INTEGRATING ARTIFICIAL INTELLIGENCE INTO ENGINEERING EDUCATION: A CDIO-ALIGNED INSTRUCTIONAL DESIGN APPROACH

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ABSTRACT

Artificial Intelligence (AI) has emerged as a transformative technology in engineering education; however, its pedagogical value depends on structured integration within established educational frameworks. This study investigates the impact of AI-supported instruction on student academic achievement when designed and implemented in alignment with the CDIO (Conceive-Design-Implement-Operate) framework. A quasi-experimental research design was employed in an undergraduate engineering course in Digital Logic. The experimental group participated in AI-supported, CDIO-aligned learning activities emphasizing active learning and integrated learning experiences, while the control group received traditional instruction. Student achievement was measured using pre- and post-tests, and data were analyzed using analysis of covariance (ANCOVA) and effect size calculations. The results demonstrate a statistically significant improvement in learning outcomes for students exposed to AI-supported instruction. The findings provide empirical evidence that AI, when embedded within CDIO-aligned pedagogy, enhances student achievement and supports evidence-based curriculum innovation in engineering education. Specifically, the experimental group achieved a mean post-test score of 82.60 compared to 77.31 in the control group, and ANCOVA results showed a statistically significant difference ($F(1,133)=22.47$, $p<.001$).

KEYWORDS

Artificial Intelligence, Engineering Education, Active Learning, Student Achievement, CDIO Standards 2, 5, 7-8, 11-12

INTRODUCTION

Engineering education is undergoing rapid transformation due to advances in digital technologies and artificial intelligence. Contemporary engineers are expected not only to master disciplinary knowledge but also to apply analytical reasoning, problem-solving, and adaptive skills in complex, technology-rich environments. Despite the efficiency of lecture-based instruction in conveying concrete knowledge, it often fails to cultivate active learning habits or higher-order competencies (Fan et al., 2025). This aligns with the "logical chain" theory in engineering education, which posits that Learning Behaviors drive Competence Development, which in turn results in Academic Achievement (Prince, 2004). However, the impact of AI remains a subject of ongoing academic debate. While GenAI has been used to enhance learning efficiency, initiative, and creativity, some scholars caution against the potential "competence paradox." Castillo and Saavedra (2024) argue that students in AI-assisted environments may develop proficiency in data analytics but lack the "experiential scaffolding" required to navigate novel, real-world ambiguities. Conversely, Chiang et al. (2024) found that virtual and online learning environments can actually foster superior problem-solving skills compared to face-to-face settings. They attribute this effect to increased opportunities for self-directed exploration, which builds students' confidence and autonomy.

As a result, engineering education institutions are increasingly exploring AI-supported instructional approaches to enhance learning effectiveness. The CDIO framework provides a comprehensive structure for curriculum design, teaching, learning, and assessment in engineering education. CDIO emphasizes the education of engineers who can conceive, design, implement, and operate complex engineering systems in real-world contexts. Within this framework, learning experiences must be active, integrated, outcome-based, and continuously evaluated. Despite growing interest in AI-enhanced learning, many implementations lack alignment with robust pedagogical frameworks and are introduced without systematic evaluation of learning outcomes. This study addresses this gap by examining the effect of AI-supported instruction embedded explicitly within CDIO-aligned learning experiences. The primary research question guiding this study is: Does AI-supported instruction, designed in alignment with CDIO Standards, significantly improve student academic achievement compared to traditional instruction**?**

CDIO FRAMEWORK AND PEDAGOGICAL ALIGNMENT

The CDIO (Conceive–Design–Implement–Operate) framework provides a comprehensive model for engineering education that integrates curriculum design, teaching, learning, and assessment around the lifecycle of real-world engineering systems. In this study, "CDIO-aligned" refers specifically to the intentional alignment of instructional activities, learning outcomes, and assessment practices with selected CDIO Standards and syllabus competencies, particularly those emphasizing active learning, systems thinking, and professional skills development.

Guided by this framework, learners move beyond rote memorization toward deep learning by applying technical foundations to the conception, design, implementation, and operation of complex systems. This approach not only strengthens core engineering competencies but also fosters leadership capacity and ethical awareness needed to navigate the societal implications of contemporary research and development (Malmqvist et al., 2023; Rosén et al., 2024).

Within this context, AI-supported instruction can be interpreted through Biggs & Tang's (2011) Constructive Alignment model. As a teaching and learning activity, AI integration is considered "aligned" insofar as it supports the intended CDIO syllabus learning outcomes and is reinforced through outcome-based assessment practices, particularly those reflected in CDIO Standard 11.

CDIO Standard 2: Learning Outcomes

CDIO Standard 2 (Learning Outcomes) emphasizes that intended learning outcomes should be consistent with the CDIO Syllabus and include disciplinary knowledge as well as personal and interpersonal skills. In this study, AI-supported activities were aligned with course learning outcomes in Digital Logic, reinforcing conceptual understanding while supporting analytical reasoning and problem-solving. Learning outcomes addressed included as follows:

- Understanding and application of Digital Logic concepts
- Analytical reasoning and system-level thinking
- Independent problem-solving and reflective learning

CDIO Standard 5: Design-Implement Experiences

CDIO Standard 5 (Design-Implement Experiences) requires that students engage in design and implementation tasks. AI was integrated as a cognitive scaffold during these phases, enabling students to analyze problems, generate solutions, and iteratively refine their designs.

- Students used AI-supported prompts to:
- Decompose engineering problems
- Test logical designs
- Evaluate alternative solutions

CDIO Standard 7: Integrated Learning Experiences

CDIO Standard 7 (Integrated Learning Experiences) highlights the integration of technical knowledge with professional skills. The instructional design combined Digital Logic concepts with AI-facilitated inquiry and reflection, supporting deeper understanding and application.

CDIO Standard 8: Active Learning

CDIO Standard 8 (Active Learning) emphasizes student engagement through experiential and interactive learning. AI-supported instruction promoted active learning by encouraging exploration, questioning, and self-directed problem solving rather than passive content consumption.

CDIO Standards 11 and 12: Assessment and Evaluation

CDIO Standard 11 (Learning Assessment) and Standard 12 (Program Evaluation) guided the research methodology through the use of valid assessment instruments and systematic comparison between instructional approaches.

Table.1 summarizes the alignment between the instructional design, research methodology, and the relevant CDIO Standards addressed in this study.

Table 1. Alignment of the Study with CDIO Standards

CDIO Standard	CDIO Standard Description	Implementation and Evidence in This Study
Standard 2	Intended learning outcomes are aligned with the CDIO Syllabus and include disciplinary knowledge as well as personal and interpersonal skills	Course learning outcomes in Digital Logic were explicitly aligned with AI-supported activities to strengthen conceptual understanding, analytical reasoning, and problem-solving skills
Standard 5	The curriculum includes design-implement experiences that are integrated into the program	Students engaged in AI-supported design and implementation tasks, using AI as a cognitive scaffold to analyze problems, generate solutions, and iteratively refine digital logic designs
Standard 7	Integrated learning experiences combine disciplinary knowledge with personal and interpersonal skills	Instructional activities integrated Digital Logic content with AI-facilitated inquiry, reflection, and reasoning to support deeper learning and application
Standard 8	Active learning methods engage students directly in the learning process	AI-supported instruction promoted active learning through exploration, questioning, self-directed problem solving, and iterative feedback
Standard 11	Assessment methods measure the achievement of intended learning outcomes	Student achievement was evaluated using validated pre- and post-tests aligned with course learning outcomes and analyzed using ANCOVA
Standard 12	Program evaluation processes ensure continuous improvement based on evidence	A systematic comparison between AI-supported and traditional instruction provided evidence for instructional effectiveness and curriculum enhancement

INSTRUCTIONAL DESIGN AND AI INTEGRATION

The AI-supported instructional model was designed to complement, not replace, instructor-led teaching. AI tools were embedded into learning activities to support:

- Conceptual clarification
- Guided inquiry
- Formative feedback

The instructor remained responsible for instructional planning, facilitation, and assessment, while AI functioned as an adaptive learning support.

- Learning activities followed the CDIO learning cycle and included:
- Problem conception and analysis
- Logical design and modeling
- Implementation and testing
- Reflection and evaluation

RESEARCH METHODOLOGY

This study employed a mixed-methods, quasi-experimental research design, integrating both quantitative and qualitative approaches to evaluate the effectiveness of AI-supported instruction within the CDIO framework. A pre-test-post-test control group design was used. Participants (N = 136) were assigned to two groups based on pre-existing class groupings:

- Experimental group: Received AI-supported instruction aligned with CDIO standards.
- Control group: Received traditional lecture-based instruction, with no use of AI tools permitted during class assignments.

Quantitative Instruments and Analysis

Student achievement was measured using instructor-developed achievement tests aligned with Digital Logic course learning outcomes. These assessments were reviewed for content validity by subject matter experts to ensure alignment with the course syllabus and CDIO-based learning objectives prior to administration. The same test instrument was used for both pre-test and post-test measurements.

Data were analyzed using as follows:

- Descriptive statistics for pre- and post-test scores
- Independent-samples t-tests for group comparisons
- Analysis of Covariance (ANCOVA) to control for baseline differences
- Effect size calculations (Cohen's d, partial η^2)

Qualitative Data Collection and Analysis

To gain insights into student experiences with AI integration, semi-structured interviews and open-ended responses were collected from a subset of the experimental group. Responses were analyzed using thematic analysis to explore perceptions of AI as a cognitive support tool and its role in active, integrated learning experiences.

Instructional Intervention: The 5S Prompting Strategy

We developed a 5S Prompting Framework that guided students in interacting with AI (e.g., ChatGPT). This framework supported structured inquiry and reflection throughout the CDIO phases (Conceive-Design-Implement-Operate).

Table. 2 illustrates how each step of the 5S Prompting Framework supports specific phases of the CDIO (Conceive- Design-Implement- Operate) learning cycle, demonstrating the pedagogical alignment between AI-supported prompting strategies and CDIO-based instructional design.

Table 2. Mapping of the 5S Prompting Framework to CDIO Learning Phases

5S Step	**Purpose**	**Example Function in CDIO Phase**
Set the Scene	Define context and AI role	***Conceive:*** Clarify system boundaries with AI as expert
Specify	Provide task constraints	***Design:*** Define input parameters and methods
Structure	Request logical organization	***Design/Implement***: Request tabular or step-wise output

Simplify	Request analogies for conceptual clarity	***Implement:*** Reinforce understanding through simplification
Share Feedback	Reflect and compare results	***Operate:*** Debug and verify personal understanding

Students were instructed to document their 5S sequences and apply the framework during lab tasks, supporting CDIO-aligned design-implement experiences.

RESULTS

A total of 136 students completed both the pre-test and post-test assessments. The baseline performance of both groups was comparable, confirming initial equivalence as follows:

- Control group (n = 58): M = 69.93, SD = 5.94
- Experimental group (n = 78): M = 69.91, SD = 6.02

Following the intervention, the experimental group exhibited statistically significant improvement in learning outcomes.

Table 3. Post-Test Performance

Group	**Post-test Mean (SD)**	**Median**
Control	77.31 (7.33)	79.00
Experimental	82.60 (5.99)	84.00

An independent-samples t-test showed that the experimental group significantly outperformed the control group:

- $t(134) = 4.88$, $p < .001$, Cohen's $d = 0.72$ (large effect)

An ANCOVA, controlling for pre-test scores, confirmed the intervention effect:

- $F(1, 133) = 22.47$, $p < .001$, partial $\eta^2 = 0.14$

Qualitative Findings

The study sample consisted of 136 engineering students enrolled in a Digital Logic course (2 ECTS credits; 48 total instruction hours), of whom 58 were assigned to the control group and 78 to the experimental group. The course structure included 16 hours of lectures and 32 hours of seminar-based instruction.

To complement the quantitative findings, a qualitative component was incorporated using semi-structured interviews. A subset of participants from the experimental group (n=8) was selected using random sampling to capture a range of student experiences with AI-supported instruction. Each interview lasted approximately 20 minutes and followed a semi-structured protocol designed to explore students' perceptions of AI as a cognitive support tool, its role in problem-solving, and its influence on learning engagement.

Interview data were analyzed using thematic analysis. Responses were transcribed, coded iteratively, and organized into emergent themes reflecting common patterns in student experiences. These qualitative insights were used to contextualize and interpret the quantitative results.

Thematic analysis of qualitative responses revealed several recurring themes:

- AI as Scaffolding: Students described the AI as a "logical thinking partner."
- Prompting Clarity: The 5S strategy helped students articulate problems clearly.
- Learning Ownership: Students valued the self-directed, feedback-driven environment.

These findings suggest that AI-supported instruction, when aligned with CDIO principles, not only improves academic performance but also enhances cognitive engagement and student agency.

This study provides empirical evidence that AI-supported instruction, when explicitly designed in alignment with CDIO Standards, enhances student academic achievement and supports constructive, student-centered learning.

Alignment with CDIO Principles

- Standard 2 (Learning Outcomes): Improved analytical reasoning and digital logic mastery
- Standard 5 (Design-Implement): AI prompted iterative problem-solving
- Standard 7 (Integrated Learning): Combined technical and reflective skills
- Standard 8 (Active Learning): Enabled exploratory, feedback-rich inquiry
- Standards 11 & 12: Assessment and evaluation validated the intervention's effectiveness

The AI engagement was measured through in-class assignments for Digital Logic class. The students in the experimental group was allowed using AI during class, whereas the control group was not allowed AI usage. The strong correlation between AI engagement and student performance ($r = 0.804$) further indicates that students used AI not merely for answers but as a cognitive partner, facilitating the development of higher-order thinking skills. This aligns with the UNESCO educational pillars of learning to know, to do, and to live together (Delors, 1996), reinforcing the social and intellectual dimensions of collaborative, technology-enhanced learning. The statistically significant improvement observed in the experimental group (Δ=12.69 vs. Δ=7.38) suggests that AI-supported instruction effectively promotes deeper learning aligned with CDIO Standard 8 (Active Learning).

The integration of AI tools within CDIO also addresses critiques such as those posed by Baylis (2007) regarding unstructured collaboration. In contrast, our 5S Prompting Framework ensures structured interaction, reducing ambiguity and promoting clarity in problem decomposition, hypothesis testing, and logical reasoning.

Descriptive statistics indicated initial equivalence between groups (Control: M=69.93, SD=5.94; Experimental: M=69.91, SD=6.02). Following the intervention, the experimental group's mean post-test score was 82.60 (SD=5.99), significantly higher than the control group's 77.31 (SD=7.33). Independent-samples t-test results confirmed this difference ($t(134)=4.88$, $p<.001$, Cohen's $d=0.72$). ANCOVA controlling pre-test scores further validated the intervention effect ($F(1,133)=22.47$, $p<.001$, partial $\eta^2=0.14$).

CONCLUSION

This study demonstrates that AI-supported instruction, when explicitly aligned with CDIO standards, results in significant and meaningful gains in student learning outcomes. The experimental group achieved higher post-test performance, supported by a large effect size and strong student-AI engagement correlation. These findings highlight the value of integrating AI tools within structured educational frameworks, such as CDIO, to enhance student-centered, inquiry-driven learning in engineering education.

From a practical perspective, the 5S Prompting Framework provides a scalable model for integrating AI into CDIO-based curricula, ensuring academic rigor while fostering critical thinking, reflection, and lifelong learning competencies. Future research should explore the long-term impact of AI-supported instruction across disciplines and its potential to support curriculum-wide innovation in engineering programs.

These findings offer several key takeaways for CDIO educators. First, AI tools can serve as effective cognitive scaffolds when integrated through structured prompting strategies such as the 5S Framework. Rather than replacing instruction, AI supports students in navigating complex problem-solving tasks by promoting clarity, logical reasoning, and reflective learning. Second, embedding AI-supported activities within the design-implement-operate phases of the CDIO cycle enhances deeper learning by fostering iterative exploration, hypothesis testing, and real-time feedback. Finally, the use of pre and post-assessment data provides strong empirical support for the validity and effectiveness of AI-enhanced, CDIO-aligned instructional models. These results reinforce the potential of combining pedagogically grounded design with emerging technologies to advance engineering education.

This study is subject to several limitations. First, it was conducted within a single course at a single institution, which may limit the generalizability of the findings to other disciplinary, institutional, or cultural contexts. Second, the relatively narrow scope of implementation constrains the ability to assess the scalability of AI-supported instruction across multiple courses or programmatic levels. Third, the potential for a Hawthorne effect cannot be excluded, as participants in the experimental group may have altered their behavior due to increased attention or the novelty of AI integration. Future research should replicate this study across diverse institutional settings, disciplines, and course formats, and consider multi-course or program-level implementations to strengthen external validity.

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