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DEVELOPING STUDENTS' COLLABORATIVE ENGINEERING PRACTICES AND COMMUNICATION SKILLS THROUGH CDIO PROJECTS

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Abstract. Contemporary engineering practice requires graduates to coordinate interdependent technical work, negotiate decisions, and communicate evidence to specialist and non-specialist audiences. Although CDIO projects provide an authentic setting for these outcomes, teamwork and communication do not develop automatically merely because students are placed in groups. This conceptual-methodological study proposes a phase-aligned framework for intentionally developing collaborative engineering practice and communication skills across the Conceive–Design–Implement–Operate lifecycle. The framework was constructed through an integrative synthesis of the CDIO Standards and Syllabus, international engineering graduate-outcome frameworks, and peer-reviewed research on engineering student teams, active learning, and team-member assessment. The analysis aligned four design dimensions—task interdependence, role structure, communication genres, and assessment evidence—with each CDIO phase. The resulting model combines authentic interdependence, rotating engineering roles, phase-specific communication artifacts, repeated feedback, and multi-source assessment. In the Conceive phase, students frame stakeholder needs and establish team norms; in Design, they justify alternatives and manage interfaces; in Implement, they coordinate integration, testing, and change; and in Operate, they communicate performance, complete handover, and reflect on system use. The article also specifies observable evidence and rubric criteria that allow instructors to assess both team processes and individual contributions without separating communication from technical work. The framework is intended as a transferable design tool for technical universities and industry-integrated projects. Its educational effects should be tested through longitudinal and mixed-method studies in specific disciplinary and institutional contexts.

Keywords: CDIO; engineering education; teamwork; communication skills; project-based learning; authentic assessment; industry-integrated learning.

Introduction. Engineering is increasingly conducted through teams that cross disciplinary, organizational, and cultural boundaries. Engineers must therefore do more than apply scientific and technical knowledge: they must create shared goals, coordinate interdependent tasks, explain assumptions, document decisions, resolve disagreements, and communicate risk and evidence to multiple audiences. A systematic review of engineering workplace competencies identifies communication, teamwork, coordination, and problem solving among the outcomes repeatedly valued across professional contexts (Passow & Passow, 2017). These expectations are also explicit in contemporary accreditation frameworks. ABET Student Outcome 5, for example, requires graduates to function effectively in teams that provide leadership, create collaborative and inclusive environments, establish goals, plan tasks, and meet objectives (ABET, 2025).

The CDIO approach offers a productive curricular response because it situates engineering education in the lifecycle of Conceiving, Designing, Implementing, and Operating products, processes, and systems. In this model, disciplinary knowledge is

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learned together with personal, interpersonal, and product-development capabilities

rather than as a detached supplement (Crawley et al., 2014). The updated CDIO Syllabus 3.0 explicitly includes collaboration, teamwork, and communication, while the CDIO Standards emphasize integrated learning experiences and active learning (CDIO Initiative, 2022a, 2022b; Malmqvist et al., 2022). CDIO projects can consequently become rehearsal spaces for authentic engineering practice.

Nevertheless, assigning a group project does not by itself create an effective team or produce transferable communication competence. Student work can remain only superficially collaborative when a task is divided into isolated pieces, one member integrates the final product, presentations occur only at the end, or grades conceal unequal contributions. Reviews of engineering student teams identify social loafing, conflict, weak trust, limited interdependence, and incomplete shared mental models as recurring concerns (Borrego et al., 2013). Communication is likewise often treated as a final presentation skill rather than as the mechanism through which technical work is coordinated, challenged, recorded, and improved.

This article addresses the resulting design problem: How can a CDIO project be structured so that collaborative engineering practice and communication skills are intentionally developed, made observable, and assessed throughout the project lifecycle? The purpose is to propose a practical, theoretically grounded framework that connects each CDIO phase with team processes, communication genres, instructional arrangements, and assessment evidence. The article is conceptual rather than experimental; it does not claim measured learning gains. Its contribution is a transparent design model that institutions can adapt and subsequently evaluate in discipline-specific settings.

Conceptual and pedagogical foundations. Teamwork in engineering education should be understood as coordinated technical practice, not merely agreeable interpersonal behavior. Effective teams combine task work—analysis, modeling, design, fabrication, programming, testing, and operation—with team processes that make the task work coherent. These processes include goal setting, role negotiation, planning, monitoring, information exchange, conflict management, mutual support, and collective quality control. Borrego et al. (2013) show that interdependence, trust, conflict, social loafing, and shared mental models are especially relevant constructs for engineering project teams. This perspective directs educators to design the conditions under which collaboration is necessary and teachable.

Authentic interdependence is central. A project may be completed by a nominal group while still functioning as a collection of individual assignments. In contrast, a collaboratively engineered outcome requires members to exchange information, coordinate interfaces, make joint decisions, and verify system-level performance. Team roles should therefore carry real responsibilities and dependencies. Role rotation is also important: if the same confident student always leads meetings while another student always prepares drawings or slides, the project reproduces narrow participation rather than broad capability development.

Communication as part of engineering work. Technical communication is not an ornamental skill added after a design has been

completed. It is embedded in engineering reasoning. Requirements become usable through precise questions and written specifications; alternatives become defensible through argument and evidence; interfaces become manageable through diagrams and review records; implementation becomes reliable through issue reports and test documentation; and operation becomes safe through demonstrations, manuals, and feedback. Communication competence therefore includes listening, questioning, visual explanation, concise writing, oral presentation, negotiation, documentation, and audience adaptation.

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A phase-specific view prevents communication from being reduced to one generic presentation rubric. Each project phase calls for different genres and purposes. A stakeholder interview is evaluated by the quality of elicitation and interpretation; a design review by the clarity of criteria, evidence, and trade-offs; an implementation meeting by the accuracy of status information and issue escalation; and an operational handover by usability, completeness, and risk communication. When these artifacts are assessed at the point where they influence technical decisions, students receive feedback while improvement is still possible.

Constructive alignment in CDIO projects. CDIO and project-based learning are compatible but contribute different strengths. Project-based learning emphasizes learner activity around complex problems, whereas CDIO provides an engineering lifecycle, program-level outcomes, and standards for curriculum and learning environments (Edström & Kolmos, 2014). Active and cooperative learning can improve engagement and achievement when tasks, accountability, and feedback are designed purposefully (Prince, 2004; Smith et al., 2005). The relevant implication is constructive alignment: intended outcomes, project tasks, learning supports, assessment criteria, and feedback sources should all point toward the same professional practices.

3. Method

3.1. Study design and source base

The study used an integrative conceptual synthesis and educational design procedure. This approach was selected because the goal was to construct a coherent instructional framework rather than estimate an intervention effect.

The source base comprised: (a) the CDIO Standards and CDIO Syllabus 3.0; (b) international graduate-outcome expectations represented by ABET and the International Engineering Alliance (2021); and (c) established peer-reviewed research on engineering team effectiveness, project-based and active learning, workplace competencies, and behaviorally anchored peer assessment. Sources were selected for direct relevance to the design and assessment of teamwork and communication in engineering education, not to claim a systematic or exhaustive review.

Analytical procedure. The framework was developed in three stages. First, broad outcomes such as ‘effective teamwork’ and ‘communication’ were decomposed into observable practices: establishing goals, allocating and rotating roles, coordinating interfaces,

monitoring progress, providing feedback, resolving disagreements, documenting decisions, presenting evidence, and adapting messages to audiences. Second, these practices were mapped to the authentic technical demands of the four CDIO phases.

Third, learning activities and assessment evidence were aligned with each phase so that the same practice was introduced, rehearsed, observed, and evaluated in context.

Four analytical dimensions guided the mapping: task interdependence, role structure, communication genre, and assessment evidence. The proposed components were retained when they met four design criteria: coherence with the CDIO lifecycle; relevance to recognized engineering graduate outcomes; feasibility in university–industry projects; and assessability through observable behavior or artifacts. The framework is presented as a design proposition open to contextual adaptation and empirical validation.

Results: A Phase-Aligned Development Framework. The synthesis produced five mutually reinforcing principles. Together, they shift teamwork and communication from assumed by-products of project work to explicit, assessable learning outcomes.

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- Authentic interdependence. The project architecture should require information exchange, interface management, joint decisions, integration, and system-level verification. Individual tasks must contribute to a shared technical result whose quality cannot be secured by one member alone.
- Structured participation and rotating roles. Teams establish a charter, decision rules, meeting routines, and responsibilities at the beginning of the project. Roles such as project coordinator, stakeholder liaison, interface lead, documentation lead, integration lead, test coordinator, and operations lead rotate at meaningful milestones.
- Phase-specific communication artifacts. Communication is practiced through authentic deliverables—requirements briefs, decision records, design reviews, interface diagrams, issue reports, test reports, demonstrations, manuals, and lessons-learned summaries—rather than through a single end-of-project presentation.
- Repeated feedback and reflection. Peer, self, instructor, and industry-partner feedback is scheduled at formative checkpoints. Teams convert feedback into documented actions, while individuals reflect on how their behavior affected technical progress and team climate.
- Multi-source, evidence-based assessment. Evaluation combines the technical product, team processes, communication artifacts, and individual contribution. Claims about participation are triangulated with project logs, version histories, meeting records, milestone evidence, observation, and peer ratings.

Table 1. Phase-aligned design of teamwork and communication learning in a CDIO project

CDIO phase	Collaborative engineering focus	Communication practices	Learning arrangements	Assessment evidence
Conceive	Interpret needs; define system purpose, constraints, goals, team norms, and responsibilities.	Stakeholder interview; problem framing; project charter; requirement brief; concept pitch.	Client brief; team-contract workshop; role matrix; question protocol; concept critique.	Need statement; traceable requirements; charter; meeting record; concept-pitch rubric.
Design	Generate alternatives; negotiate criteria; manage interfaces; justify trade-offs and risk.	Design rationale; drawings and models; decision record; design review; critique and response.	Design studio; decision matrix; peer review; interface checkpoint; industry design gate.	Design package; review minutes; rationale log; interface evidence; revised proposal.
Implement	Coordinate work packages; integrate components; test; control quality and change.	Stand-up update; issue escalation; technical instruction; change request; test report.	Sprint board; pair work; integration rehearsal; fault review; mentor consultation.	Prototype/code; version history; issue and change logs; test data; moderated peer rating.

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CDIO phase	Collaborative engineering focus	Communication practices	Learning arrangements	Assessment evidence
Operate	Validate use; demonstrate performance; hand over; respond to users; capture learning.	Demonstration; user briefing; manual; performance report; lessons-learned discussion.	Operational simulation; client demonstration; user test; after-action review; reflection.	Performance evidence; user feedback; handover package; reflection; improvement plan.

Note. The mapping is a configurable design template; deliverables and assessment weights should be adapted to discipline, project scale, and partner expectations. Source: developed by the author.

The developmental cycle. The four phases create a developmental progression rather than four isolated episodes. During Conceive, communication is exploratory: students listen, question, synthesize needs, and convert ambiguous stakeholder language into agreed goals and traceable requirements. Team formation occurs at the same time as problem formation. The team charter should specify roles, meeting and response expectations, decision procedures, inclusive participation norms, conflict-escalation steps, and evidence-management routines.

During Design, communication becomes argumentative and representational. Students compare alternatives against criteria, make assumptions visible, coordinate subsystem interfaces, and defend decisions with calculations, models, drawings, and evidence. Structured design reviews are especially valuable because they require the team to explain not only what it proposes, but why the proposal is technically and contextually defensible. Review feedback should be recorded together with the team's response and subsequent revision.

During Implement, communication becomes operational and time-sensitive. Teams coordinate work packages, maintain configuration and version control, report progress accurately, escalate issues early, negotiate changes, and integrate components. Short stand-up meetings can strengthen shared situation awareness if they focus on completed work, next actions, dependencies, blockers, and risks. Logs, issue trackers, test records, and change requests create an auditable link between communication behavior and technical performance.

During Operate, students communicate system performance and use. They demonstrate the product or process, brief users, explain limitations and safety considerations, prepare handover documentation, interpret feedback, and evaluate whether the solution meets its intended purpose. An after-action review then reconnects operational evidence to earlier assumptions and decisions. Reflection is most useful when it identifies a concrete behavior, its effect on the team or system, and a specific change for future practice.

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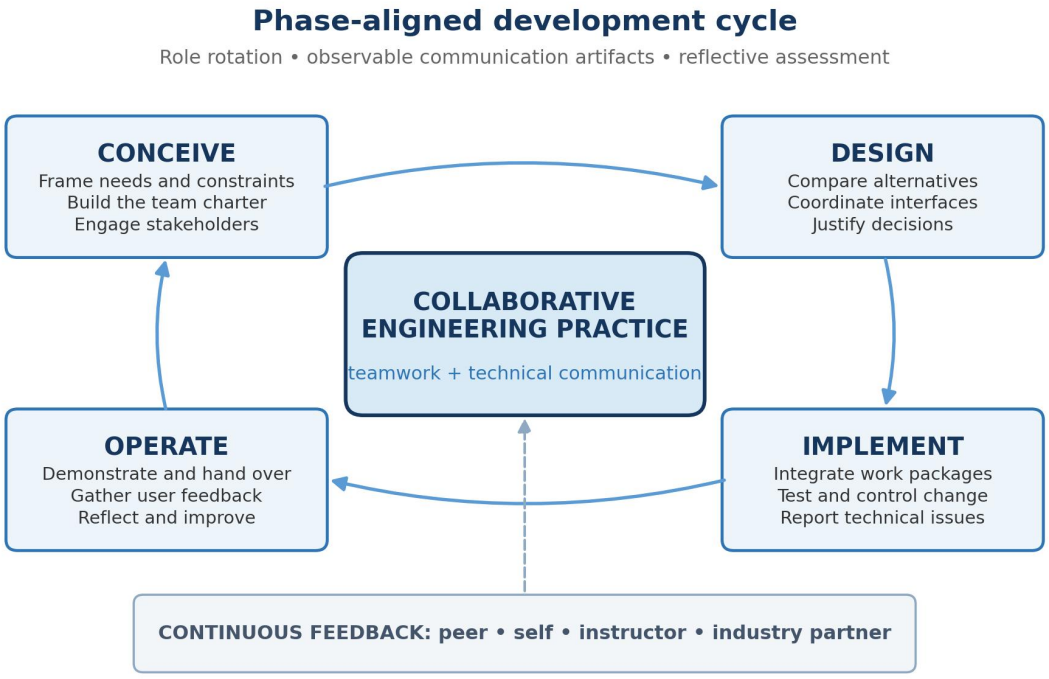


Figure 1. A phase-aligned framework for developing collaborative engineering practice and communication skills in CDIO projects. Source: developed by the author.

Assessment architecture. Assessment should distinguish, but then reconnect, three objects: the team's technical outcome, the quality of collaborative processes, and each student's contribution and learning. A technically strong prototype does not necessarily demonstrate equitable teamwork; equally, harmonious interaction does not compensate for weak engineering judgment. A balanced assessment therefore uses common technical criteria for the team product and individual evidence for behaviors, explanations, decisions, and reflections.

Teamwork criteria can include contribution and reliability, coordination and task management, inclusive interaction, constructive response to conflict and change, and promotion of shared quality. These dimensions are consistent with behaviorally anchored team-member assessment approaches such as CATME (Ohland et al., 2012). Communication criteria can include clarity of purpose and audience, technical accuracy, reasoning and use of evidence, visual and data communication, traceability of decisions, listening and responsiveness, and professional language. Each criterion should include observable descriptors at several performance levels rather than vague labels such as 'excellent' or 'poor.'

Peer assessment is most defensible when it is formative before it is summative, anchored in specific behavior, supported by examples, and moderated against project evidence. Students need brief calibration activities to distinguish contribution from popularity, confidence, language fluency, or friendship. Instructor and industry-partner judgments should serve complementary functions: instructors protect learning validity and fairness, while external partners contribute authentic audience expectations and feedback on professional relevance. Industry mentors should not be the sole graders because their exposure to individual students and academic criteria may be uneven.

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Discussion. The framework clarifies why some group projects generate substantial professional learning while others produce only a shared submission. Its first mechanism is engineered interdependence. When system interfaces, review gates, integration tests, and handover requirements connect students' work, collaboration becomes necessary for technical success. Its second mechanism is observability. Repeated communication artifacts and milestone interactions make normally hidden processes—questioning, coordination, reasoning, feedback, and adaptation—available for coaching and assessment. Its third mechanism is iteration. Students can act on feedback within the same project rather than receiving a final score after the learning opportunity has ended.

The phase-aligned structure also gives communication a technically authentic purpose. Instead of teaching oral presentation and report writing as generic forms, it situates communication in decisions that matter to project quality. This responds to the CDIO principle that professional capabilities should be integrated with disciplinary learning (Crawley et al., 2014) and to the updated Syllabus emphasis on collaboration, teamwork, and communication (Malmqvist et al., 2022). It also addresses the workplace relevance identified by Passow and Passow (2017): professional competence is expressed through combinations of technical and interpersonal action, not isolated knowledge categories.

Industry integration can deepen authenticity, but it requires educational mediation. External partners can provide real constraints, evolving information, specialist critique, standards, and user perspectives.

However, partner involvement should be scheduled around clear milestones and feedback protocols. Instructors must translate a partner's sometimes tacit expectations into assessable learning criteria and ensure that commercial urgency does not reduce students to unpaid task labor.

A good partnership preserves space for experimentation, failure analysis, reflection, and rotation through unfamiliar roles.

The model also has implications for inclusion. Transparent roles, participation norms, written decision records, and multiple communication modes can reduce dependence on informal dominance. Rotation prevents technical leadership and visible communication from becoming the property of a small subset of students. At the same time, rotation should not be mechanical: students need scaffolding before assuming a new role and enough time to perform it meaningfully. Instructors should monitor whose ideas are acknowledged, who performs coordination and documentation labor, and whether language confidence is being mistaken for technical competence.

Practical implementation in technical universities. A department can introduce the framework incrementally. Before the project, instructors define a limited set of teamwork and communication outcomes and identify the project moments in which those outcomes are naturally required. They then prepare a common team-charter template, a small number of phase-specific artifact templates, and behaviorally anchored rubrics. The project brief should contain genuine constraints and a system architecture that creates manageable interdependence among work packages.

At project launch, students complete a short readiness workshop on team norms, roles, meeting practice, feedback, and technical documentation. During delivery, the teaching team schedules a small set of high-value gates: needs review, concept review, design review, integration review, and operational demonstration. Each gate produces an artifact, feedback, and a documented action. Digital project boards and version-control histories can reduce assessment burden by preserving evidence generated through the work itself.

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For program-level development, complexity can increase across successive projects. Early projects may provide fixed roles, communication prompts, and frequent coaching. Intermediate projects can introduce role rotation, cross-team interfaces, and external review. Capstone projects can expect students to select and justify their own collaboration processes while responding to industry stakeholders. Such vertical progression prevents every project from restarting teamwork instruction at the same introductory level.

Limitations and future research. The proposed framework is conceptual and has not been tested as a complete intervention. Its components are grounded in established frameworks and research, but their combined effectiveness cannot be inferred without empirical evidence. Institutional culture, class size, disciplinary conventions, project duration, language of instruction, digital infrastructure, and the availability of industry partners may all affect implementation. Peer ratings and digital traces can also create privacy, bias, and workload concerns if used without transparent rules.

Future studies should examine both learning outcomes and implementation processes. A mixed-method, longitudinal design could compare student performance at successive CDIO milestones using rubric scores, artifact quality, peer ratings, observations, and interviews.

Research should investigate whether role rotation broadens participation, whether feedback is converted into observable behavioral change, how individual learning can be separated from team product quality, and which supports are required for multilingual teams. Cross-disciplinary studies would also clarify which elements are general and which must remain specific to mechanical, electrical, civil, information, or process engineering.

Conclusion. CDIO projects provide a strong context for learning teamwork and communication, but the context alone is insufficient. These capabilities become teachable when the project requires authentic interdependence, distributes and rotates meaningful roles, embeds communication in phase-specific engineering work, provides repeated feedback, and assesses observable evidence from multiple sources. The framework presented in this article connects these conditions to the Conceive–Design–Implement–Operate lifecycle and offers a practical basis for curriculum design, industry collaboration, and future evaluation. Its central proposition is simple: students develop collaborative engineering competence when collaboration and communication are designed as part of the engineering system of work, not left as incidental features of a group assignment.

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