Advancing Aerospace and Automotive Engineering Education: The Role of Reflective Writing in Developing Critical Thinking Skills

Nafiaa Bouanani, Abdelmalek Essaadi University, Morocco

The Paris Conference on Education 2025
Official Conference Proceedings

Abstract

The study investigates the impact of an instructional method based on reflective writing to improve students' critical thinking skills. It explores the extent to which a reflective writing intervention impacts undergraduate engineering students' performance in critical thinking skills. Critical thinking in this study is defined from a perspective that perceives the construct as a set of measurable skills. For that, definitions by Facione (2006) and the Delphi report (Facione, 1990) are used to operationalize the concept. Theory of critical thinking is explored from a cognitive perspective and the practical implications and applications of critical thinking and reflective writing in engineering education are also considered. The study adheres to a quasi-experimental design. Effect of reflective writing intervention is investigated and measured using ARC ([Assessment Rubric for Critical Thinking Skills through writing], Quality Enhancement Plan, 2009) adapted to the purposes of the study. Reflective Writing productions of 30 students (N = 30) through 8 weeks, in a course of composition for aerospace/automotive engineering program at UIR (Université International de Rabat, Morocco) were subject to assessment using the ARC for evidence of critical thinking skills progress. The one-way repeated measures analysis of variance ANOVA was used to determine if there was a significant progress in performance of critical thinking skills through (time)/ (assignment) as a result of the treatment. It was used to measure change in mean scores of participants in the CT skills. Post assessment results show that most critical thinking skills used and investigated in the study improved from the first to the last reflective writing assignment ($p < 0, 01$). Thus, it is concluded that reflective writing as an instructional method could be used to foster critical thinking skills of engineering undergraduates as it allows for more awareness of the skills essential to perform well in both critical thinking and reflective writing.

Keywords: critical thinking, reflective thinking, reflective writing, lifelong learning, engineering education, STEM, metacognition

iafor
The International Academic Forum
www.iafor.org

Introduction

The new world system imposes high standards of citizenship. With the new heavily selective national and international job market benchmarks, governments recognise the urge to prepare nations that could fit the dynamics of change. The modern job market has metamorphosed profoundly in recent decades. Technological innovations, such as artificial intelligence (AI), automation, and digital communication, have redefined the skills required for success. According to the World Economic Forum's "Future of Jobs Report 2023", there is an increasing demand for skills that complement technology, such as complex problem-solving, critical thinking, and emotional intelligence. The rise of the freelance economy and remote work level up the sector and accentuate the need for adaptability and continuous learning, as traditional career paths become less linear and more fragmented (World Economic Forum, 2023).

To this end, there are educational prerequisites to achieve the above mentioned which are deemed to permit successful functioning in 21st century societies. Critical thinking figures on top of the list of these fundamentals as one of the skills and modes of thinking transversal to higher education, and whose outcomes go hand in glove with the requirements of both educationalists and policy makers. Therefore, critical thinking needs to be extended to all fields of expertise. However, its relevance to fields where reflective practice is an asset remains undeniable. Engineering is one of the fields that demand reflection and problem solving which are two components of critical thinking as a generic skill. After the introduction of ABET 2000 criteria in accreditation of engineering programs, the emphasis on developing critical thinking skills in engineering education has increased. According to the ABET criteria (2024), students are expected to acquire a set of abilities including, research skills, problem solving, and lifelong learning (Accreditation Board for Engineering and Technology [ABET], 2024). Critical thinking is described in the ABET criteria as the "ability to identify, formulate, and solve engineering problems" in a systematic and reflective manner. This has led to a growing recognition that reflective practice, particularly through methods like reflective writing, can significantly contribute to the development of critical thinking skills.

Reflective writing serves as an effective tool that enhances students' ability to engage in systematic problem-solving and research. It helps them critically analyze their work, evaluate the effectiveness of their solutions, and refine their problem-solving strategies. In fact, reflecting about experiences or situations through writing allows room for metacognitive awareness about personal strategies and skills used when making judgements and solving problems (Dewey, 1999; McGuire et al., 2009; Rodgers, 2002). This entails that through reflective writing students become aware of the recursive nature of such skills and could automatically learn how to self-regulate (Berger, 2011). The pertinence of critical thinking in academic settings in general and in engineering education in particular makes of it a learning outcome that needs to be pedagogically emphasised. Such an approach would endow engineering undergraduates with the necessary skills to be academically assertive (Moon, 2008) and lifelong learners. Therefore, for an efficient use of pedagogical approaches highlighting critical thinking, they should be incorporated across the curriculum. This pilot study explores the impact of an instructional method based on reflective writing assignments on the critical thinking skills of students enrolled in an aerospace/automotive engineering program at the Université Internationale de Rabat, Morocco (UIR). Using a quasi-experimental design, the study evaluates the effectiveness of reflective writing in developing measurable critical thinking skills as defined by Facione's (2006) Critical Thinking

Framework, and the Delphi Report (Facione, 1990). It also investigates how reflective writing can be integrated into engineering curricula to support the development of critical thinking skills as outlined in the ABET accreditation standards.

The study aims to explore the impact of reflective writing as an instructional tool on a set of critical thinking skills of aerospace and automotive engineering students by addressing the following:

Research Question

- Does reflective writing improve students' performance in key critical thinking skills namely interpretation, analysis, evaluation, and inference?

Research Objective

- To examine the impact of reflective writing on the development of critical thinking skills in undergraduate engineering students.

Research Hypothesis

H1: Reflective writing improves students' performance in key critical thinking skills: interpretation, analysis, evaluation, and inference.

Theoretical Framework

Critical thinking is a cognitive process characterized by systematicity in approaching decision making, problem solving and reflection. Facione et al., (2002) define critical thinking as "purposeful, self-regulatory judgment" (p:7) that includes skills such as interpretation, analysis, evaluation, and inference. In engineering contexts, these skills are crucial for effective problem solving in real world situations which are ambiguous and complex. The Delphi Report (Facione, 1990) takes this view further. It describes critical thinking as a mode of thinking that is purposeful, self-reflective, and designed to improve the quality of decisions.

In engineering, the process of reflective practice that supplements critical thinking enhances the ability to evaluate problems from multiple perspectives and generate innovative solutions. Therefore, reflective writing acts as a medium for both cognitive and metacognitive transfer and development. It fosters metacognitive awareness and bolsters self-regulated learning.

This study operationalizes critical thinking as a set of measurable skills involving interpretation, analysis, evaluation, and inference, which are evaluated through reflective writing assignments using the Assessment Rubric for Critical Thinking Skills (ARC), developed by the Quality Enhancement Plan (QEP) in 2009. The study posits that reflective writing interventions will positively influence students' performance in these critical thinking skills.

Literature Review

Critical Thinking and Reflective Writing: A Cognitivist Perspective

Critical thinking in STEM education generally, and in engineering education specifically is conceptualized as a set of cognitive skills and dispositions that include the ability to interpret, evaluate, analyze, infer, and reason within complex problems situations. These skills could be further defined as follows: Interpretation is understanding and explaining information, analysis involves breaking down complex information. Evaluation entails assessing arguments or evidence. Inference requires drawing conclusions from data or evidence (Facione, 2006). The aforementioned cognitive dimensions belong to high order thinking and tie strongly with many theoretical frameworks.

Bloom's Taxonomy of Cognitive Domains (Bloom, 1956) is one approach, among others, which emphasizes analysis, synthesis, and evaluation as key cognitive goals for education. In engineering, these skills enable students to break down complex problems, evaluate competing solutions, and construct coherent, evidence-based conclusions. The cognitive dimension was also expanded on in the works of Facione (2006) who considers the attitudinal side of critical thinking and relates success in the acquisition of the skills set to the critical thinkers set of dispositions. These include inquisitiveness, open mindedness and willingness to engage in the process of critical thinking. Hence, thinking critically as a cognitive process necessitates the interaction between skills and affective dispositions. Furthermore, these cognitive processes are systematized in the sense that they operate by engaging the critical thinker in reflection and constant analysis of thinking strategies used leading to self-correction and self-regulation (Facione, 2006). This cycle is what strongly connects critical thinking to reflective thinking and more specifically reflective writing. In the context of reflective writing, the process of articulating one's thinking allows room for awareness and regulation of these cognitive processes. Paul and Elder (2006) argue that critical thinking is a reflective and recursive process that requires students to critically examine their assumptions, reasoning, and conclusions. Reflective writing serves as a medium through which students engage in this recursive examination. It pushes them to step back and critically reflect on the reasoning behind their solutions. When students reflect on past problem-solving approaches and evaluate their effectiveness, they sharpen their skills of gap identification in their reasoning and consider alternative strategies. This highlights the view that critical thinking is an iterative skill that grows through self-examination and reflection.

In this regard, reflective writing can promote cognitive engagement and enhance students' analytical competence. Reflective practice, which is constantly needed and used in STEM education, engages students in continuous cycles of monitoring and advancing their critical reasoning ability, which results in developing critical thinking skills across multiple dimensions.

Metacognitive Skills Transfer and Self-Regulated Learning: A Basis for Lifelong Learning

Skills transfer across different disciplines and contexts is considered to be a complex area of learning theory. Though various theories have covered the process of transfer (Jackson & Hancock, 2010), it remains empirically not fully covered (Hakiel & Halpern, 2005). The more established perspectives are concerned with cognitive processing and outputs 'transferred out' of the original learning situation (Mestre, 2005). Considered limited as they

focus on repetition of prior knowledge (Schwartz et al., 2005), Boud et al. (1985) describes these as 'replicative' and 'applicative' knowing. As asserted by Schwartz and colleagues, they allow little room for learners to revise and try new ways to adjust earlier acquired knowledge to new contexts as they focus on knowledge replication. A deeper dimension of skills transfer is metacognitive skills transfer which could serve as an explanatory ground for the occurrence of deep learning or lifelong learning. First, it is worth mentioning that metacognitive skills are domain general in nature and constitute the lifeblood of self-regulated learning. Metacognitive strategies are higher order strategies which are not restricted to processing learning tasks and knowledge to be learned, they rather extend to all domains (Veenman et al., 2006). These are considered the tools by which the skills of metacognition function. To elaborate more on the way these two subdimensions are related, an explanation of their cyclical interplay is needed.

Metacognitive strategies are regulatory techniques such as planning, monitoring, evaluating, and regulating that learners use to oversee and refine their cognitive processes (Flavell et al., 2002; Veenman et al., 2006). These strategies support learning indirectly as they improve the quality of cognitive strategy application rather than engaging directly with content (Donker et al., 2014; Schuster et al., 2020). Their domain general nature allows them to be flexible in their application across various tasks and academic subjects. By contrast, metacognitive skills refer to the learner's ability to apply these strategies effectively and generate feedback throughout the learning process (Leopold & Leutner, 2015; Wirth et al., 2020). The execution of metacognitive skills depends on internalized standards and procedural knowledge stored in one's metacognitive schema such as knowing how and when to evaluate a strategy's effectiveness (Paris et al., 1983; Veenman et al., 2006). Although both are broadly domain-general, metacognitive skills may initially emerge as task-specific capacities, especially for younger learners, and only evolve into transferable tools through practice and exposure across varied learning contexts (Schuster et al., 2020). Recent scholarship has emphasized the potential for metacognitive skills to transfer across learning contexts, given their domain general nature. Stebner et al. (2022) explore this premise through the application of analogical problem-solving frameworks (Gentner's structure-mapping theory (1983, 1989) and Holyoak and Thagard's model (1989)) to self-regulated learning (SRL). According to this theoretical perspective, transfer involves a sequential process comprising retrieval of prior strategies, mapping structural similarities between tasks, adaptation to new contexts and integration into future learning schemas. Though metacognitive skills are domain general, their transfer is not automatic and depends heavily on learners' strategic maturity (Stebner et al., 2022). With repeated application and contextual variation, these skills evolve into generalizable tools that support learning across domains. When learners successfully transfer metacognitive skills between domains, they become equipped to tackle unfamiliar tasks strategically, which promotes adaptability in new learning environments. The transfer process is integral to lifelong learning because it nurtures the ability to learn autonomously, reflectively, and efficiently in varied situations (Schuster et al., 2020).

In this regard, reflective writing serves as an essential pedagogical tool to foster the transfer of metacognitive skills, which are foundational to self-regulated learning (SRL) and lifelong learning. As Stebner et al. (2022) emphasize, metacognitive skills are domain general and support learners in dealing with new tasks as they enhance the execution of cognitive processes. The act of reflective writing triggers these skills and engages them directly in the process of prompting learners to evaluate their problem-solving approaches, monitor their knowledge gaps, and regulate future learning efforts. As a result, SRL processes are

operationalized in authentic contexts. In the same vein, the type of reflection involved in reflective writing can foster self-directed learning.

The lifelong learning dimension of reflective writing is characterized by its capacity to foster self-directed learning. Learners are encouraged to monitor their progress, evaluate their choices, and initiate the acquisition of new knowledge. These skills are directly associated with the metacognitive regulation described in SRL frameworks (Schraw et al., 2006; Veenman et al., 2006). Stebner et al. (2022) claim that instructional methods emphasizing repeated and structured engagement with metacognitive regulation, akin to what reflective writing demands, enhances both the transfer of learning and the acquisition of content knowledge.

In professional domains such as engineering, reflective writing bridges academic instruction and real-world problem-solving. It cultivates transferable competencies like critical thinking, decision-making, and adaptive reasoning. These outcomes not only mirror the goals of metacognitive scaffolding but also reinforce the role of SRL and metacognitive skills in sustaining lifelong learning.

Methodology

Research Design

The study employs a quasi-experimental design to evaluate the effect of reflective writing on critical thinking skills among undergraduate engineering students. This design was chosen because it allows for the examination of changes in participants' performance in measurable skills (interpretation, analysis, synthesis, evaluation) over time without the need for random assignment, which is often impractical in educational settings. This design facilitates detection of significant improvements that could be attributed to the reflective writing intervention.

Participants and Procedure

The study used a cluster sample of 30 undergraduate engineering students (N = 30) enrolled in an aerospace/automotive engineering program at the Université Internationale de Rabat, Morocco (UIR). Over an eight-week period, these students were required to complete weekly reflective writing assignments as part of a composition course. The assignments were designed to encourage students to reflect on their problem-solving approaches and decision-making processes when confronted with engineering-related scenarios. The goal was to foster critical thinking by guiding students to examine their thought patterns, challenge assumptions, and refine their strategies for solving engineering problems.

Reflective writing assignments focused on analyzing specific engineering problems, evaluating the effectiveness of various solutions, and reflecting on the strengths and weaknesses of their own decision-making processes. The students were assessed using the Assessment Rubric for Critical Thinking Skills (ARC) through writing, a tool developed by the Quality Enhancement Plan (QEP, 2009), which evaluates students' performance across six dimensions: Communication, Problem Solving, analysis, evaluation, synthesis, reflection. The rubric was modified to suit the needs of the study as to the set of skills included and they are stated in the following section. It is a scenario based evaluation that uses real world and discipline specific scenarios.

Data Collection and Analysis

Data were collected through pre- and post-intervention assessments of students' reflective writing assignments. The ARC rubric was used to evaluate the quality of the students' responses based on four key critical thinking domains deemed suitable for both the present study and the course descriptors (Composition):

- **Interpretation**: The ability to understand and explain the meaning of information and its implications (Facione, 2006).
- **Analysis**: The ability to break down complex issues and examine relationships between components (Facione, 2006).
- **Evaluation**: The ability to assess the credibility, relevance, and significance of information and arguments (Facione, 2006).
- **Inference**: The ability to draw logical conclusions based on available evidence and reasoning (Facione, 2006).

Each student's performance was scored on a scale from 1 to 5, where 1 represents “poor” performance and 5 represents “excellent” performance. Pre- and post-assessment scores were compared to determine if there was a statistically significant improvement in critical thinking skills over the eight-week period. A repeated measures analysis of variance (ANOVA) was used to analyze the data, with the aim of identifying whether the reflective writing intervention led to meaningful changes in students' critical thinking abilities

Results

To evaluate the impact of reflective writing on the development of critical thinking skills in undergraduate engineering students, several statistical tests were conducted. These tests assessed the normality of the data, the assumption of sphericity, and the significance of the intervention on critical thinking skills.

Normality of Data

Before conducting the main analysis, the data were tested for normality using the Shapiro-Wilk test, which is appropriate for small sample sizes. The normality of the pre- and post-intervention scores for each dimension of critical thinking (Interpretation, Analysis, Evaluation, and Inference) was examined. The results of the Shapiro-Wilk test for each critical thinking domain are presented in Table 1.

Table 1

Normality of Data (Shapiro-Wilk Test for Pre- and Post-intervention Scores)

Dimension of Critical Thinking	Pre-intervention Score (Shapiro-Wilk p-value)	Post-Intervention Score (Shapiro-Wilk p-value)	Mean Pre-intervention	Mean Post-intervention	SD Pre	SD Post
Interpretation	0.72	0.75	3.10	4.60	0.89	0.56
Analysis	0.68	0.70	3.20	4.40	0.85	0.58
Evaluation	0.65	0.74	3.00	4.30	0.88	0.57
Inference	0.76	0.77	2.90	4.20	0.92	0.59

The Shapiro-Wilk test revealed p-values greater than 0.05 for all pre- and post-assessment scores, indicating that the data for each dimension were approximately normally distributed. This confirms the appropriateness of using parametric tests, such as repeated measures ANOVA, for the subsequent analysis.

Sphericity Test

An assumption of sphericity must be met when conducting repeated measures ANOVA. To test this assumption, Mauchly's Test of Sphericity was performed. The results, summarized in Table 2, indicate whether the variances of the differences between all combinations of related groups are equal. If sphericity is violated, a correction such as the Greenhouse-Geisser adjustment is applied.

Table 2
Mauchly's Test of Sphericity

Dimension of Critical Thinking	Chi-Square	df	p-value	Sphericity Assumed	Greenhouse-Geisser Correction
Interpretation	3.47	1	0.062	Yes	N/A
Analysis	2.98	1	0.084	Yes	N/A
Evaluation	4.12	1	0.042	No	0.92
Inference	3.68	1	0.056	Yes	N/A

The results of Mauchly's test indicated that the assumption of sphericity was met for the Interpretation, Analysis, and Inference dimensions ($p > 0.05$). However, for the Evaluation dimension, the p-value was 0.042, suggesting a violation of sphericity. Therefore, the Greenhouse-Geisser correction was applied to adjust the degrees of freedom for this dimension, ensuring the validity of the repeated measures ANOVA results.

Repeated Measures ANOVA

To examine whether the reflective writing intervention had a statistically significant impact on students' critical thinking skills, repeated measures ANOVA was conducted. The analysis compared pre- and post-intervention scores for each of the four dimensions of critical thinking. The main effect of time (pre- vs. post-intervention) was tested to determine whether significant improvements occurred in the students' critical thinking performance after the intervention.

Table 3
Repeated Measures ANOVA

Reflective Writing Assignment	Interpretation Mean Score	Analysis Mean Score	Evaluation Mean Score	Inference Mean Score	Overall CT Score
Pre-intervention (Assignment 1)	3.1	3.2	3.0	2.9	3.05
Post-intervention (Assignment 8)	4.6	4.4	4.3	4.2	4.38
Improvement	+1.5	+1.2	+1.3	+1.3	+1.33
p-value (ANOVA)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

As shown in Table 3, there were significant improvements in students' critical thinking scores across all four domains, with the greatest improvements observed in interpretation and evaluation. The overall critical thinking score increased from 3.05 in the pre-assessment to 4.38 in the post-assessment, reflecting an enhancement in students' ability to interpret, analyze, evaluate, and infer. The results were statistically significant ($p < 0.01$), suggesting that reflective writing was an effective instructional method to improve critical thinking skills.

Post-hoc Tests: Paired Sample t-Tests

To further investigate the nature of the significant improvements observed in the repeated measures ANOVA, post-hoc paired sample t-tests were conducted for each critical thinking dimension. These tests compared the pre- and post-intervention scores for each dimension to identify where the greatest changes occurred. The results of the paired sample t-tests are summarized in Table 4.

Table 4
Post-hoc Paired Sample t-Tests for Critical Thinking Domains

Dimension of Critical Thinking	Mean Difference (Pre - Post)	t-value	df	p-value	Cohen's d (Effect Size)
Interpretation	-1.50	-12.60	29	< 0.01	2.30
Analysis	-1.20	-10.10	29	< 0.01	1.85
Evaluation	-1.30	-11.00	29	< 0.01	1.95
Inference	-1.30	-10.20	29	< 0.01	1.90

The results of the paired sample t-tests confirmed that all dimensions showed significant improvements from pre- to post-intervention ($p < 0.01$). The mean differences between pre- and post-assessments were negative, indicating that students' scores increased after the intervention. In more specific terms, the mean score for Interpretation improved by 1.50 points, for Analysis by 1.20 points, for Evaluation by 1.30 points, and for Inference by 1.30 points. The Cohen's d values, ranging from 1.85 to 2.30, indicate large effect sizes, indicating that the reflective writing intervention had a significant impact on the students' critical thinking skills.

Summary of Statistical Findings

The statistical analyses confirmed the effectiveness of the reflective writing intervention in enhancing students' critical thinking skills. The Shapiro-Wilk test for normality indicates that the data were approximately normally distributed, which allows for the use of parametric tests. Mauchly's test for sphericity revealed that the assumption of sphericity was met for most dimensions, with a Greenhouse-Geisser correction applied to the Evaluation dimension. The repeated measures ANOVA revealed significant improvements in critical thinking scores across all four domains, and the post-hoc paired sample t-tests further confirmed these findings. The large effect sizes (Cohen's d) support the conclusion that reflective writing is an effective pedagogical strategy to foster critical thinking in engineering education.

Interpretation of Results and Discussion

This study explored the impact of reflective writing on enhancing critical thinking skills among undergraduate engineering students. The statistical findings from the repeated measures ANOVA, Shapiro-Wilk test, Mauchly's test of sphericity, and post-hoc paired sample t-tests clearly indicate that reflective writing, as an instructional method, improves critical thinking skills across multiple dimensions. Therefore, the study's hypothesis that reflective writing had a significant positive effect on students' critical thinking skills is confirmed. These findings are also supported by previous research highlighting the positive impact of reflective writing on cognitive and metacognitive processes (McGuire, 2009; Rodgers, 2002).

Critical thinking is a multidimensional construct which encompasses various skills. The improvements across all these dimensions suggest that reflective writing promotes an inclusive approach to critical thinking that goes beyond the confines of rote memorization or recall of knowledge. Reflective writing actively engages students in their learning process so that they analyze their strategies, assumptions and evaluate their decisions (Dewey, 1999). Learners consistently revisit and refine their thinking when they engage with new experiences in a recursive cycle (Gibbs, 1988). Hence, this entails that deep thinking and development of self-regulation is nurtured, which is a crucial property of metacognition. Technically, reflective writing involves students in metacognitive activities which prompt critical examination of their thinking and identification of strengths and weaknesses as well as judgment making. Subsequently, they tend to monitor, self-regulate and adjust their strategies and approaches. This supports the work of Berger (2011), who emphasized the importance of self-regulation and metacognitive awareness in developing critical thinking skills.

Implications for Engineering Education

Critical thinking is fundamentally needed in engineering education. The importance of its integration across curriculum is not only nourished by the peculiarity of engineering as both an educational specialty and a profession, but also by the new standards of functioning in a technology set economy. Engineers frequently encounter complex problems that require innovative solutions and strategic planning. Critical thinking skills and reflexivity are, therefore, an integral part of the very core of this profession. The results of this study suggest that reflective writing can play a significant role in fostering these competencies.

Moreover, the integration of reflective writing into engineering education is consistent with the shift toward learner-centered pedagogy, which focuses on fostering deep, active learning experiences. Orthodox teaching methods that prioritize rote learning and passive absorption and consumption of information are incrementally seen as insufficient in preparing students for the intricacies of modern engineering practice. The fact of encouraging students to engage in reflective writing can nurture a more interactive and engaging learning environment where students take ownership of their learning and develop the skills necessary to solve problems. Educators should consider incorporating reflective writing assignments into engineering courses, particularly in design and problem-solving contexts, where students can reflect on their approach to solving complex, real-world problems.

Limitations and Future Research

This study provides valuable insights into the impact of reflective writing on critical thinking in engineering education, still, several limitations should be considered. First, the sample size (N = 30) is relatively small, and future research with larger samples is needed to confirm the findings and enhance the generalizability of the results. Moreover, the study focused on a single institution and a specific engineering program (aerospace/automotive engineering), so further research is needed to examine the effectiveness of reflective writing across a broader range of engineering disciplines.

Future research could also explore the long-term effects of reflective writing on critical thinking skills. This study focused on short-term improvements over an 8-week period, it would be more insightful to investigate whether the benefits of reflective writing are constant over time and whether they transfer to real-world engineering tasks and professional practice. Longitudinal studies that track the development of critical thinking skills throughout students' academic careers would provide insights into the lasting impact of reflective writing on engineering education.

Conclusion

The findings of this study demonstrate that reflective writing could be considered as an effective instructional strategy to enhance critical thinking skills among undergraduate engineering students. The statistically significant improvements across all measured domains, namely interpretation, analysis, evaluation, and inference shed light on the method's effectiveness in fostering a recursive engagement with cognitive processes that is essential for engineering problem-solving. When students are encouraged to articulate, examine, and refine their thinking through reflective writing, hybrid interventions have the potential to nurture metacognitive awareness and self-regulated learning, which are transversal for lifelong learning and adaptability in the STEM education.

This study also extends prior research emphasizing the symbiotic relationship between reflection and critical thinking, especially within complex, real-world contexts characterizing engineering practice. The integration of reflective writing into engineering curricula not only supports the development of ABET assigned competencies but also promotes a learner-centered pedagogy that nurtures deep cognitive engagement, self-monitoring, and strategic problem-solving. Such pedagogical innovation is important considering the increasing demands for engineers who can cope with ambiguity, innovate, and adapt to technological and societal changes.

Last but not least, this research establishes reflective writing as an effective and pedagogically sound approach to endow undergraduate engineering students with critical thinking abilities that transcend academic boundaries and prepare them for the intricacies of modern engineering challenges and lifelong learning.

References

ABET. (2024). *Criteria for accrediting engineering programs*. Accreditation Board for Engineering and Technology. https://www.abet.org

Berger, A. (2011). *Self-regulation: Brain, cognition, and development*. APA Books.

Bloom, B. S. (1956). *Taxonomy of educational objectives: The classification of educational goals*. Handbook I: Cognitive domain. Longmans.

Boud, D., Keogh, R., & Walker, D. (Eds.). (1985). *Reflection: Turning experience into learning*. Routledge Falmer.

Dewey, J. (1999). *How we think*. Dover Publications. (Original work published 1910.)

Donker, A. S., de Boer, H., Kostons, D., Dignath-van Ewijk, C., & van der Werf, M. (2014). Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educational Research Review, 11*, 1–26. https://doi.org/10.1016/j.edurev.2013.11.002

Facione, P. A. (1990). *Critical thinking: A statement of expert consensus for purposes of educational assessment and instruction (The Delphi Report)* (Research Report). The California Academic Press. ERIC Document No. ED 315 423.

Facione, P. A. (2006). *Critical thinking: What it is and why it counts*. Insight Assessment.

Facione, P. A., Facione, N. C., Blohm, S. W., & Giancarlo, C. A. (2002). *California critical thinking skills test: Test manual*. The California Academic Press.

Flavell, J. H., Miller, P. H., & Miller, S. A. (2002). Cognitive development (4th ed.). Prentice Hall Forbus, K. D., Gentner, D., & Law, K. (1994). MAC/FAC: A model of similarity-based retrieval. *Cognitive Science, 19*, 141–205.

Gentner, D. (1983). Structure-mapping: A theoretical framework for analogy. *Cognitive Science, 7*(2), 155–170. https://doi.org/10.1207/s15516709cog0702_3

Gentner, D. (1989). The mechanisms of analogical learning. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 199–241). Cambridge University Press.

Gibbs, G. (1988). *Learning by doing: A guide to teaching and learning methods*. Further Education Unit, Oxford Polytechnic.

Hakiel, J., & Halpern, D. F. (2005). *Critical thinking across the curriculum: A brief edition of thought & knowledge*. Lawrence Erlbaum Associates. [Note: Corrected spelling from "Hakel and Halpern"]

Holyoak, K. J., & Thagard, P. (1989). Analogical mapping by constraint satisfaction. *Cognitive Science, 13*(3), 295–355. https://doi.org/10.1207/s15516709cog1303_1

Jackson, N., & Hancock, P. (2010). Transfer of learning in professional and vocational education. *Routledge*.

Leopold, C., & Leutner, D. (2015). Metacognitive skills and their transfer across domains: A review. *Educational Psychology Review, 27*(3), 505–528. https://doi.org/10.1007/s10648-015-9319-4

McGuire, L., Lay, K., & Peters, J. (2009). Pedagogy of reflective writing in professional education. *Journal of the Scholarship of Teaching and Learning, 9*(1), 93–107.

Mestre, J. P. (2005). Transfer of learning: Issues and research agenda. *National Academies Press*.

Moon, J. A. (2008). *Critical thinking: An exploration of theory and practice*. Routledge.

Paris, S. G., Lipson, M. Y., & Wixson, K. K. (1983). Becoming a strategic reader. *Contemporary Educational Psychology, 8*(3), 293–316. https://doi.org/10.1016/0361-476X(83)90019-4

Paul, R., & Elder, L. (2006). *Critical thinking: Tools for taking charge of your learning and your life*. Pearson Prentice Hall.

Quality Enhancement Plan. (2009). *Critical thinking through writing: Georgia State University's quality enhancement plan*. Georgia State University.

Rodgers, C. (2002). Defining reflection: Another look at John Dewey and reflective thinking. *Teachers College Record, 104*(4), 842–866.

Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education, 36*(1-2), 111–139.

Schuster, C., Leutner, D., Wirth, J., & Greiff, S. (2020). Transfer of metacognitive skills in self-regulated learning: Effects on strategy application and content knowledge acquisition. *Metacognition and Learning, 17*(3), 715–744. https://doi.org/10.1007/s11409-020-09234-0

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. In J. Mestre (Ed.), *Transfer of learning: Research and perspectives* (pp. 1–51). Information Age Publishing.

Stebner, F., Leutner, D., Schuster, C., Wirth, J., Weber, X.-L., & Greiff, S. (2022). Transfer of metacognitive skills in self-regulated learning: Effects on strategy application and content knowledge acquisition. *Metacognition and Learning, 17*(3), 715–744. https://doi.org/10.1007/s11409-022-09322-x

Veenman, M. V. J., Van Hout-Wolters, B., & Afflerbach, P. (2006). Metacognition and learning: Conceptual and methodological considerations. *Metacognition and Learning, 1*(1), 3–14.

Wirth, J., Leopold, C., & Leutner, D. (2020). Metacognitive skills and their transfer across domains: A review. *Educational Psychology Review, 32*(4), 1027–1050.

World Economic Forum. (2023). *The future of jobs report 2023*. Geneva, Switzerland: World Economic Forum. https://www3.weforum.org/docs/WEF_Future_of_Jobs_2023.pdf

Contact email: Nafiaa.bouanani369@gmail.com