despite clear goals, traditional teaching models face numerous challenges in effectively implementing critical thinking cultivation. Firstly, large class sizes make it difficult for teachers to provide detailed tracking and guidance on each student's thinking process. Secondly, the delayed and general nature of feedback often leads students to focus more on language errors than logical flaws. Finally, as the subject of thinking, students' internal, implicit thinking activities are difficult to effectively stimulate and visualize, resulting in superficial cultivation outcomes.

3) Exploration of Technology-Enhanced Cultivation Pathways

To break through these dilemmas, researchers have attempted to leverage technological means. For example, using online collaboration platforms to broaden the scope of peer review, or using corpus tools to enhance the data support for arguments. However, these technologies mostly function as channels or resource banks. Unlike AIGC, they do not act as thinking opponents or thinking mirrors with generative and dialogic capabilities that directly challenge students' cognitive processes.

Although critical thinking cultivation is highly valued in English writing instruction, traditional approaches have shown limited effectiveness, and existing technology interventions have failed to address the core challenge of continuously stimulating and supporting students' high-quality internal deliberation.

C. RESEARCH GAP AND THE RATIONALE FOR THE PRESENT STUDY

A synthesis of the literature in these two areas reveals a significant disconnect: research on AIGC empowerment often emphasizes efficiency gains and model innovation but pays limited attention to how it can be systematically directed towards the core educational goal of critical thinking. Research on critical thinking cultivation clearly recognizes the dilemmas of traditional pathways but lacks deeply integrated, operational theoretical frameworks and practical models for leveraging the revolutionary technology of AIGC to resolve these dilemmas.

Therefore, this study establishes its necessity and innovation based on identifying this research gap. Merely introducing AIGC or discussing critical thinking in the abstract is insufficient to provide effective guidance for current teaching reform. There is an urgent need for a bridge that can organically integrate the two—namely, a cyclic mechanism that can guide students to continuously engage in self-examination, dialectical analysis, and cognitive reconstruction during their interaction with AIGC.

The "Q-D-R" cyclical framework proposed in this study aims to fill this gap. The framework intends to: (1) Systematically utilize AIGC: Position it not only as a writing tool but also as a "target" to stimulate questioning, a "debating opponent" and "think tank" providing dialectical material, and a "scaffold" assisting cognitive reconstruction. (2) Externalize and guide the thinking process: Through structured task design, externalize the implicit critical thinking process into observable, assessable learning behaviors, while explicitly distinguishing between task completion and the quality of cognitive engagement demonstrated within the task. In the "Reconstruction" phase, cognitive reconstruction—namely the reorganization, refinement, and justification of one's own viewpoint—constitutes the primary objective, while language revision functions as a secondary, supportive process serving the clarified cognitive stance.

This study examines whether students' performance demonstrates transferable critical thinking indicators— such as the independent assumption identification, the evidence-based counter-argumentation, and the reflective judgment—within and beyond the task structure. Moreover, the framework may use task structure as scaffold to elicit higher-order thinking qualities. Given that these qualities appear analytically separable, the framework could demonstrate that procedural adherence shows distinct characteristics from thinking qualities.

D. THEORETICAL FOUNDATION

The "Q-D-R" model is built upon three theoretical pillars.

1) Process Writing Approach

This theory posits writing as a recursive, non-linear cognitive process including stages like pre-writing, drafting, revising, and editing [14]. It provides a natural framework for embedding AIGC differentially and purposefully into various phases of instruction.

2) Scaffolding Theory

Inspired by Vygotsky's Zone of Proximal Development [16], AIGC can act as an intelligent scaffold, providing support when students' abilities are insufficient and gradually being withdrawn as their competence increases.

3) Critical-constructive Thinking Model

Complete critical thinking involves both deconstructive and constructive dimensions [17]. The deconstructive dimension involves questioning, analyzing, and deconstructing existing information, whereas the constructive dimension involves synthesizing, innovating, and constructing new knowledge. This model aims to cultivate both dimensions through human-AI interaction.

III. RESEARCH METHODOLOGY

This study adopted a design-based research paradigm, aiming to explore and construct an effective teaching model for fostering critical thinking through AIGC by engaging in three iterative cycles of design, implementation, evaluation, and refinement. The research was conducted over a 16-week semester in an English Writing course.

A. PARTICIPANTS

The participants were 131 second-year non-English major students from two intact classes at a university in Guangdong, China (65 in the experimental class, 66 in the control class). All participants provided informed consent. The experimental class received instruction based on the constructed "Q-D-R" cyclical model, while the control class followed a traditional teaching method centered on teacher lectures and conventional writing exercises. A detailed breakdown of the instructional variables for both groups is provided in Table 1.

B. RESEARCH DESIGN AND PROCEDURE

The research design was closely aligned with the "Q-D-R" framework. As outlined in Figure 1, the study was conducted over a 16-week semester and comprised three distinct phases. The specific process is as follows:

1) Preparatory phase

Both classes underwent a pre-test of English writing proficiency and the Chinese revised version of the California Critical Thinking Disposition Inventory (CCTDI) to ensure no significant initial differences between the groups.

2) Model implementation (experimental class)

Tools and platform: Mainstream AIGC text-generation tools such as ChatGPT, DeepSeek and Ernie Bot were primarily used. These tools were not standardized in terms of output style or response depth; instead, their heterogeneity was intentionally retained as a pedagogical variable to induce cognitive conflict and comparative evaluation during the Dialectic phase.

The teaching process consisted of three iterative cycles centered on a core writing project (e.g., the opportunities and challenges of AI for the future job market). Each cycle was divided into three cyclical stages guided by the "Q-D-R" process.

Cycle 1: Topic exploration and thesis generation. Students used AIGC to generate diverse viewpoints and sample essays on the topic, then proceeded to question the breadth, depth, and potential biases of its content; they engaged in dialectical reasoning through group discussions and source verification, comparing AIGC outputs with authoritative literature; finally, they reconstructed their own unique and well-supported thesis statements.

Cycle 2: Structure and argumentation development. Students prompted AIGC to generate different essay outlines and argumentative paragraphs for their theses, then questioned their logical rigor and sufficiency of evidence; they engaged in dialectical reasoning by mapping mind maps and identifying logical fallacies; they reconstructed more persuasive, personalized outlines and argumentation systems.

Cycle 3: Language polishing and reflective enhancement. Students input their first drafts into AIGC for polishing and revision suggestions, then questioned whether the alterations distorted their original intent or involved excessive embellishment; they engaged in dialectical reasoning by comparing suggestions from different AIGC tools and teacher feedback; finally, they reconstructed their final drafts by prioritizing the alignment between linguistic expression and their independently reconstructed cognitive position, accompanied by reflective journals summarizing their entire writing and thinking journey.

3) Data collection

The data collected in this study included: (1) Quantitative data: pre/post-test CCTDI scores and student writing scores (independently graded by two uninformed instructors using a unified rubric); (2) Qualitative data: students' AIGC dialogue records, reflective journals, group discussion records, and transcripts from semi-structured interviews with selected students.

The CCTDI could indicate that general critical thinking dispositions rather than discipline-specific analytical skills are measured, although this significant empirical study adopts engineering-related writing tasks as a contextualized cognitive domain rather than as an assessment target per se. Moreover, the role of discipline-specific technical discourse in the study may provide an authentic, cognitively demanding context in which the general dispositions—such as open-mindedness, analytic inclination, and truth-seeking—can be meaningfully activated and observed. Given that the CCTDI captures changes in underlying critical thinking tendencies, engineering-related writing might function as a situated medium through which tendencies are enacted, not as a construct directly measured by the scale.

C. DATA ANALYSIS

A mixed-methods approach was used. Quantitative data were analyzed using SPSS software, including paired-samples and independent-samples t-tests to compare within-group and between-group differences. Qualitative data were analyzed using thematic analysis [18], involving coding and categorizing to identify manifestations of critical thinking development and evidence of the model's effectiveness.

IV. RESULTS AND DISCUSSION

A. QUANTITATIVE RESULTS ANALYSIS

This study employed SPSS 26.0 to analyze the pre-test and post-test data from the experimental class (N = 65) and the control class (N = 66). Paired-sample t-tests were conducted to examine within-group changes before and after the experimental intervention, and independent-sample t-tests were used to compare differences between the groups after the intervention, aiming to evaluate the effectiveness of the teaching model based on the "Q-D-R". The significance level was set at $\alpha = 0.05$.

The paired-sample t-tests were performed for both the experimental and control classes. The results are presented in Table 2, which showed that in the experimental class, the post-test total score for critical thinking skills (M = 79.68, SD = 7.56) was significantly higher than the pre-test score

TABLE 1. Comparison of instructional schemes for the experimental and control groups

Dimension	Experimental Group (AIGC-Empowered)	Control Group (Traditional)
Core tool	AIGC tools (e.g., ChatGPT, DeepSeek, Ernie Bot)	Traditional model essays, textbooks, teacher handouts
Questioning phase	Analyze AIGC-generated texts containing biases or logical flaws.	Analyze teacher-provided model essays, with potential issues pointed out by the teacher.
Dialectical phase	Engage in multi-turn dialogues with AIGC, demanding counter-evidence and supplementary information to challenge its initial stance.	Participate in group discussions and teacher-led debates, summarized by the teacher.
Reconstruction phase	Write a critical analytical essay based on the dialectical engagement with AIGC, explaining the evolution of their own perspective.	Write assigned essays or reading reflections based on class discussions and teacher feedback.
Teacher's role	Facilitator, framework designer, metacognitive questioner	Knowledge transmitter, discussion leader, final assessor
Feedback source	AIGC immediate feedback + teacher in-depth feedback	Primarily teacher feedback

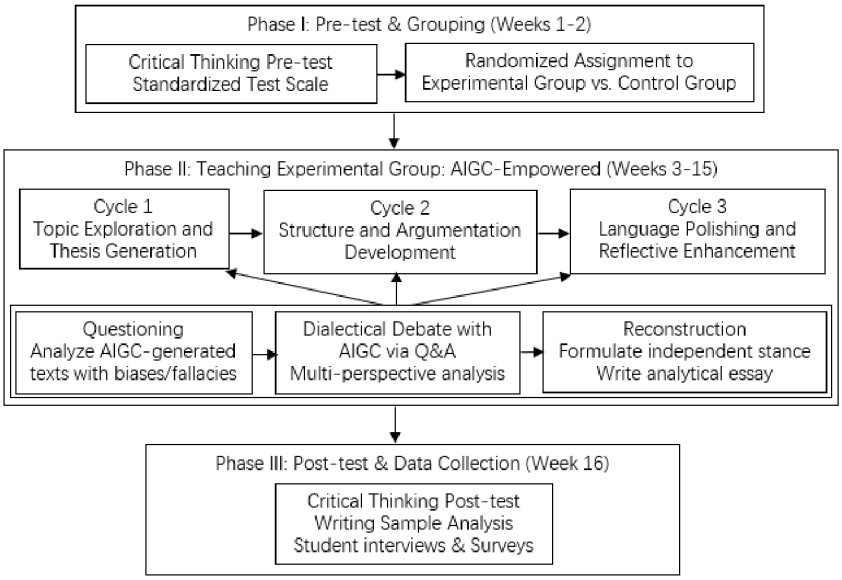

FIGURE 1. The teaching experiment design based on the "Q-D-R" cyclical framework

(M = 72.45, SD = 8.12). The difference was statistically significant, t(64) = -5.832, $p < 0.001$. This indicates that students in the experimental class demonstrated a significant improvement in their critical thinking skills after receiving the teaching intervention. In the control class, no significant difference was found between the post-test score (M = 73.21, SD = 8.78) and the pre-test score (M = 71.89, SD = 8.45), t(65) = -1.245, $p = 0.217 > 0.05$. This suggests that students' critical thinking skills did not change significantly under the traditional teaching mode.

To compare the effects of the teaching interventions between the two groups, an independent-sample t-test was conducted on the post-test scores. Levene's test for equality of variances was performed first ($p = 0.402 > 0.05$), indicating equal variances, thus the results based on pooled variances were adopted. As shown in Table 3, the independent-sample t-test revealed that the post-test total score of the experimental class (M = 79.68, SD = 7.56) was significantly higher than that of the control class (M = 73.21, SD = 8.78), t(129) = 4.576, $p < 0.001$. This difference is statistically significant, with Cohen's d = 0.80, indicating a medium-to-large effect. This indicates that the experimental class, which received the AIGC-empowered instruction, achieved significantly better outcomes in the development of critical thinking skills compared to the control class that received traditional instruction.

Assuming that critical thinking skills comprise three dimensions—analysis, evaluation, and inference—an additional analysis was conducted. As shown in Table 4, the experimental class's post-test scores were significantly higher than those of the control class in analysis ($t = 3.987$, $p < 0.001$) and inference ($t = 4.892$, $p < 0.001$). For evaluation, although the experimental class also scored higher than the control class and the difference was statistically significant ($t = 2.145$, $p = 0.034$), both the significance level and effect size were lower than those observed for the other two dimensions. This may indicate that the teaching model was particularly effective in enhancing students' ability to analyze information and engage in logical reasoning, while its effect on cultivating complex value judgment and evaluation criteria was relatively more moderate or requires further reinforcement.

The qualitative analysis of writing samples, summarized in Table 5, offers compelling evidence for the development of specific critical thinking sub-skills. The frequency data show that students in the experimental group were far more likely to identify underlying assumptions and construct well-reasoned counter-arguments.

TABLE 2. Paired-Sample t-Test Results for Pre-test and Post-test Total Scores of Critical Thinking Skills

Group	Test Time	N	Mean (M)	Std. Deviation (SD)	t-value	p-value
Experimental	Pre-test	65	72.45	8.12	-5.832	< 0.001
	Post-test	65	79.68	7.56		
Control	Pre-test	66	71.89	8.45	-1.245	0.217
	Post-test	66	73.21	8.78		

TABLE 3. Independent-Sample t-Test Results for Post-test Total Scores of Critical Thinking Skills

Group	N	Post-test Mean (M)	Post-test Std. Deviation (SD)	t-value	p-value	Cohen's d
Experimental	65	79.68	7.56	4.576	< 0.001	0.80
Control	66	73.21	8.78			

TABLE 4. Independent-Sample t-Test Results for Post-test Scores on Critical Thinking Sub-Scales

Dimension	Group	Mean (M)	Std. Deviation (SD)	t-value	p-value
Analysis	Experimental	26.54	3.21	3.987	< 0.001
	Control	23.89	3.67		
Evaluation	Experimental	25.85	3.15	2.145	0.034
	Control	24.62	3.48		
Inference	Experimental	27.29	3.28	4.892	< 0.001
	Control	24.70	3.80		

TABLE 5. Coding Framework and Exemplary Results for the Analysis of Critical Thinking Elements in Writing Samples (N = 131)

Analytic Dimension	Operational Definition	Exemplary Performance (Exp. Group, Post-test)	Exemplary Performance (Ctrl. Group, Post-test)	Frequency of Occurrence (Exp./Ctrl.)
Identifying Assumptions	Identifies unstated presuppositions or values in a text.	"The AIGC's argument initially assumes that economic growth is always the primary goal, but this overlooks environmental costs."	"The author's view is based on his personal experience."	85% / 45%
Providing Counter-arguments	Provides evidence or viewpoints that contradict the original argument.	"While the AIGC claims technology causes unemployment, history shows it also creates new industries, such as..."	"Some people might disagree with this view."	78% / 40%
Multi-perspective Analysis	Analyzes an issue from at least two distinct perspectives.	"From a consumer's perspective... However, from a producer's standpoint..."	Primarily elaborates on a single line of argument.	90% / 55%
Logical Coherence	Demonstrates clear and rigorous logical connections between claims, evidence, and conclusions.	Clear essay structure, uses connectives like "first", "however", "therefore"; complete logical chain.	Paragraph transitions are abrupt; some evidence does not directly support the claim.	82% / 60%
Judiciousness of Conclusion	Presents a non-absolute conclusion, acknowledging limitations of the argument or the tentative nature of knowledge.	"In conclusion, while the evidence leans towards supporting A, more research is needed in area B."	"Therefore, A is correct."	70% / 35%

The exemplary performances shown in Table 5 indicate that these students demonstrated not only successful task completion but also the ability to independently examine assumptions and construct substantiated counter-arguments. The results further show that students were able to independently identify underlying assumptions, construct substantiated counter-arguments, and formulate conditional conclusions that acknowledge the limitations of the evidence. The indicators emerge as evidence of internalized dispositions. Thus, these indicators reduce the risk of validation bias.

B. QUALITATIVE RESULTS ANALYSIS

Thematic analysis of reflective journals and interview transcripts yielded three core themes, vividly illustrating the operational mechanism of the framework:

1) Shift from passive acceptance to active questioning

Most students initially reported taking AIGC outputs at face value but, after training within the framework, began habitually asking questions such as: "What are its sources?" "Are there counterexamples to this conclusion?" and "Is it ignoring certain perspectives?" For instance, Student S10 wrote: "I used to think whatever AI wrote was correct. Now I instinctively question it first and verify the information myself. This process has deepened my understanding of the topic immensely." This aligns with Caulfield's concept of technology-mediated critical thinking [19], reflecting the new literacy of critical thinking in the digital environment.

2) Dialectical reasoning fosters cognitive dissonance and integration

Students experienced noticeable cognitive conflict when comparing different AIGC outputs and contrasting AIGC viewpoints with scholarly literature. Student S06 stated in the interview: "When ChatGPT and Ernie Bot gave completely opposite suggestions on the same issue, I was stunned. It forced me to consider their respective standpoints and limitations. In the end, I integrated the reasonable parts from both to form my own judgment." This finding resonates with discussions positioning cognitive conflict as crucial for critical thinking development.

3) Reconstruction as embodiment of knowledge internalization and creative expression

The ultimate learning outcome was not only high-quality essays but also the establishment of personal viewpoints. The reflection of Student S23 was representative: "I am no longer simply piecing together materials from AIGC. I use it as an 'advanced sparring partner'. The final viewpoint reflects my own judgment, and the evidence is what I critically selected and verified; AIGC mainly assisted in refining the expression. I feel I truly 'own' this essay". The framework intentionally used variations in AIGC output quality as prompts for dialectical reasoning, rather than treating the differences as methodological noise. Moreover, students may have been guided to compare and evaluate conflicting AI-generated responses. Thus, students could adjudicate between outputs. However, this approach might shift focus from accepting correct answers to examining epistemic limitations underlying each output. Given that the design choice enhances systematic cultivation of critical thinking, the framework could demonstrate that the Dialectic phase may provide important opportunities for developing these analytical capacities.

V. DISCUSSION

Based on the experimental data and qualitative analysis, this study proposes a model of AIGC's empowering pathways for critical thinking cultivation. As shown in Figure 2, AIGC primarily functions through three core mechanisms, which interact with the "Q-D-R" to jointly promote the development of both cognitive skills (analysis, evaluation, inference) and affective dispositions (curiosity, open-mindedness) of critical thinking. The significant improvement in CCTDI scores suggests a shift in students' general thinking dispositions, which was facilitated—but not defined—by engagement with engineering discourse. This supports the view that domain-specific writing tasks can serve as effective catalysts for cultivating transferable critical thinking dispositions when embedded within a structured pedagogical framework. The findings confirm that embedding AIGC within the "Q-D-R" framework transforms it from an answer generator into a catalyst for thinking.

First, the model successfully operationalizes critical thinking cultivation into concrete teaching procedures. The initial texts generated by AIGC provide students with tangible objects for questioning, overcoming the abstraction often associated with critical thinking targets in traditional instruction. The framework compels students to engage in deep, critical dialogue with AIGC, thereby grounding higher-order thinking training in practical activity.

Second, the design of the cyclical framework aligns with constructivist learning theory. Learning is not the unilateral transmission of knowledge but a process of meaning-making where students continuously deconstruct and reconstruct knowledge through multifaceted interactions with AIGC, peers, and the teacher. Each "Reconstruction" represents an optimization and upgrade of the student's cognitive structure.

Finally, the study also revealed practical challenges. For instance, some students initially exhibited over-reliance on or rejection of the technology, requiring significant teacher effort for guidance and scaffolding. This indicates that successful AIGC integration depends not only on the technological tools but, more importantly, on deliberate pedagogical design (i.e., instructional model construction).

VI. CONCLUSION

A. MAJOR FINDINGS

Through a design-based research intervention, this study explored and constructed a model for fostering critical thinking in EFL learners' writing empowered by AIGC, specifically tailored to the analytical demands of engineering and technical communication. By integrating engineering-oriented scenarios into the writing process, the pathway enables students to evaluate AI-generated technical discourse against the practical realities of system design, technical implementation, and applied engineering analysis. The main conclusions are as follows:

1) Pathway effectiveness

The cyclical teaching framework, with "Questioning-Dialectic-Reconstruction" at its core, is an effective pathway for the deep integration of AIGC and critical thinking cultivation. It systematically transforms AIGC outputs into pedagogical resources for developing students' abilities in analysis, evaluation, inference, and self-reflection.

2) Model structure

The constructed model features a clear operational workflow and iterative nature, emphasizing that sustained critical interaction between students and AIGC within authentic writing tasks drives a spiral ascent in thinking, ultimately leading to knowledge internalization and creative expression.

3) Significant outcomes

Both quantitative and qualitative data demonstrate that the model not only significantly enhances students' critical thinking dispositions and English writing performance but, more importantly, fosters a thinking habit characterized by proactive questioning, prudent dialectical reasoning, and autonomous reconstruction.

B. PRACTICAL IMPLICATIONS AND RECOMMENDATIONS

Based on these findings, this study offers the following recommendations for educators:

For teachers, they should transition from being authoritative knowledge transmitters to designers of learning environments, facilitators of critical dialogue, and coaches of thinking processes. Proficiency with AIGC tools and the ability to design learning tasks that induce cognitive conflict are essential.

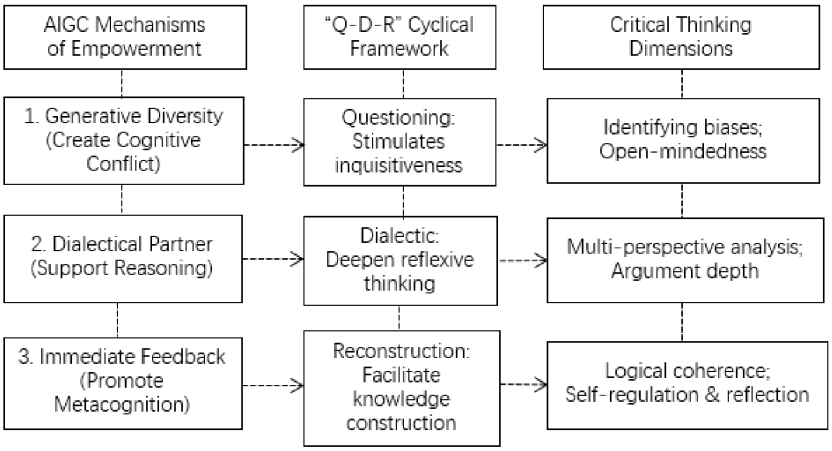

FIGURE 2. A Model of AIGC's empowering pathways for cultivating critical thinking within the "Q-D-R" framework

For curriculum designers, they should actively integrate such fusion models into the curriculum framework and develop corresponding teaching resources, activity templates, and assessment rubrics to support the model's large-scale application.

C. LIMITATIONS AND FUTURE RESEARCH

This study has several limitations. First, the research duration was relatively short, and the sample size was limited. The long-term effects and generalizability require verification through larger-scale, longitudinal studies. Second, the study focused primarily on text-based AIGC tools. Future research could explore the application of multimodal AIGC (e.g., image, video generation) in English writing instruction.

In conclusion, in the age of AIGC, cultivating students' critical thinking is more urgent than ever. This study confirms that through careful instructional design, we can transform the challenges posed by technology into opportunities for educational innovation, building a learning environment that connects AI-assisted language processing with the practical analytical demands of engineering discourse. Fundamentally, this human-AI collaborative framework enhances students' capacity for deep analytical thinking, requiring them to continuously question, verify, and reconcile AI-generated outputs with their own disciplinary understanding.

AUTHOR CONTRIBUTIONS

Xinglan Qiao designed, collected and analyzed the data, and drafted the manuscript. Xinglan Qiao conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Xinglan Qiao participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

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