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Enhancing Critical Thinking through Hybrid Writing-to-Learn Pedagogy in Technology Engineering Education: A Pilot Study at HBCU

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Abstract

This qualitative study examines the impact of a culturally responsive Writing-to-Learn Pedagogy (WTLP) intervention on the critical thinking development of underrepresented undergraduate STEM students at a public Historically Black College or University (HBCU). WTLP integrates reflective journaling and writing-to-explain in a hybrid Industrial

Electricity course to foster metacognitive engagement, deepen conceptual understanding and improve critical thinking skills. Data from 11 students in the 2025 cohort were analyzed using rubric-based content analysis and thematic analysis of student writing. Results indicate significant growth in critical thinking dispositions—particularly inquisitiveness and confidence in reasoning—and in abilities such as analytical and reflective thinking. A positive relationship was found between the depth of explanatory writing and performance on applied problem-solving tasks. These findings suggest that structured WTLP scaffolds, especially learning plans, can effectively bridge reflection and application, offering a promising, equity-focused pedagogical model for HBCU STEM contexts.

Keywords: Writing-to-Learn, critical thinking, HBCU, STEM education, reflective journaling, underrepresented students

Introduction

The cultivation of critical thinking is a paramount objective in STEM education, yet traditional instructional methods often limit the development of higher-order cognitive skills [1], [2]. Writing-to-Learn Pedagogy (WTLP) has emerged as an effective strategy to foster critical thinking by using writing as a tool for reflection, knowledge construction, and metacognitive development [3], [4]. However, its implementation and efficacy within Historically Black Colleges and Universities (HBCUs)-institutions that produce 24% of Black STEM bachelor's degrees [5] - remain critically understudied. This gap is significant given the need for culturally responsive pedagogies that align with the asset-based, community-oriented learning environments characteristic of HBCUs [6].

This study addresses this gap by investigating the effectiveness of a hybrid WTLP intervention in enhancing the critical thinking skills of underrepresented STEM students at an HBCU. The research questions are:

1. To what extent did students demonstrate growth in critical thinking abilities through WTLP?
2. How did reflective journaling influence their critical thinking dispositions?
3. What relationship exists between explanatory writing and problem-solving performance?

Writing-to-Learn Pedagogy (WTLP) strategically employs writing as a cognitive tool to deepen learning, develop critical thinking, and improve communication [7]. In STEM education,

WTLP structures such as reflective journaling and problem-based writing have been shown to enhance metacognitive awareness and conceptual understanding [8], [9]. Critical thinking, as defined by Ennis [10], comprises both affective dispositions (e.g., open-mindedness, inquisitiveness) and cognitive abilities (e.g., analytical thinking, judiciousness). While WTLP has demonstrated promise in mainstream STEM contexts, its application within HBCUs—and its alignment with the "equity ethic" of Black STEM students—remains unexplored [6]. This study contributes to filling this empirical and contextual void.

Methodology

This study employed a qualitative research design with quantitizing techniques to systematically analyze patterns in student writing. Following Braun and Clarke's [11] approach to reflexive thematic analysis, themes were first allowed to emerge inductively from repeated readings of student journals and explanatory writing. After the thematic framework was established, frequencies were counted to identify the prevalence and salience of themes across the cohort, a process referred to as "quantitizing" qualitative data [12]. This approach maintains the interpretive integrity of qualitative inquiry while enabling the identification of patterns that might otherwise remain implicit.

A qualitative design was employed to explore how WTLP structures influenced critical thinking in an Industrial Technology course at a public HBCU in the Southern U.S. The course served as a gateway for underrepresented students into technical STEM pathways. The 2025 cohort consisted of 11 undergraduate students (8 male, 3 female) majoring in Industrial Technology, all identifying as members of underrepresented racial/ethnic groups.

The intervention is implemented within a sophomore-level Basic Electronics course (ITE 111), primarily serving students in the Electronics Technology concentration. It utilizes a hybrid WTL model, combining Monday/Wednesday in-class instruction with online assignments administered via Canvas on Fridays. Students engage in three structured instructional cycles, each requiring homework, a learning plan, quizzes, and reflective writing and evaluation. These assignments embed explicit cognitive, metacognitive, and motivational regulation prompts [10] to systematically foster higher-order thinking and self-regulated learning. Two core WTLP structures were adopted as interventions:

1) *Reflective journaling:* Students responded to prompts about learning challenges, misconceptions, and study strategies.
2) *Writing-to-Explain:* Students write clear explanations of complex concepts or processes in their own words. This practice strengthens understanding, helps clarify misconceptions, and improves the ability to communicate technical information effectively.

Data included reflective journal entries and explanatory writings collected via Google Forms. Analysis involved: 1) Rubric-based content analysis: Using rubrics (Appendix A & B)

based on Ennis [10]'s taxonomy to assess pre/post changes in dispositions and abilities; and 2) Thematic analysis: Identifying emergent themes related to student agency, metacognition, and conceptual integration. It is important to clarify that the critical thinking rubrics presented in Appendices A and B were used exclusively for research analysis to assess students' dispositions and abilities, and were not shared with students nor used to assign instructional grades. Student writing was graded for course credit using a separate, simpler completion-based rubric that emphasized effort, timely submission, and good-faith engagement with reflective prompts. This separation between instructional grading and research analysis was intentionally designed to achieve two goals: (1) to reduce the risk of students writing to meet predefined critical thinking criteria rather than engaging in authentic reflection, and (2) to allow the research team to apply Ennis [10]'s (1987) theoretical framework systematically during post-semester analysis to assess the depth and quality of students' critical thinking dispositions and abilities without influencing student performance or instructor evaluations during the course. Consequently, the rubric scores reported in this study represent the research team's independent assessment of critical thinking development, not grades assigned to students.

To mitigate the potential influence of grading on student candor, the reflective writing assignments were framed as low-stakes, formative assessments focused on process over performance, and students were assured that honest analysis of misconceptions—not correct answers—was the primary criterion for evaluation. This approach aimed to foster a safe environment for authentic metacognitive reflection, encouraging students to prioritize personal learning insights over responses tailored to perceived instructor expectations.

Results and Discussions

The demographic composition of the 2025 cohort was comprised of 8 male and 3 female students, with academic standings spanning from sophomore to senior levels. All participants identified as members of underrepresented racial or ethnic groups. Throughout the Fall 2025 semester, students engaged in three structured cycles of learning activities—homework preparation, quizzes, reflective learning evaluations, and journaling—with the 2025 cohort also authoring personalized learning plans as a core component of their reflective practice.

Growth in Critical Thinking Dispositions

Students demonstrated an average dispositional growth of +1.0 level (Table 1). The most pronounced gains were in inquisitiveness and confidence in reasoning. One student noted: *"Figuring out why the current divides in parallel branches, not just how to calculate it, made the whole concept click."*

Table 1. Critical Thinking Dispositions Development (2025 Cohort, n=11)

Student	Pre-Intervention	Post-Intervention	Growth
Average	2.18	3.18	+1.0

Note: Scores represent research team's rubric-based assessment of student writing using Appendix A; these were not instructional grades shared with students.

Growth in Critical Thinking Abilities

Analytical thinking showed the strongest improvement, with 45% of students reaching “Proficient” or “Exemplary” levels. Reflective thinking also improved (+0.8 levels), though judiciousness remained a developmental challenge.

Table 2. Critical Thinking Abilities Development (2025 Cohort, n=11)

Student	Pre-Intervention	Post-Intervention	Growth
Average	1.82	2.82	+1.0

Note: Scores represent research team's rubric-based assessment of student writing using Appendix A; these were not instructional grades shared with students.

Thematic Insights from Student Experiences

Beyond the quantitative rubric scores, inductive thematic analysis of journal entries and open-ended responses surfaced several recurring themes that contextualize the numerical findings:

1) *Agency and Self-Direction:* Students increasingly framed learning as an active process within their control. Language shifted from external attribution ("*The teacher didn't explain it well*") to internal ownership ("*I need to find another way to understand this concept*").
2) *Strategic Metacognition:* Vague resolutions ("*study more*") were replaced by specific, actionable strategies ("*I will rework the homework problems without looking at the solutions and then use the textbook examples to check my process*").
3) *Conceptual Integration:* Students began making explicit connections between isolated facts and broader principles, moving beyond procedural mimicry. For example, several linked their difficulties with specific calculations to a foundational misunderstanding of energy conservation or charge flow.

Analytical thinking emerged as the most substantially developed competency, with 45% of students attaining "Proficient" or "Exemplary" levels by semester's end. This growth aligns with the technical demands of circuit analysis within the course and suggests that the writing-to-

explain activities and structured reflections effectively scaffolded students' capacity to break down complex problems into constituent parts and examine them systematically. Students' journals reflected this development, moving from vague descriptions of difficulty ("parallel circuits are hard") to precise diagnostic statements ("I mistakenly summed resistances in parallel instead of calculating reciprocals because I failed to distinguish between the underlying configuration rules").

Reflective thinking also showed meaningful improvement (+0.8 levels), with students' journal entries evolving from basic task descriptions ("I need to study more") to more metacognitive examinations of their own reasoning processes. This finding extends the work of Zarestky [4], who found that reflective writing supports metacognition and self-regulation in graduate computational science. The current study demonstrates that similar gains are achievable at the undergraduate level and within the specific context of an HBCU, where fostering metacognitive awareness may be particularly important for students navigating STEM pathways historically characterized by exclusionary practices [6].

However, *judiciousness*—the ability to make sound, evidence-based judgments by evaluating evidence and weighing multiple perspectives—proved the most challenging to cultivate. It remained the cohort's weakest area post-intervention, with only two students (18%) reaching "Proficient" levels. This finding aligns with Ennis[10]'s (1987) observation that evaluative judgment may represent a higher-order skill that develops more slowly than analytical or reflective capacities. It also resonates with research by King and Kitchener [13] on reflective judgment, which suggests that the ability to evaluate evidence and make reasoned judgments in ill-structured domains typically emerges later in cognitive development and may require more sustained practice than a single-semester intervention can provide. For engineering contexts, where practitioners must constantly evaluate competing design alternatives and weigh multiple constraints, this finding signals a need for more targeted pedagogical attention to judiciousness throughout the curriculum.

Practical Recommendations for HBCU STEM Instructors

The study implies that STEM instructors, especially those in the context of HBCU, should:

1) *Systematically Integrate Learning Plans:* Embed brief, focused planning exercises following major assessments. These need not be lengthy; a 15-minute writing task where students articulate specific study strategies based on quiz performance can significantly enhance the transfer of learning.

2) *Differentiate WTLP Prompts:* Recognize varying entry points for critical thinking. Provide more structured, step-by-step prompts for emerging thinkers (e.g., "List the first two steps you would take to analyze this circuit and why") while offering open-ended,

complex scenarios for high performers (e.g., "Compare and justify two different solution paths for this design problem").

3) *Target Judiciousness Explicitly:* Given its identification as a persistent challenge, design activities that specifically exercise evaluative judgment. Use case studies comparing multiple solution approaches, or implement peer review sessions where students must apply rubric criteria to assess each other's explanatory writing.

4) *Leverage Writing as a Professional Tool:* Frame WTLP activities not as academic exercises but as practice in essential professional communication. Emphasize that clear explanations, systematic troubleshooting, and reflective practice are hallmarks of competent engineers and technologists.

5) *Create a Culture of Reflective Practice:* Normalize error analysis and the admission of confusion as integral to the learning process, not as indicators of failure. Instructor modeling of this mindset is crucial.

Addressing Challenges

This pilot study also sheds light on some challenges: 1) Successfully integrating WTLP requires intentional course redesign to embed writing activities sustainably without overwhelming content coverage; 2) The prevalence of generative AI presents a real challenge for take-home, open-ended writing tasks. In this study, it is important to note that writing-to-explain tasks were predominantly completed in class as handwritten exercises, minimizing AI exposure for the writing samples most directly linked to problem-solving performance. Reflective journaling prompts, however, were completed outside of class to allow for deeper metacognitive processing. To address potential AI influence on these take-home reflections, the research team compared journal entries with in-class writing samples to identify stylistic inconsistencies and examined whether reflections demonstrated the specific, personal, and contextually grounded details that characterize authentic student voice. No evidence of AI-generated content was found that would compromise the integrity of the thematic analysis. Nevertheless, future iterations of this course may incorporate more in-class reflective writing or explicitly teach students how to use AI as a collaborative thought-partner rather than a substitute for personal reflection. Consider balancing these with in-class, low-stakes writing or using AI-detection tools, while also discussing the ethical and practical use of AI as a learning aid.

Conclusion and Future Directions

This study provides evidence that a hybrid WTLP intervention, particularly when enhanced with structured learning plans, can effectively cultivate critical thinking among underrepresented STEM students at an HBCU. The marked growth in analytical skills, reflective depth, and the demonstrable link between writing quality and problem-solving performance underscore the value of integrating planning scaffolds into reflective practice. These findings

offer a scalable, equity-focused pedagogical model for HBCU STEM educators seeking to foster both cognitive and affective dimensions of critical thinking.

This study has limitations that point toward fruitful future inquiries. The single-institution context and modest sample sizes caution against overgeneralization. Possible future research includes:

1) Employ longitudinal, mixed-method designs across multiple HBCUs to build more robust, generalizable evidence about WTLP's effectiveness.
2) Investigate the optimal design and frequency of learning plans through controlled experimental studies.
3) Proactively explore how emerging technologies, including generative AI, can be harnessed as collaborative tools within WTLP rather than solely viewed as threats to academic integrity.
4) Examine the long-term retention of critical thinking gains and their transfer to subsequent courses, internships, and early career performance.

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Appendix A. Critical Thinking Dispositions Rubrics

This rubric evaluates the internal inclinations and attitudes necessary for critical thinking.

Category	0 - Not Evident	1 - Emerging	2 - Developing	3 - Proficient	4 - Exemplary
Open-mindedness	Rigidly holds to one view; ignores or dismisses bias.	Acknowledges other views but shows significant bias in evaluation.	Considers different perspectives with some guidance; attempts to be neutral.	Receptive to new info; willing to change views when presented with evidence.	Actively seeks diverse perspectives; fully embraces evidence-based change.
Inquisitiveness	Shows no interest; avoids asking questions or exploring.	Asks surface-level questions; requires prompting to explore.	Displays natural curiosity; asks relevant questions about the subject.	Actively engages in learning; seeks deep understanding of the world.	Proactively investigates complex topics; demonstrates persistent intellectual curiosity.
Intellectual Humility	Refuses to admit mistakes; defensive about personal limitations.	Rarely admits errors; reluctant to accept corrective feedback.	Acknowledges some limitations; occasionally open to feedback.	Recognizes own limitations; willing to learn from mistakes and revise beliefs.	Consistently seeks feedback; proactively identifies and corrects personal errors.
Skepticism	Accepts all claims at face value without questioning.	Questions very obvious claims but accepts most information as true.	Asks for evidence occasionally; shows healthy doubt toward complex claims.	Critically evaluates validity and reliability before accepting information.	Consistently demands rigorous logical reasoning and evidence for all claims.

Category	0 - Not Evident	1 - Emerging	2 - Developing	3 - Proficient	4 - Exemplary
Confidence in Reasoning	Avoids intellectual risks; does not defend or express opinions.	Hesitant to share views; struggles to provide logical defense.	Displays some belief in own ability; attempts to defend arguments.	Willing to take intellectual risks; defends arguments with logic and evidence.	Fully trusts own critical thinking; articulates and defends complex views with poise.

Appendix B. Critical Thinking Abilities Rubrics

This rubric evaluates the cognitive skills used to process and apply information.

Category	0 - Not Evident	1 - Emerging	2 - Developing	3 - Proficient	4 - Exemplary
Analytical Thinking	Unable to break down problems; views issues only as a whole.	Identifies some components but fails to see systematic connections.	Breaks down problems; identifies basic patterns and conclusions.	Analyzes systems/components; identifies clear patterns and logical results.	Masters systematic analysis; uncovers deep underlying structures and patterns.
Reflective Thinking	No awareness of personal biases or own thought processes.	Occasionally notices a bias but does not examine its impact.	Examines thought processes; considers some strengths or weaknesses in reasoning.	Self-aware; actively evaluates own assumptions and reasoning quality.	Consistently engages in deep meta-reflection to refine and improve reasoning.
Judiciousness	Makes impulsive decisions; ignores available evidence.	Relies on single sources; makes judgments with limited reasoning.	Evaluates source credibility; weighs basic pros and cons before deciding.	Makes sound, well-reasoned judgments based on multiple perspectives and evidence.	Consistently makes expert-level, balanced judgments in highly complex situations.
Creative Problem-solving	Follows only standard procedures; cannot generate new ideas.	Generates obvious solutions; struggles to think "outside the box”.	Explores alternative approaches; attempts to connect different ideas.	Generates innovative and effective solutions by connecting unrelated ideas.	Pioneers novel, highly effective solutions to complex, non-routine problems.