The CDIO™ Standards

In January 2004, the *CDIO Initiative* adopted 12 standards that describe CDIO programs. These guiding principles were developed in response to program leaders, alumni, and industrial partners who wanted to know how they would recognize CDIO programs and their graduates. As a result, these CDIO Standards define the distinguishing features of a CDIO program, serve as guidelines for educational program reform and evaluation, create benchmarks and goals with worldwide application, and provide a framework for continuous improvement.

The 12 CDIO Standards address program philosophy (Standard 1), curriculum development (Standards 2, 3 and 4), design-build experiences and workspaces (Standards 5 and 6), new methods of teaching and learning (Standards 7 and 8), faculty development (Standards 9 and 10), and assessment and evaluation (Standards 11 and 12). Of these 12 standards, seven are considered *essential* because they distinguish CDIO programs from other educational reform initiatives. (An asterisk [*] indicates these essential standards.) The five *supplementary* standards significantly enrich a CDIO program and reflect best practice in engineering education.

For each standard, the *description* explains the meaning of the standard, the *rationale* highlights reasons for setting the standard, and *evidence* gives examples of documentation and events that demonstrate compliance with the standard.

Standard 1 -- CDIO as Context*
Adoption of the principle that product and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education

Description: A CDIO program is based on the principle that product and system lifecycle development and deployment are the appropriate context for engineering education. *Conceiving--Designing--Implementing--Operating* is a model of the entire product lifecycle. The *Conceive* stage includes defining customer needs; considering technology, enterprise strategy, and regulations; and, developing conceptual, technical, and business plans. The second stage, *Design*, focuses on creating the design, that is, the plans, drawings, and algorithms that describe what will be implemented. The *Implement* stage refers to the transformation of the design into the product, including manufacturing, coding, testing and validation. The final stage, *Operate*, uses the implemented product to deliver the intended value, including maintaining, evolving and retiring the system.

CDIO is considered the *context* for engineering education in that it is the cultural framework, or environment, in which technical knowledge and other skills are taught, practiced and learned. The principle is *adopted* by a program when there is explicit agreement of faculty to initiate CDIO, a plan to transition to a CDIO program, and support from program leaders to sustain reform initiatives.

Rationale: Beginning engineers should be able to *Conceive--Design--Implement--Operate* complex value-added engineering products and systems in modern team-based environments. They should be able to participate in engineering processes, contribute to the development of engineering products, and do so while working in engineering organizations. This is the essence of the engineering profession.

Evidence:

- a mission statement, or other documentation approved by appropriate responsible bodies, that describes the program as being a CDIO program
- faculty and students who can articulate the CDIO principle

Standard 2 -- CDIO Syllabus Outcomes*
Specific, detailed learning outcomes for personal, interpersonal, and product and system building skills, consistent with program goals and validated by program stakeholders

Description: The knowledge, skills, and attitudes intended as a result of engineering education, *i.e.*, the *learning outcomes*, are codified in the *CDIO Syllabus*.[1] These learning outcomes, also called learning objectives, detail what students should know and be able to do at the conclusion of their engineering programs. In addition to learning outcomes for technical disciplinary knowledge (Section 1), the *CDIO Syllabus* specifies learning outcomes as personal, interpersonal, and product and system building. *Personal* learning outcomes (Section 2) focus on individual students' cognitive and affective development, for example, engineering reasoning and problem solving, experimentation and knowledge discovery, system thinking, creative thinking, critical thinking, and professional ethics. *Interpersonal* learning outcomes (Section 3) focus on individual and group interactions, such as, teamwork, leadership, and communication. *Product and system building* skills (Section 4) focus on conceiving, designing, implementing, and operating systems in enterprise, business, and societal contexts.

Learning outcomes are reviewed and validated by key *stakeholders*, groups who share an interest in the graduates of engineering programs, for consistency with *program goals* and relevance to engineering practice. In addition, stakeholders help to determine the expected level of proficiency, or standard of achievement, for each learning outcome.

Rationale: Setting specific learning outcomes helps to ensure that students acquire the appropriate foundation for their future. Professional engineering organizations and industry representatives have identified key attributes of beginning engineers both in technical and professional areas. Moreover, many evaluation and accreditation bodies expect engineering programs to identify program outcomes in terms of their graduates' knowledge, skills, and attitudes.

Evidence:

- learning outcomes that include knowledge, skills, and attitudes of graduating engineers
- learning outcomes validated for content and proficiency level by key stakeholders (for example, faculty, students, alumni, and industry representatives)

Standard 3 -- Integrated Curriculum*
A curriculum designed with mutually supporting disciplinary subjects, with an explicit plan to integrate personal, interpersonal, and product and system building skills

Description: A CDIO curriculum includes learning experiences that lead to the acquisition of *personal, interpersonal, and product and system building skills* (Standard 2), integrated with the learning of disciplinary content. Disciplinary subjects are *mutually supporting* when they make explicit connections among related and supporting content and learning outcomes. An *explicit plan* identifies ways in which the integration of CDIO skills and multidisciplinary connections are to be made, for example, by mapping CDIO learning outcomes to courses and co-curricular activities that make up the curriculum.

Rationale: The teaching of personal, interpersonal and product and system building skills should not be considered an addition to an already full curriculum, but an integral part of it. To reach the intended learning outcomes in both disciplinary and personal, interpersonal, and product and system building skills, the curriculum and learning experiences have to make dual use of available time. Faculty play an active role in designing the integrated curriculum by suggesting appropriate disciplinary linkages, as well as opportunities to address specific CDIO learning outcomes in their respective teaching areas.

Evidence:

- a documented plan that integrates CDIO skills with technical disciplinary content and that exploits appropriate disciplinary linkages
- inclusion of CDIO learning outcomes in courses and co-curricular activities
- faculty and student recognition of CDIO learning outcomes in the curriculum

Standard 4 -- Introduction to Engineering
An introductory course that provides the framework for engineering practice in product and system building, and introduces essential personal and interpersonal skills

Description: The *introductory* course, usually one of the first required courses in a program, provides a framework for the practice of engineering. This *framework* is a broad outline of the tasks and responsibilities of an engineer, and the use of disciplinary knowledge in executing those tasks. Students engage in the *practice of engineering* through problem solving and simple design exercises, individually and in teams. The course also includes personal and interpersonal knowledge, skills, and attitudes that are *essential* at the start of a program to prepare students for more advanced product and system building experiences. For example, students can participate in small team exercises to prepare them for larger product-based development teams.

Rationale: Introductory courses aim to stimulate students' interest in, and strengthen their motivation for, the field of engineering by focusing on the application of relevant core engineering disciplines. Students usually elect engineering programs because they want to build things, and introductory courses can capitalize on this interest. In addition, introductory courses provide an early start to the development of the essential skills described in the *CDIO Syllabus*.

Evidence:
- learning experiences that introduce essential personal, interpersonal, and product and system building skills
- student acquisition of CDIO learning outcomes described in Standard 2
- high levels of student interest in their chosen field of study, demonstrated, for example, in surveys or choices of subsequent elective courses

Standard 5 -- Design-Build Experiences*
A curriculum that includes two or more design-build experiences, including one at a basic level and one at an advanced level

Description: The term *design-build experience* denotes a range of engineering activities central to the process of developing new products and systems. Included are all of the activities described in Standard One at the *Design* and *Implement* stages, plus appropriate aspects of conceptual design from the *Conceive* stage. Students develop product and system building skills, as well as the ability to apply engineering science, in design-build experiences integrated into the curriculum. Design-build experiences are considered *basic* or *advanced* in terms of their scope, complexity, and sequence in the program. For example, simpler products and systems are included earlier in the program, while more complex design-build experiences appear in later courses designed to help students integrate knowledge and skills acquired in preceding courses and learning activities. Opportunities to conceive, design, implement, and operate products and systems may also be included in required co-curricular activities, for example, undergraduate research projects and internships.

Rationale: Design-build experiences are structured and sequenced to promote early success in engineering practice. Iteration of design-build experiences and increasing levels of design complexity reinforce students' understanding of the product and system development process. Design-build experiences also provide a solid foundation upon which to build deeper conceptual understanding of disciplinary skills. The emphasis on building products and implementing processes in real-world contexts gives students opportunities to make connections between the technical content they are learning and their professional and career interests.

Evidence:

- two or more required design-build experiences in the curriculum (for example, as part of an introductory course and an advanced course)
- required co-curricular opportunities for design-build experiences (such as, research labs or internships)
- concrete learning experiences that provide the foundation for subsequent learning of disciplinary skills

Standard 6 -- CDIO Workspaces
Workspaces and laboratories that support and encourage hands-on learning of product and system building, disciplinary knowledge, and social learning

Description: The physical learning environment includes traditional learning spaces, for example, classrooms, lecture halls, and seminar rooms, as well as engineering *workspaces* and *laboratories*. Workspaces and laboratories support the learning of *product and system building skills* concurrently with *disciplinary knowledge*. They emphasize *hands-on learning* in which students are directly engaged in their own learning, and provide opportunities for *social learning*, that is, settings where students can learn from each other and interact with several groups. The creation of new workspaces, or remodeling of existing laboratories, will vary with the size of the program and resources of the institution.

Rationale: Workspaces and other learning environments that support hands-on learning are fundamental resources for learning the process of designing, building, and testing products and systems. Students who have access to modern engineering tools, software, and laboratories have opportunities to develop the knowledge, skills, and attitudes that support product and system building competencies. These competencies are best developed in workspaces that are student-centered, user-friendly, accessible, and interactive.

Evidence:

- adequate spaces equipped with modern engineering tools
- workspaces that are student-centered, user-friendly, accessible, and interactive
- high levels of faculty, staff, and student satisfaction with the workspaces

Standard 7 -- Integrated Learning Experiences*
Integrated learning experiences that lead to the acquisition of disciplinary knowledge, as well as personal, interpersonal, and product and system building skills

Description: Integrated learning experiences are pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal, interpersonal, and product and system building skills. They incorporate professional engineering issues in contexts where they coexist with disciplinary issues. For example, students might consider the analysis of a product, the design of the product, and the social responsibility of the designer of the product, all in one exercise. Industrial partners, alumni, and other key stakeholders are often helpful in providing examples of such exercises.

Rationale: The curriculum design and learning outcomes, prescribed in Standards 2 and 3 respectively, can be realized only if there are corresponding pedagogical approaches that make dual use of student learning time. Furthermore, it is important that students recognize engineering faculty as role models of professional engineers, instructing them in both disciplinary skills and personal, interpersonal and product and system building skills. With integrated learning experiences, faculty can be more effective in helping students apply disciplinary knowledge to engineering practice and better prepare them to meet the demands of the engineering profession.

Evidence:
- integration of CDIO learning outcomes and disciplinary skills into learning experiences
- direct involvement of engineering faculty in implementing integrated learning experiences
- involvement of industrial partners and other stakeholders in the design of learning experiences

Standard 8 -- Active Learning
Teaching and learning based on active experiential learning methods

Description: Active learning methods engage students directly in thinking and problem solving activities. There is less emphasis on passive transmission of information, and more on engaging students in manipulating, applying, analyzing, and evaluating ideas. Active learning in lecture-based courses can include such methods as partner and small-group discussions, demonstrations, debates, concept questions, and feedback from students about what they are learning. Active learning is considered *experiential* when students take on roles that simulate professional engineering practice, for example, design-build projects, simulations, and case studies.

Rationale: Students remember less than a fourth of what they hear and only about half of what they see and hear. By engaging students in thinking about concepts, particularly new ideas, and requiring some kind of overt response, students not only learn more, they recognize for themselves what and how they learn. This process of metacognition helps to increase students' motivation to achieve program learning outcomes and form habits of lifelong learning. With active learning methods, instructors can help students make connections among key concepts and facilitate the application of this knowledge to new settings.

Evidence:

- successful implementation of active learning methods, documented, for example, by observation or self-report
- a majority of instructors using active learning methods
- high levels of student achievement of all CDIO learning outcomes
- high levels of student satisfaction with learning methods

Standard 9 -- Enhancement of Faculty CDIO Skills*
Actions that enhance faculty competence in personal, interpersonal, and product and system building skills

Description: CDIO programs provide support for faculty to improve their own competence in the *personal, interpersonal, and product and system building skills* described in Standard 2. They develop these skills best in contexts of professional engineering practice. The nature and scope of faculty development vary with the resources and intentions of different programs and institutions. Examples of *actions that enhance faculty competence* include: professional leave to work in industry, partnerships with industry colleagues in research and education projects, inclusion of engineering practice as a criterion for hiring and promotion, and appropriate professional development experiences at the university.

Rationale: If faculty are expected to teach a curriculum of personal, interpersonal, and product and system building skills integrated with disciplinary knowledge, as described in Standards 3, 4, 5, and 7, they need to be competent in those skills themselves. Many engineering professors tend to be experts in the research and knowledge base of their respective disciplines, with only limited experience in the practice of engineering in business and industrial settings. Moreover, the rapid pace of technological innovation requires continuous updating of engineering skills. Faculty need to enhance their engineering knowledge and skills so that they can provide relevant examples to students and also serve as role models of contemporary engineers.

Evidence:

- majority of faculty with competence in personal, interpersonal, and product and system building skills, demonstrated, for example, by observation and self-report
- high number of faculty with experience in engineering practice
- university's acceptance of professional development in these skills in its faculty evaluation and hiring policies and practices
- commitment of resources for faculty development in these skills

Standard 10 -- Enhancement of Faculty Teaching Skills
Actions that enhance faculty competence in providing integrated learning experiences, in using active experiential learning methods, and in assessing student learning

Description: A CDIO program provides support for faculty to improve their competence in *integrated learning experiences* (Standard 7), active and experiential learning (Standard 8), and assessing student learning (Standard 11). The nature and scope of faculty development practices will vary with programs and institutions. Examples of *actions that enhance faculty competence* include: support for faculty participation in university and external faculty development programs, forums for sharing ideas and best practices, and emphasis in performance reviews and hiring on effective teaching skills.

Rationale: If faculty members are expected to teach and assess in new ways, as described in Standards 7 8, and 11, they need opportunities to develop and improve these skills. Many universities have faculty development programs and services that might be eager to collaborate with CDIO program faculty. In addition, if CDIO programs want to emphasize the importance of teaching, learning, and assessment, they must commit adequate resources for faculty development in these areas.

Evidence:
- majority of faculty with competence in teaching, learning, and assessment methods, demonstrated, for example, by observation and self-report
- university's acceptance of effective teaching in its faculty evaluation and hiring policies and practices
- commitment of resources for faculty development in these skills.

Standard 11 -- CDIO Skills Assessment*
Assessment of student learning in personal, interpersonal, and product and system building skills, as well as in disciplinary knowledge

Description: Assessment of student learning is the measure of the extent to which each student achieves specified learning outcomes. Instructors usually conduct this assessment within their respective courses. Effective learning assessment uses a variety of methods matched appropriately to learning outcomes that address *disciplinary knowledge,* as well as *personal, interpersonal, and product and system building skills*, as described in Standard 2. These methods may include written and oral tests, observations of student performance, rating scales, student reflections, journals, portfolios, and peer and self-assessment.

Rationale: If we value personal, interpersonal, and product and system building skills, set them as learning outcomes, and design them into curriculum and learning experiences, then we must have effective assessment processes for measuring these skills. Different categories of learning outcomes require different assessment methods. For example, learning outcomes related to *disciplinary knowledge* may be assessed with oral and written tests, while those related to design-build skills may be better measured with recorded observations. Using a variety of assessment methods accommodates a broader range of learning styles, and increases the reliability and validity of the assessment data. As a result, determinations of students' achievement of the intended learning outcomes can be made with greater confidence.

Evidence:

- assessment methods matched appropriately to CDIO learning outcomes
- successful implementation of assessment methods
- high number of instructors using appropriate assessment methods
- determination of student achievement based on reliable and valid data

Standard 12 -- CDIO Program Evaluation
A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement

Description: Program evaluation is a judgment of the overall value of a program based on evidence of a program's progress toward attaining its goals. A CDIO program should be evaluated relative to *these 12 CDIO Standards*. Evidence of overall program value can be collected with course evaluations, instructor reflections, entry and exit interviews, reports of external reviewers, and follow-up studies with graduates and employers. The evidence can be regularly reported back to instructors, students, program administrators, alumni, and other key stakeholders. This *feedback* forms the basis of decisions about the program and its plans for *continuous improvement*.

Rationale: A key function of program evaluation is to determine the program's effectiveness and efficiency in reaching its intended goals. Evidence collected during the program evaluation process also serves as the basis of continuous program improvement. For example, if in an exit interview, a majority of students reported that they were not able to meet some specific learning outcome, a plan could be initiated to identify root causes and implement changes. Moreover, many external evaluators and accreditation bodies require regular and consistent program evaluation.

Evidence:

- a variety of program evaluation methods used to gather data from students, instructors, program leaders, alumni, and other key stakeholders
- a documented continuous improvement process based on results of the program evaluation
- data-driven changes as part of a continuous improvement process

References

[1] Crawley, E. F. *The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education,* MIT CDIO Report #1, 2001.. Available at http://www.cdio.org