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Bridging Metacognition and Performance: Writing-to-Learn Pedagogy and Critical Thinking Development in an HBCU STEM Context

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ABSTRACT

This study investigates the efficacy of a Writing-to-Learn Pedagogy (WTLP) intervention in fostering critical thinking among underrepresented STEM students at an Historically Black College and University (HBCU). Utilizing Ennis's (1987) taxonomy, the research employed a qualitative descriptive design to evaluate shifts in dispositions and abilities through reflective journaling and writing-to-explain within a hybrid industrial electricity course. Findings from two cohorts of 23 students revealed significant growth in analytical thinking, inquisitiveness, and confidence in reasoning. However, the generalizability of these findings is limited by the small sample size and single-institution design. Notably, the integration of structured learning plans bridged the gap between metacognitive awareness and applied problem-solving performance. This research provides empirical evidence *for asset-based instructional strategies implemented within the distinctive context of HBCU STEM education, contributing to the preparation of a competent and diverse STEM workforce.*

Keywords: Critical thinking, HBCU, pedagogy, STEM education, writing-to-learn

INTRODUCTION

The cultivation of critical thinking is a paramount objective in STEM (Science, Technology, Engineering, and Mathematics) education, as these fields demand more than the mere acquisition of factual knowledge. Traditional STEM instructional methods, which often emphasize passive learning through lectures, rote memorization, and isolated problem-solving, can inadvertently limit students' development of higher-order cognitive skills (Prince, 2004; National Research Council, 2012). This approach may fail to adequately prepare students for the complex, real-world challenges that require analytical reasoning, innovative problem-solving, and evidence-based judgment (Barr & Tagg, 1995; Derting & Ebert-May, 2010).

Critical thinking enables students to move beyond surface-level understanding to analyze information, evaluate evidence, synthesize concepts, and construct reasoned arguments. These abilities are essential for scientific inquiry, engineering design, data interpretation, and effective communication within and beyond the STEM disciplines (Ennis, 1987). Furthermore, in an era of rapid technological advancement and information proliferation, the ability to think critically—marked by dispositions such as open-mindedness, intellectual humility, and healthy skepticism—is crucial for responsible innovation and ethical decision-making (Facione, 2011).

Enhancing critical thinking directly addresses common pitfalls in traditional STEM education by fostering active engagement, deepening conceptual understanding, and bridging the gap between theory and practice. It promotes the development of metacognitive awareness, allowing students to monitor and regulate their own learning processes (Flavell, 1979). Therefore, integrating pedagogical strategies specifically designed to enhance critical thinking is not merely beneficial but fundamental to achieving the overarching goals of STEM education and preparing an adaptable, competent workforce for the future.

The implementation of writing-to-learn (WTL) strategies serves as a primary mechanism for fostering critical thinking by requiring students to articulate their internal thought processes and engage in reflective inquiry (Ke, 2025). This pedagogical approach not only clarifies conceptual understanding but also significantly enhances metacognitive awareness, which empowers students to actively monitor their own learning and identify personal misconceptions (Zarestky et al., 2022). Ultimately, cultivating these higher-order thinking skills is vital for preparing future STEM professionals to effectively communicate research findings and apply their knowledge to solve complex, real-world challenges (Carney-Anderson, 2026; Ke, 2025)

Despite growing evidence that Writing-to-Learn Pedagogy (WTLP) enhances critical thinking in undergraduate STEM education (Phillips, 2023), its efficacy and implementation within Historically Black Colleges and Universities (HBCUs) remain critically unexamined. Recent research indicates that critical thinking must be integrated through student-centered strategies (Rahmawati et al., 2025), yet the existing literature lacks systematic studies focused on marginalized populations, including African American learners (Ke, 2025). This oversight fails to consider how cultural context, student identity, and institutional mission shape pedagogical effectiveness.

The omission is particularly consequential given that HBCUs produce 24% of all Black STEM bachelor’s degrees in the United States (UNCF, 2023). Theoretically, while WTLP is framed as a tool for metacognition and self-regulated learning, its interaction with the asset-based, community-oriented learning environments characteristic of HBCUs is unexplored (Hodges et al., 2026). The HBCU context is distinctive, shaped by historical mission, institutional culture, and student populations that differ from predominantly white institutions. Understanding how pedagogical approaches like WTLP function within this context is essential for developing evidence-based practices that support the success of underrepresented STEM students (Akman et al., 2026). This study therefore asks: How does WTLP function within an HBCU STEM context, and what evidence exists for its effectiveness with underrepresented students?

Practically, there is no empirical guidance on implementing technology-enhanced WTLP—such as digital portfolios or collaborative platforms—within the specific resource-constrained contexts of HBCU STEM departments. As STEM careers are projected to grow by 11% through 2031 (U.S. Bureau of Labor Statistics, 2022), addressing these gaps is essential for fostering inclusive and affirming spaces where Black students can persist and thrive (Ayers et al., 2025; Spencer, 2024).

The purpose of this study is to investigate the effectiveness of a Writing-to-Learn (WTL) instructional intervention in enhancing the critical thinking skills of undergraduate STEM students at a public Historically Black College or University (HBCU). The study is designed to generate empirical, context-specific evidence that addresses the documented gap in equity-focused pedagogical research by examining how tailored WTL activities function within this institutional setting.

THEORETICAL BACKGROUND

Writing-To-Learn Pedagogy (WTLP) and Its Structures

WTLP is defined as an instructional approach that strategically employs writing not merely as a product for assessment, but as a dynamic cognitive tool to promote and enhance learning across subject areas. It involves integrating structured writing activities into the curriculum to help students deepen their understanding of content, develop critical thinking skills, and improve their ability to communicate complex ideas (Graham & Hebert, 2011; Warschauer, 2006). In essence, WTLP positions writing as a process of discovery, reflection, and knowledge construction, moving beyond traditional composition goals to foster deeper engagement with disciplinary concepts.

The literature identifies several commonly adopted WTLP structures that have proven effective in various educational settings, particularly within STEM. These structures are designed to elicit specific cognitive and metacognitive processes. Key pedagogical structures include:

1. *Reflective Journaling:* Students maintain journals to reflect on their learning experiences, thoughts, and insights. This practice encourages self-reflection, deepens conceptual understanding, and helps students make connections between ideas (Zarestky et al., 2022).
2. *Concept Mapping:* Students create visual representations of concepts and their interrelationships. This activity enhances critical thinking by facilitating knowledge organization and synthesis, helping students explore complex ideas systematically (Barta et al., 2022).
3. *Problem-Based or Inquiry-Based Writing:* Students engage in writing activities to solve specific problems or propose evidence-based solutions.

This approach fosters critical thinking and problem-solving skills by requiring the application of knowledge to authentic, real-world scenarios (Jeon et al., 2021; Pelaez, 2002).

4. *Peer Review and Feedback:* Students participate in structured exchanges where they provide and receive constructive feedback on written work. This process promotes collaboration, refines communication skills, and develops the ability to give and use constructive criticism (Ke, 2025).
5. *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.
6. *Argumentative Writing:* Students develop and defend positions using evidence-based reasoning. This structure cultivates logical reasoning, analytical evaluation of evidence, and the ability to articulate and defend a viewpoint, though its impact on open-mindedness is noted as potentially complex (Southworth, 2021; Tarchi et al., 2022).

Ke (2025) noted that reflective journaling, concept mapping, and problem-based writing have been the most extensively implemented and researched within STEM education, often serving as foundational WTLP tools.

Taxonomy of Critical Thinking

To effectively assess the development of critical thinking, a clear conceptual framework is required. This study is guided by the seminal taxonomy of critical thinking established by Ennis (1987), which provides a comprehensive structure for understanding its core components. Ennis's model distinguishes between two fundamental dimensions: the affective dispositions that motivate an individual to think critically, and the cognitive abilities required to execute critical thinking effectively. This bifurcation is essential, as possessing the skills without the willingness to employ them—or vice versa—limits meaningful critical engagement (Facione, 2011).

Critical Thinking Dispositions refer to the consistent internal motivations, attitudes, and habits of mind that incline a person toward engaging in critical thought. As outlined in Ennis's (1987) taxonomy and supported by subsequent research, these key dispositions include:

1. *Open-mindedness*: The willingness to consider different perspectives, ideas, and evidence without bias or prejudice.
2. *Inquisitiveness*: A natural curiosity and desire to explore, ask questions, and seek understanding.

3. *Intellectual Humility*: The recognition of one's own cognitive limitations and the willingness to acknowledge and learn from mistakes.
4. *Skepticism*: A healthy tendency to question claims and arguments, requiring sufficient evidence and logical reasoning before acceptance.
5. Confidence in Reasoning: The belief in one's own capacity to think through problems and defend positions using logical and evidence-based reasoning.

Critical thinking abilities constitute the applied skills and processes used to perform critical thinking tasks. These core abilities, which operationalize the dispositions, include:

1) *Analytical Thinking:* The ability to deconstruct complex problems or information into constituent parts and examine them systematically.
2) *Reflective Thinking:* The practice of metacognitively examining one's own thought processes, assumptions, and potential biases.
3) *Judiciousness:* The ability to make sound, well-reasoned judgments by evaluating evidence, considering multiple perspectives, and weighing implications.
4) *Creative Problem-Solving:* The capacity to generate innovative and effective solutions by thinking flexibly, exploring alternative approaches, and synthesizing disparate ideas.

This taxonomy offers a robust lens for evaluating how pedagogical interventions like Writing-to-Learn (WTL) might cultivate both the inclination and the capacity for critical thought. By examining shifts in these specific dispositions and abilities, researchers can move beyond generic assessments to pinpoint the precise cognitive and affective impacts of instructional strategies (Paul & Elder, 2006; Straser et al., 2026).

Informed by the literature, the following questions are used to guide the study to reach the research purpose:

1. To what extent did underrepresented students demonstrate growth in specific critical thinking abilities, particularly analytical thinking, reflective thinking, and judiciousness, in their written work (e.g., learning plans, explanations, reflective journals) over the duration of the STEM course?
2. How did the practice of reflective journaling influence underrepresented students' critical thinking dispositions, such as intellectual humility, inquisitiveness, and confidence in reasoning, as evidenced in their journal entries and final course evaluations?
3. What relationship exists between underrepresented students' performance on applied problem-solving tasks (quizzes, evaluations) and the depth of critical

thinking demonstrated in their explanatory writing (e.g., writing-to-explain in learning plans)?

RESEARCH DESIGN

This study employed a qualitative descriptive design to investigate how Writing-to-Learn Pedagogy (WTLP) structures, specifically reflective journaling and writing-to-explain, influenced the critical thinking dispositions and abilities of underrepresented students in a hybrid industrial electricity course. The design was selected to provide an in-depth, contextualized understanding of student experiences and cognitive processes, aligning with the study's exploratory aim to understand how and why these pedagogical tools function within a specific HBCU STEM environment. A qualitative approach is particularly suited to equity-focused educational research, as it centers participant voice and meaning-making, allowing for the emergence of contextually relevant insights that quantitative measures alone might obscure (Creswell & Poth, 2018; Merriam & Tisdell, 2016).

Research Context and Participants

The study was conducted within a basic industrial electricity course offered in the Industrial Technology (ITE) program at a public Historically Black University (HBCU) in the southern United States. As an introductory electronics course, it covers fundamental electrical and electronic principles, laws, and basic circuits, and typically includes hands-on laboratory work with components such as oscilloscopes, multimeters, and logic gates. The course was delivered in a hybrid format, blending face-to-face instruction with online learning components. Data were collected from student participants enrolled during the Spring and Fall semesters of 2025. This course context is significant as it represents a critical gateway for students, many from underrepresented backgrounds, into technical STEM pathways. Aligned with the course's learning objectives, reflective journaling was integrated as a primary pedagogical tool to deepen students' cognitive and metacognitive engagement with complex technical concepts, thereby also serving as the main data source for this research.

Data Collection

Data were collected via Google Forms administered as a core component of the course's reflective practice. This instrument included a series of structured and open-ended prompts designed to elicit reflective and explanatory writing. Primary qualitative data sources included: 1) *Reflective journaling* in response to prompts about learning challenges, problem-solving processes, and conceptual understanding, for instance, students were asked to answer: “How will you address the gaps in understanding identified in this quiz in your future study plans?"; and 2) *Writing-to-explain responses* where students articulated their reasoning behind solutions to technical problems. These textual responses constitute a rich corpus of student-generated narratives detailing their cognitive engagement with course material. Examples of questions are: Provide your rationale for the principles used in this problem solving; For the questions you answered incorrectly, what was your thought process while answering them? What were the misconceptions or gaps in understanding that led to the incorrect answers?

The use of a digital platform provided an efficient means of gathering in situ, reflective writing from participants, with the added benefit of producing transcribed data ready for analysis (Braun & Clarke, 2022) automatically.

Data Analysis: Rubric-Based Content Analysis and Thematic Analysis

The analysis followed a hybrid approach integrating deductive, rubric-based content analysis with inductive thematic analysis to systematically evaluate critical thinking competencies while capturing emergent student experiences (Vaismoradi et al., 2016).

First, a deductive, rubric-based content analysis was conducted to directly assess students' critical thinking development throughout the learning process. Two analytic rubrics were developed based on Ennis's (1987) taxonomy to operationalize the study's core constructs:

1. *Critical Thinking Dispositions Rubric* (Appendix A): This rubric included criteria for evaluating evidence of Open-mindedness, Inquisitiveness, Intellectual Humility, Skepticism, and Confidence in Reasoning within student writing.
2. *Critical Thinking Abilities Rubric* (Appendix B): This rubric included criteria for evaluating Analytical Thinking, Reflective Thinking, Judiciousness, and Creative Problem-Solving.

Student responses (journal entries and explanatory writings) were systematically rated using these rubrics at multiple points during the semester. This structured scoring allowed for the tracking of competency levels and the identification of patterns in the development of specific dispositions and abilities, providing direct, criterion-referenced evidence to answer the primary research questions regarding the impact of WTLP.

Subsequently, an inductive thematic analysis was performed following the six-phase process outlined by Braun and Clarke (2022): familiarization, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the report. This phase analyzed the same textual data to identify broader, data-driven themes related to students' lived experiences with the WTLP activities. Attention was paid to themes concerning the perceived utility of writing tasks, emotional and cognitive responses to reflection, and challenges encountered by students as underrepresented learners in STEM. The integration of findings from both analytical phases enabled a comprehensive interpretation: the rubric-based analysis provided a structured assessment of *what* critical thinking competencies developed and to *what degree*, while the thematic analysis helped explain *how* these developments were experienced and *what contextual and perceptual factors* influenced the process. Content analysis will quantify conceptual gains and assess the manifestation of CT dispositions and abilities.

Rating Process and Bias Mitigation

Student responses (journal entries, learning plans, and explanatory writings) were systematically rated by the course instructor, who also served as a primary researcher. To enhance the trustworthiness of the ratings and mitigate potential bias, several strategies were employed. First, ratings were conducted in two separate rounds spaced two weeks apart, allowing for temporal distance that reduced the influence of immediate recall on scoring decisions. Second, all student work was de-identified prior to rating, with names replaced by numerical codes to minimize conscious or unconscious bias related to student characteristics or prior performance. Third, the instructor engaged in reflexive journaling throughout the rating process, documenting rationales for scoring decisions and noting any instances where personal expectations might influence judgments. Fourth, a random sample of 20% of the responses (n = approximately 45 entries) was independently reviewed by a researcher familiar with qualitative research methods but not involved in the study; the reviewer was provided with the rubrics and brief training. Comparison of the two ratings yielded 87% agreement on disposition scores and 84% agreement on abilities scores, with all discrepancies resolved through discussion. While this does not constitute formal inter-rater reliability testing, the process provided a check on the consistency and transparency of the scoring.

FINDINGS

Participant Demographics and Response Rates

Data from this study were drawn from a combined cohort of 23 undergraduate students, consisting of two distinct groups: the 2024 cohort (n=12) and the 2025 cohort (n=11). All participants were enrolled in a basic Industrial Electricity course within the Industrial Technology program at a public Historically Black University (HBCU) located in the Southern United States. The demographic composition of the 2025 cohort comprised 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. Due to the lack of post-survey data of the 2024 cohort, the data analysis in this paper will focus more on the 2025 cohort. Critical thinking dispositions and abilities are rated using rubrics Appendix A & Appendix B.

Composite Score Calculation

To facilitate interpretation of student growth, composite scores were calculated for critical thinking dispositions (Table 1) and abilities (Table 2). As detailed in the table notes, each composite represents the mean of ratings across the relevant rubric categories, using the 0-4 scales defined in Appendices A and B.

Influence of Reflective Journaling on Critical Thinking Dispositions

The practice of sustained reflective journaling exerted a measurable influence on students' critical thinking dispositions, particularly their inquisitiveness, intellectual humility, and confidence in reasoning (Table 1).

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

Student	Pre-Intervention Level	Post-Intervention Level	Growth	Key Dispositional Shifts
1	1.5	2.5	+1.0	Increased open-mindedness, developing skepticism
2	3.0	4.0	+1.0	Exemplary inquisitiveness, strong confidence
3	2.5	3.5	+1.0	Improved humility, maintained high confidence
4	1.0	2.0	+1.0	Emerging dispositions across all categories
5	2.5	4.0	+1.5	Exemplary confidence, strong inquisitiveness
6	2.0	2.5	+0.5	Moderate growth, balanced profile

7	2.0	3.0	+1.0	Improved skepticism and confidence
8.	2.0	3.0	+1.0	Growth in humility and open-mindedness
9	3.0	4.0	+1.0	Exemplary across dispositions
10	2.0	2.5	+0.5	Limited but positive growth
11	2.5	4.0	+1.5	Exemplary confidence and inquisitiveness

Note. Disposition composite scores represent the mean of ratings across five disposition categories (Open-mindedness, Inquisitiveness, Intellectual Humility, Skepticism, Confidence in Reasoning) using the 0-4 scale in Appendix A. Means are reported to one decimal place. Growth = Post-intervention composite − Pre-intervention composite.

The cohort demonstrated consistent positive growth in dispositions, with nine of eleven students (82%) gaining at least one full rubric level from pre- to post-intervention. The most pronounced gains were observed in inquisitiveness and confidence in reasoning. Journal prompts that asked students to identify lingering questions or areas of curiosity stimulated deeper intellectual engagement. Several students transitioned from passive receivers of information to active investigators, using their learning plans to schedule independent research on self-identified "*interesting but confusing*" topics. As one student noted, "*Figuring out why the current divides in parallel branches, not just how to calculate it, made the whole concept click*".

Confidence in reasoning also increased notably, though its manifestation evolved. For some students, initial overconfidence gave way to a more calibrated self-assurance rooted in methodological competence rather than perceived innate ability. One student articulated this shift: "*I'm less sure I'll instantly know the answer, but I'm more confident I can work through any circuit methodically because I now have a reliable process.*"

Growth in intellectual humility - the willingness to acknowledge errors and cognitive limitations—was more modest but significant. The structured process of analyzing quiz mistakes in journals created a safe space for admitting confusion without judgment. A student who initially blamed errors on "*careless mistakes*" later reflected, "*I realize I don't truly understand Kirchhoff's voltage law conceptually; I've just been memorizing the procedure. I need to go back to the first principles.*" This progression from defensiveness to accountable self-assessment is a critical marker of developing intellectual maturity.

Growth in Critical Thinking Abilities

The analysis of students' written artifacts—including reflective journals, learning evaluations, and explanatory writing within learning plans—revealed substantial growth in targeted critical thinking abilities, particularly in analytical thinking, reflective thinking, and judiciousness (Table 2).

Table 2

Critical Thinking Abilities Development – 2025 Cohort (n=11)

Student	Pre-Intervention Level	Post-Intervention Level	Growth	Key Ability Gains
1	1.5	2.5	+1.0	Strong analytical growth, developing reflection
2	2.5	3.5	+1.0	Exemplary analytical & creative problem-solving
3	1.5	2.5	+1.0	Strong creative skills, weaker judgment
4	1.0	1.8	+0.8	Emerging abilities across all areas
5	2.0	3.3	+1.3	Exemplary analytical & creative skills
6	1.5	2.5	+1.0	Balanced growth across abilities
7	1.5	2.3	+0.8	Moderate analytical improvement
8	2.0	3.0	+1.0	Strong growth in judgment and reflection
9	2.5	3.8	+1.3	Exemplary across all abilities
10	1.0	1.5	+0.5	Limited but consistent development
11	2.0	3.3	+1.3	Strong analytical and creative advancement

Note. Ability composite scores represent the mean of ratings across four ability categories (Analytical Thinking, Reflective Thinking, Judiciousness, Creative Problem-Solving) using the 0-4 scale in Appendix B. Means are reported to one decimal place. Growth = Post-intervention composite − Pre-intervention composite.

Across the 2025 cohort, students demonstrated consistent positive growth in critical thinking abilities, with a median increase of +1.0 composite level and eight of eleven students (73%) gaining at least one full rubric level. Analytical thinking emerged as the most substantially developed competency, with five students (45%)

attaining "Proficient" or "Exemplary" levels in systematic problem decomposition by the semester's end. This development 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. One student, for instance, progressed from identifying "parallel circuit questions" as challenging to articulating that they "mistakenly summed resistances in parallel instead of calculating reciprocals because [they] failed to distinguish between the underlying configuration rules."

Reflective thinking also showed meaningful improvement, with an average gain of +0.8 levels. Students' journal entries evolved from basic task descriptions ("I need to study more") to more metacognitive examinations of their own reasoning processes. As one student reflected, "I notice I rush through calculations when I feel anxious about time, which leads to careless unit conversion errors. I need to build in a verification step." This shift indicates a growing capacity for self-regulated learning, a core objective of the WTLP intervention.

However, the ability of judiciousness—making sound, evidence-based judgments—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 suggests that while students developed stronger technical analysis and self-reflection skills, the evaluative dimension of critical thinking, which requires weighing multiple perspectives and evidence, represents a significant and persistent developmental hurdle within the technical STEM context.

Relationship Between Explanatory Writing and Problem-Solving Performance

A discernible positive relationship emerged between the depth of critical thinking evident in students' explanatory writing and their performance on applied problem-solving tasks such as quizzes and evaluations. The integration of learning plans in the 2025 cohort appeared to strengthen this connection significantly. Students who produced more nuanced, strategic explanations in their plans—detailing not just *what* steps to take but *why* certain approaches were chosen—consistently demonstrated stronger performance on subsequent circuit analysis quizzes. Students whose reflective writing was coded at Level 3 (Strategic Reflection) or higher tended to perform more strongly on applied assessments than students writing at Level 1 or 2, suggesting a positive relationship between explanatory writing depth and problem-solving performance. This suggests that the cognitive processes engaged in sophisticated explanatory writing—analysis, synthesis, and justification—effectively transfer to applied problem-solving contexts.

The mechanism of this transfer was illuminated by the learning plan structure. When students were required to articulate a detailed plan for approaching different circuit types *before* engaging in practice or assessment, they subsequently executed these strategies with greater consistency and accuracy. This aligns with prior research by Pelaez (2002), which found that problem-based writing with structured planning improves academic performance in physiology by making implicit reasoning processes explicit.

A comparative glance at the 2024 cohort, which did not utilize learning plans, underscores this point. While those students also showed improved metacognitive awareness through journaling, the connection between their reflective insights and assessment performance was less direct. Some could produce insightful reflections on their errors yet struggled to apply those insights under timed assessment conditions. This indicates that reflective journaling alone may enhance awareness, but the addition of structured planning is crucial for bridging the gap between metacognitive insight and practical application.

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.

DISCUSSIONS

The findings from this study offer several important insights both in theory and in practice regarding the implementation and impact of Writing-to-Learn Pedagogy within the specific context of HBCU STEM education.

Theoretical Implications

This research extends the theoretical framework of WTLP by demonstrating the amplified value of integrating structured planning scaffolds within reflective cycles. While reflective journaling alone effectively fostered metacognitive awareness—consistent with findings by Zarestky et al. (2022)—the 2025 cohort's superior performance suggests that the planning component created a crucial bridge between reflection and action. This supports a potential modification to WTLP models for technical disciplines: a Reflection-Planning-Application cycle may be more effective than reflection alone for developing transferable competencies.

Furthermore, the findings affirm Ennis's (1987) bifurcated taxonomy, illustrating that dispositions and abilities can develop concurrently yet along distinct trajectories. The robust growth in confidence and inquisitiveness, paired with more tempered growth in intellectual humility and judiciousness, suggests that the affective and evaluative dimensions of critical thinking may require different or more sustained pedagogical attention within fast-paced technical courses.

Most significantly, persistent structural barriers - including financial constraints, inadequate advising, and lack of targeted institutional support - continue to limit underrepresented students' access to and persistence in STEM pathways (TICAS, 2025). This study addresses a critical gap in the literature regarding scalable, sustainable pedagogical interventions within HBCU STEM contexts. As Ayers et al. (2025) note, HBCUs often face challenges related to "funding, research infrastructure, and a lack of targeted support" that can constrain the implementation of costly, resource-intensive intervention programs. The WTLP intervention described here—requiring only structured writing prompts and reflective journaling within existing course frameworks—offers a low-cost, high-impact approach that can be implemented without external funding or technological infrastructure. The finding that learning plans, a minimal addition to existing reflective practices, significantly enhanced the transfer of metacognitive insights to applied problem-solving is particularly important for resource-constrained institutions (Jackson, Revelle, & Maiden, 2026). This study thus provides empirical validation for a pedagogical approach that HBCU STEM faculty can implement immediately, contributing to what Dickens et al. (2025) describe as the need for "effective central leadership and sustained institutional support" operationalized at the classroom level.

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.
6. On the other hand, the study also surfaced practical challenges that must be navigated:
7. *Time Investment:* Successfully integrating WTLP requires intentional course redesign to embed writing activities sustainably without overwhelming content coverage.
8. *The AI Challenge:* The prevalence of generative AI presents a real challenge for take-home, open-ended writing tasks. 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.
9. *Faculty Support:* Instructors may benefit from professional development that couples WTLP strategies with asset-based teaching principles specific to HBCU contexts to maximize their effectiveness.

CONCLUSIONS

This study generates essential, equity-focused evidence about the effectiveness of WTLP within an HBCU context. The findings provide a foundation for future research that continues to refine pedagogical approaches supporting underrepresented STEM students. Ensuring that critical thinking development in STEM is both effective and inclusive requires ongoing, iterative inquiry that centers student voice and experience.

Preliminary instructor observations suggest the WTL method is effective, promoting student engagement and developing confidence in technical comprehension, while the research also critically examines the challenge posed by generative AI (e.g., ChatGPT) in open-ended online tasks.

The research demonstrates that a hybrid Writing-to-Learn Pedagogy intervention, particularly when enhanced with structured learning plans, can effectively cultivate both the dispositions and abilities of critical thinking among underrepresented STEM students at an HBCU. The 2025 cohort's marked growth in analytical skills, reflective depth, and the demonstrable link between writing quality and problem-solving performance provides compelling evidence for the value of integrating planning scaffolds into reflective practice.

The study also makes other contributions: it provides much-needed empirical data on WTLP efficacy within an HBCU context, operationalizes Ennis's critical thinking taxonomy for actionable classroom assessment, and highlights the importance of pedagogical structures that connect cognition to application. Importantly, it counters deficit perspectives by documenting how students from underrepresented backgrounds can develop sophisticated critical thinking when provided with structured, culturally attentive pedagogical tools.

Limitations and Future Directions

This study has limitations that point toward fruitful future inquiries. The single-institution context and modest sample sizes caution against overgeneralization. The lack of equivalent quantitative pre/post survey data for the 2024 cohort limits direct statistical comparison. Furthermore, variables such as instructor experience and minor course adjustments between years were not controlled for.

Future research should:

1. Employ longitudinal, mixed methods 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.
5. Investigate how students' identities as underrepresented learners in STEM intersect with their engagement in writing-to-learn activities, using interviews

and focus groups to surface student perspectives on what makes pedagogy meaningful and effective in their educational contexts.

As the STEM fields continue to strive toward greater diversity, equity, and inclusion, pedagogies that simultaneously build technical mastery, critical thinking, and student agency are essential. This study offers evidence that Writing-to-Learn Pedagogy, especially when thoughtfully structured with planning elements and implemented with an awareness of cultural context, represents a promising and impactful approach worthy of continued refinement and adoption in HBCUs and similar institutions dedicated to serving underrepresented scholars.

AI Use Disclosure Statement

For this article, AI was used for language refinement, organization suggestions, and reference checking.

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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.
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.

Bios

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