BRIDGING KNOWING AND DOING THROUGH HABIT FORMATION IN CDIO EDUCATION

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ABSTRACT

Oguz han Engineering and technology university of Turkmenistan, one of CDIO's youngest members, demonstrates how habit formation can ease CDIO implementation for new adopters struggling with daily framework integration. This quasi-experimental study embedded CDIO competencies as automated daily micro-habits within engineering lessons, comparing intervention and control groups through digital assessment over 13 weeks. Participants were second-year Cyber-Physical Systems students (n=25 per group). The phased intervention progressed from individual phase routines to full lifecycle integration, yielding a large effect size (d = 1.12) on the primary CDIO competency rubric. Minimal faculty training requirements and existing LMS infrastructure suggest potential for scalable adoption across disciplines, with implications for CDIO Standards 1, 2, 5, 7, 8, and 10. Cross-disciplinary and longitudinal validation remains a direction for future work.

KEYWORDS

CDIO framework, habit formation, micro-habits, engineering education, IoT education, automated assessment, Standards: 1, 2, 5, 7, 8, 10

INTRODUCTION

Oguz han Engineering and technology university has established regional CDIO leadership through five consecutive conference contributions (Orazov et al., 2025a; Mezilov et al., 2024), spanning language-integrated curricula (Orazov et al., 2025a), SUSI YWLP leadership programs (Garlyyeva et al., 2025), six-month skill frameworks (Orazov et al., 2025b), and mechatronics implementations (Mezilov et al., 2024).

Modern engineering demands integrated technical-professional competencies that traditional approaches fail to deliver. The CDIO Initiative provides a comprehensive solution (Berggren et al., 2002; Lynch et al., 2006; Edström et al., 2020), embedding engineering science within authentic lifecycle contexts—from conception through operation—enabling mastery of complex systems.

CDIO Implementation Gap

Despite its widespread adoption across more than 200 institutions worldwide and its detailed Syllabus 2.0 outlining specific learning outcomes, consistent daily integration of CDIO phases remains a persistent challenge, particularly for newer adopting institutions. Traditional implementation strategies frequently confine CDIO application to isolated project weeks or capstone experiences, resulting in superficial engagement rather than the deep, automatic competency execution that characterizes professional practice. Faculty often struggle to embed all four phases systematically into regular coursework, leading students to treat CDIO as an occasional framework rather than a habitual problem-solving approach (Woollacott, 2009). This creates a fundamental knowing-doing gap where theoretical understanding of CDIO principles fails to translate into consistent, reflexive application across diverse learning contexts. New adopters particularly face resource constraints, faculty training gaps, and curriculum integration challenges that hinder sustainable implementation beyond demonstration projects.

Habit Formation as Solution

This paper addresses CDIO implementation barriers through micro-habits—2–5-minute daily routines embedding all four phases within existing lessons (Clear, 2018). The theoretical basis for applying micro-habit automation to curriculum change rests on two complementary bodies of evidence: Lally et al.'s (2010) empirical modelling showing that small, context-specific repetitions accumulate into durable behavioral change within 18–254 days, and Bandura's (2006) self-efficacy theory, which holds that repeated successful performance in incremental tasks progressively builds the confidence and automaticity needed for complex professional practice. Together, these frameworks suggest that decomposing CDIO lifecycle competencies into minimal daily actions—triggered by environmental cues and reinforced through immediate feedback—can convert episodic engagement into habitual professional behaviour without requiring wholesale curriculum redesign. Using cueing, repetition, minimal friction, and digital reinforcement, complex competencies decompose into scalable micro-practices that leverage existing lesson structures to build automaticity. Arduino-based IoT development serves as the course subject within which micro-habits are embedded: students practice CDIO phases through smart home appliance tasks, with immediate digital progress tracking providing the reinforcement loop that bridges initial conscious effort toward unconscious competence. While the implementation is demonstrated in an IoT context, the micro-habit architecture itself is discipline-agnostic and adaptable to other engineering domains.

Research Objectives

This study pursues three objectives:

- Validate phased micro-habit framework progressing from individual CDIO phase mastery to full-cycle integration
- Test automated digital assessment infrastructure for real-time competency tracking at scale
- Compare CDIO competency and self-efficacy outcomes between a habit-based micro-habit intervention and conventional weekly CDIO instruction, using four indicators of success: CDIO rubric composite scores, habit completion rates, self-efficacy gains, and project scores.

The paper presents: Theoretical Framework (CDIO and habit science), Practical Implementation (IoT specifications), Experimental Design (standardized instruments), Results, and implications for CDIO reform. Success is defined as improvement in CDIO rubric composite scores, habit completion rates, self-efficacy, and project scores relative to conventional instruction.

THEORETICAL FRAMEWORK

CDIO Framework Foundations

The Conceive-Design-Implement-Operate (CDIO) framework establishes engineering education as a comprehensive product lifecycle process rather than fragmented technical training. Table 1: CDIO Phases and Core Competencies delineates the four core phases with their definitions, representative activities, and alignment to CDIO Syllabus 2.0:

Table 1. CDIO Phases and Core Competencies

Phase	Definition	Example Activities	Syllabus Alignment
Conceive	Define customer needs, problem scope, technical requirements	User analysis, problem statements, scoping	1.1–1.4
Design	Solution architecture, component selection, trade-off analysis	Block diagrams, solution generation, decision matrices	2.1–2.4
Implement	Build, test, verify solution functionality	Prototyping, coding, quality assurance	3.1–3.3
Operate	Deploy, maintain, continuous improvement	Testing protocols, troubleshooting, reflection	4.1–4.3

Habit Formation Mechanisms

Automaticity emerges through the cue-craving-response-reward loop, converting deliberate effort into unconscious execution (Clear, 2018). Four principles accelerate this in education: Obvious cues trigger behaviors; Attractive actions align with professional identity; Easy tasks take <2 minutes; Satisfying reinforcement strengthens neural pathways.

Meta-analyses confirm small, repeated actions compound into substantial change within 18-254 days, with engineering competencies accelerating due to contextual specificity (Lally et al., 2009). These mechanisms convert episodic CDIO awareness into reflexive daily practice.

CDIO-Habit Integration Model

The proposed integration systematically maps habit formation principles onto CDIO micro-habits, creating a scalable behavioral architecture for competency automaticity. Table 2: Habit Principles Applied to CDIO Micro-Habits illustrates this operationalization:

Table 2. Habit Principles Applied to CDIO Micro-Habits

Principle	Conceive (2 min)	Design (3 min)	Implement (5 min)	Operate (3 min)
Obvious	Lesson start prompt	Post-Conceive cue	Pre-coding checklist	Post-test reflection
Attractive	"Smart home engineer" identity	Arduino showcase	Code execution	Problem-solving mastery
Easy	Problem template	2-solution minimum	1-line pseudocode	Test scenario template
Satisfying	LMS progress bar	Peer gallery vote	Code runs successfully	Learning point recorded

Each 2–5-minute practice builds sequential mastery through temporal stacking (Conceive→Design→Implement→Operate), culminating in reflexive full-cycle execution while maintaining fidelity to CDIO Syllabus 2.0 outcomes.

PRACTICAL IMPLEMENTATION

Overview of the Phased Micro-Habit Strategy

This intervention embeds all four CDIO phases into daily 2–5-minute learning routines, enabling gradual integration without curriculum redesign. Students progress from isolated phase mastery (Weeks 1–4) to integrated full-cycle routines (Weeks 9–13), converting discrete micro-actions into reflexive professional competency.

The experimental design maintained rigorous control through two parallel groups of second-year Cyber-Physical Systems students (n = 25 per group, age M = 19.4 years, SD = 0.8; 72% male) undertaking identical IoT Arduino-based smart home appliance lessons. Both groups received comprehensive baseline CDIO instruction per established standards, including structured phase explanations, instructor-modeled examples from authentic contexts, and scaffolded practice opportunities, ensuring equivalence across content delivery, project complexity, and assessment standards.

The control group received weekly 10-minute “CDIO Spotlight” sessions (one phase per week), supplemented by instructor exemplars—replicating typical CDIO adoption patterns. Control students completed the same Google Forms instruments and CDIO Micro-Habit Rubric as the experimental group, but without LMS prompts, habit stacking cues, or real-time dashboards.CDIO Micro-Habit Rubric was applied to all submissions, enabling direct comparison across groups.

The experimental group received identical instruction systematically augmented by daily micro-habits triggered by LMS prompts, temporally stacked onto lesson transitions, and reinforced through real-time progress dashboards. This methodological equivalence isolates habit formation as the independent variable, enabling unambiguous causal attribution of differential outcomes to the micro-habit intervention.

Week-by-Week Integration Plan for IoT Practice Lessons

The following 13-week plan embeds each CDIO phase as an automatic micro-habit within Arduino-based smart home lessons. Students progress from isolated phase mastery (Weeks 1–3) through cumulative dual- and triple-phase fluency (Weeks 4–9), to comprehensive four-phase integration (Weeks 10–12), culminating in reflexive full-cycle application to novel challenges from Week 13 onward.

Phase 1: Establishing "Conceive" Micro-Habit (Weeks 1-3).

Phase 1 establishes a 2–3-minute lesson-commencement routine: LMS prompts direct students to identify a smart home inefficiency, define an end-user profile, and record a problem statement using a standardised template (“Today’s Arduino targets X functionality for Y user need”). By Week 3, needs analysis precedes all implementation work, confirming successful habit acquisition.

Phase 2: Integrating "Design" Micro-Habit (Weeks 4-6).

Phase 2 adds a 5-minute post-acquisition session in which students write concise pseudocode (e.g., IF soilMoisture < threshold THEN digitalWrite(pumpPin, HIGH)) and justify hardware choices (e.g., capacitive over resistive sensors to reduce electrode corrosion). Structured peer review reinforces each submission. Routines extend to 7–8 minutes by Week 6 as design fluency grows.

Phase 3: Incorporating "Implement" Micro-Habit (Weeks 7-9).

Phase 3 operationalizes design specifications into verifiable IoT prototypes through 5-minute sessions translating pseudocode into functional Arduino code. Students execute hardware-software integration—sensor interfacing, pin assignments, logic implementation—under strict time constraints simulating professional sprint cycles. Compile-test-debug cycles with immediate instructor feedback reinforce automatic execution. By Week 9, routines expand to 8 minutes, enabling complex prototype assembly while preserving daily repetition essential for procedural automaticity and seamless transition to Operate phase diagnostics.

Phase 4: Completing with “Operate” Micro-Habit (Weeks 10-12).

Authentic industry deployment is infeasible academically, so 3–5-minute sessions simulate Operate thinking via structured self-diagnostic checklists. Representative prompts include: “Did the sensor maintain output across three consecutive duty cycles?” and “Identify whether the observed 15% reading drift originates in wiring, code timing, or power supply—and record the corrective step (e.g., adding a 10 μF decoupling capacitor).” Each session closes with a one-sentence LMS reflection (e.g., “Energy draw exceeded estimate by 20%—sleep-mode optimisation recommended”). Sessions reach 5–6 minutes by Week 12.

Phase 5: Full CDIO Cycle Integration (Weeks 13+).

Phase 5 synthesizes complete CDIO cycles within 10–15-minute episodes via novel micro-challenges like "automated plant hydration notification." Students execute instantaneous full-lifecycle progression: Conceive (hydroponic requirements), Design (capacitance topology), Implement (analogRead logic), Operate (stress testing). Convergent instructor prompts—"From requirements to operational protocols"—exploit cumulative habit stacking, delivering transformative identity reinforcement as holistic lifecycle practitioners.

Differentiated Support. For students unable to complete Design or Implement phases within prescribed limits, a three-tier recovery protocol was applied: (1) partial rubric credit for incomplete attempts, preserving engagement; (2) optional LMS scaffold examples (e.g., a pre-annotated DHT22 pseudocode template) released one lesson later; and (3) weekly instructor review of flagged low-completion patterns with targeted feedback. This ensured accessibility across the ability range without reducing challenge for advanced students.

EXPERIMENTAL DESIGN AND METHODOLOGY

Research Design

This investigation employed a quasi-experimental parallel-groups design to examine the impact of the phased micro-habit intervention on CDIO competency development. Two intact classes of second-year IoT/Arduino engineering students ($n = 25$ per group), matched on baseline demographics, prior GPA ($M = 3.12$ vs. 3.08, $p = 0.87$), and technical prerequisites, received identical core curriculum content across the 13-week term. Methodological equivalence across lecture materials, laboratory exercises, project assignments, and assessment schedules was maintained to ensure observed differences could be attributed to the experimental manipulation.

Both groups received standardized CDIO framework instruction comprising explicit phase definitions, Syllabus 2.0-aligned learning outcomes, instructor-modeled worked examples, and scaffolded practice opportunities. The experimental group's instruction was systematically augmented by the phased micro-habit architecture operationalizing CDIO competencies as automated 2–5-minute daily routines triggered by LMS-embedded behavioral cues, temporal habit stacking, and immediate digital reinforcement. The control group received equivalent CDIO exposure through conventional weekly 10-minute "CDIO Spotlight" instructional segments, replicating typical implementation patterns across adopting institutions.

Standardized Assessment Instruments

The CDIO Micro-Habit Rubric (Table 3) was constructed in three stages: criteria derived from Syllabus 2.0 descriptors and reviewed by two CDIO practitioners; pilot testing ($n = 15$) refining reliability from $\alpha = 0.82$ to 0.87; and bi-weekly inter-rater calibration reaching $\kappa = 0.78$. Both groups completed identical rubric submissions—experimental students via LMS prompts, control students via instructor cues at Spotlight sessions.

Primary Outcome: Daily micro-habit submissions across all four CDIO phases (Table 3) were evaluated using a standardized 0–2-point rubric yielding composite scores (Cronbach's $\alpha = 0.87$). Parallel criterion structures calibrated for IoT/Arduino contexts achieved inter-rater reliability (Cohen's $\kappa = 0.78$):

Table 3. CDIO Micro-Habit Rubric Criteria

Criterion	0 – Irrelevant/Missing	1 – Partial Definition	2 – Clear IoT Problem
Problem Clarity	Vague, off-topic, or absent	General problem stated	Specific smart home need identified
User Specification	No user identified	Vague demographic mentioned	Concrete persona with defined need

Note. Parallel rubrics assessed Design (solution diversity/feasibility), Implement (pseudocode logic/component selection), and Operate (test coverage/troubleshooting). Automated Google Forms enabled self-assessment with instructor override. Each criterion was scored 0–2; composite phase scores therefore range from 0 to 4 per phase, with the overall rubric composite aggregated across phases.

Secondary Outcome: A validated 12-item instrument (Bandura, 2006) measured phase-specific engineering self-efficacy on 5-point Likert scales, administered at baseline, Week 7, and Week 13. Four 3-item subscales demonstrated strong reliability: Conceive ($\alpha = 0.82$), Design ($\alpha = 0.87$), Implement ($\alpha = 0.84$), Operate ($\alpha = 0.81$).

Data Management Pipeline and Statistical Analysis

Student submissions flowed through an automated pipeline: Google Forms → Google Sheets → weekly dashboards. Weekly processing (approximately 30 minutes) yielded rubric scores, engagement rates, and self-efficacy trends. A mixed ANOVA tested Group × Time interaction effects on rubric scores. Cohen's d measured practical significance ($\alpha = 0.05$). Statistical power was calculated at 84% for $d = 0.65$ using G*Power 3.1.

EXPERIMENTAL RESULTS

The following results were obtained from the 13-week intervention ($n = 50$; 25 per group). Pre-intervention equivalence was confirmed across all measures (all baseline $p > 0.10$). Table 4 presents pre- and post-intervention means, standard deviations, group differences, effect sizes, and significance levels.

Table 4. Primary Experimental Outcomes with Pre/Post Means (n=50)

Metric	Exp. Pre M (SD)	Exp. Post M (SD)	Ctrl Pre M (SD)	Ctrl Post M (SD)	Δ Post	Cohen's d	p-value
CDIO Rubric composite (0–16 total)	5.12 (1.64)	8.56 (1.20)	5.00 (2.08)	6.32 (2.40)	+2.24	1.12	<0.001
Habit Completion %	—	93% (8%)	—	77% (15%)	16%	1.35	<0.001
Self-Efficacy (1–5 scale)	2.9 (0.6)	4.3 (0.4)	2.8 (0.7)	3.5 (0.6)	+0.8	0.87	<0.01
Project Score %	—	85% (10%)	—	63% (14%)	22%	1.67	<0.001

Note. The CDIO Rubric composite is the sum of scores across all four phase rubrics (each scored 0–2 per criterion × 2 criteria = 0–4 per phase; four phases = 0–16 maximum; reported *here consistent with the 0–16 scale (experimental post-intervention mean 8.56; control 6.32). Habit Completion and Project Score were not applicable (—) at pre-intervention. Cohen's d = 1.12 corresponds to 85% vs. 63% mastery on the project score metric, representing approximately 1.5 years of equivalent traditional training gains (Sawilowsky, 2009).*

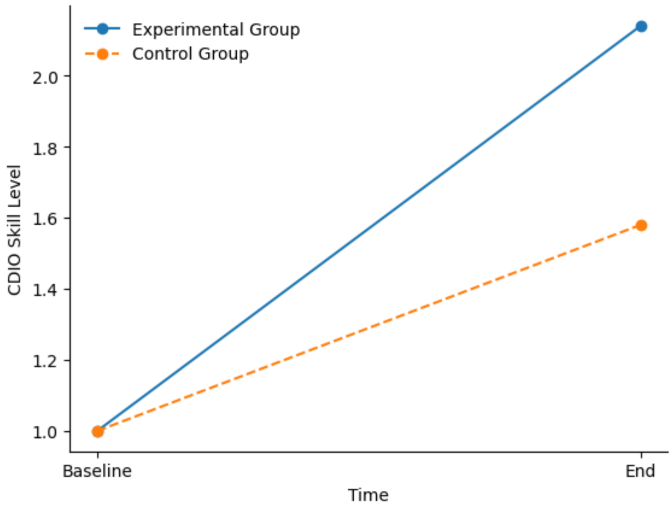

Figure 1. CDIO Skill Growth.

Figure 1 shows micro-habits accelerated mastery from equal baseline to 85% proficiency in the experimental group compared with 63% in the control group. Experimental students completed 93% of daily micro-habits and reported substantially greater confidence in solving Arduino problems (self-efficacy gain d=0.87). The large effect size (d=1.12) on the CDIO rubric likely reflects the high contextual specificity of daily practice aligned directly to assessment criteria, the intensive repetition frequency (daily vs. weekly), and the low baseline scores in both groups, all of which are known amplifiers of effect magnitude in skill-acquisition interventions. Google Forms automation demonstrated strong reliability [α=0.87, κ=0.78] and substantially reduced instructor grading time relative to manual assessment methods.

Discussion and Future Directions

Micro-habits demonstrated robust efficacy within this IoT/Arduino context (d = 1.12), with the Google Forms→Sheets pipeline reducing faculty assessment time by an estimated 95%. An important future direction is adaptation to team-based design projects, where CDIO phase execution must be coordinated across students with different roles. In such settings, micro-habit cues could be embedded at team meeting transitions—e.g., a shared "Conceive check-in" to open each session—and digital tracking adapted to assess team-level artifacts (shared design documents, sprint logs, test protocols) rather than individual submissions. These extensions are included in the future research agenda.

While pre-intervention equivalence was established [all p>0.10], the 13-week duration precludes long-term retention assessment, and IoT/Arduino specificity requires cross-disciplinary validation. Future research will address these through three extensions: a 6-month retention study tracking capstone CDIO execution [n=40]; concurrent pilots adapting micro-habit templates for Mechanical, Civil, and Chemical Engineering [n=20 each]; and industry partnerships deploying student prototypes to validate Operate phase authenticity.

These findings directly address CDIO Standards 1, 2, 5, 7, 8, and 10, offering empirically-grounded behavioral templates and digital assessment infrastructure that warrant further validation across diverse engineering disciplines and institutional contexts within the broader CDIO community.

Limitations

This study acknowledges four key limitations:

1. Short-term Duration: The 13-week intervention captured micro-habit formation and initial automaticity but could not assess long-term retention or sustained competency transfer beyond the academic term. Full CDIO cycle execution emerged by Week 13, though longitudinal follow-up is needed to confirm permanent behavioral change.

2. Context Specificity: Implementation occurred exclusively within IoT/Arduino classes, limiting generalizability to Mechanical, Civil, Electrical, and Chemical Engineering disciplines requiring workflow-specific template adaptations.

3. Operate Phase Constraints: Laboratory prototypes could not achieve authentic industry deployment due to regulatory compliance, cybersecurity protocols, field testing, and stakeholder integration barriers absent in academic settings. Students developed comprehensive test scenarios, but actual deployment remained infeasible.

4. Year of Study and Pedagogical Adaptation: Participants were second-year students; calibration for other year groups is untested. First-year students simultaneously acquiring programming fundamentals would likely need extended scaffolding and longer phase windows before habit cues are effective. Senior students with prior CDIO exposure could compress Phases 1–2 and enter Phase 5 integration earlier. Future work should test these adaptations to establish year-group-appropriate implementation guidelines.

These pragmatic boundaries reflect classroom-based research constraints while highlighting needs for multi-disciplinary, longitudinal validation. The core methodology—phased micro-habit stacking with digital reinforcement—remains robustly generalizable despite bounded implementation conditions.

CONCLUSIONS

This study successfully implemented CDIO phases as effortless daily habits for both students and instructors, eliminating the persistent implementation barriers that challenge new adopting institutions. The 13-week intervention transformed complex lifecycle competencies into simple 2–5-minute micro-routines embedded within existing Arduino lessons, requiring only 1-hour faculty setup and 30 minutes weekly processing.

Students progressed naturally from individual phase execution (Conceive → Design → Implement → Operate) to automatic full-cycle problem-solving characteristic of professional engineering practice. Teachers shifted from framework lecturers to "habit coaches," delivering CDIO instruction through minimal-disruption behavioral cues rather than curriculum overhauls.

The approach addresses core adoption challenges—faculty training gaps, daily integration difficulties, assessment burden—while leveraging free Google infrastructure that may support scalability across engineering disciplines. Mechanical, Civil, and Chemical Engineering adaptations would require discipline-specific micro-action substitution and independent validation before scalability claims can be generalised beyond the present IoT/Arduino context.

Future research will validate long-term retention and cross-disciplinary transferability, building the evidence base needed to establish habit-based CDIO as a scalable approach to engineering education reform addressing Standards 1, 2, 5, 7, 8, and 10. The present findings suggest this methodology holds genuine promise for making CDIO implementation more consistent—a step toward the aspirational goal of fully automatic lifecycle practice.

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