International Collaboration in the Reform of Engineering Education

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Abstract

In October 2000, with support from the Wallenberg Foundation, four universities
launched an international collaboration designed to improve undergraduate engineering
education in Sweden, the United States, and worldwide. This is a closely coordinated
program with parallel efforts at the Royal Institute of Technology (KTH) in Stockholm,
Linköping University (LiU) in Linkoping, Chalmers University of Technology (Chalmers)
in Göteborg, and the Massachusetts Institute of Technology (MIT). The vision of the
project is to provide students with an education that stresses engineering fundamentals set
in the context of Conceiving-Designing-Implementing-Operating (CDIO) real-world
systems and products. The collaboration calls for three face-to-face meetings per year,
alternating venues among the four institutions. Videoconferencing, email, and a dedicated
Web page facilitate collaboration between meetings. This paper describes the results of
the first year of the collaboration, the impact of the reform efforts, and the plans for the
next three years.

Introduction

With support from the Wallenberg Foundation, four universities (Chalmers University of
Technology (Chalmers) in Göteborg, the Royal Institute of Technology (KTH) in
Stockholm, Linköping University (LiU) in Linköping, and the Massachusetts Institute of
Technology (MIT)) formed an international collaboration to improve undergraduate
engineering education in Sweden, the United States, and worldwide.[1] Three overall goals
direct the alliance endeavors, namely, to educate students to
- master a deep working knowledge of technical fundamentals
- lead in the creation and operation of new products and systems
- understand the importance and strategic value of their future research work

The vision of the project is to provide students with an education that stresses engineering
fundamentals set in the context of Conceiving-Designing-Implementing-Operating (CDIO)
real-world systems and products

The project strategy to implement CDIO has four themes:

1. *curriculum* reform to ensure that students have opportunities to develop the knowledge, skills, and attitudes to conceive and design complex systems and products
2. improved *teaching and learning* necessary for deep understanding of technical information and skills
3. experiential learning environments provided by *laboratories and workshops*
4. effective *assessment* methods to determine quality and improve the learning process.

Each participating institution has at least one representative for each of the four theme areas, and an overall program director. Students from each of the four institutions participate in the four theme areas, as well as contribute as a separate student group. A steering committee consisting of engineering deans and industry representatives guides the project and serves as liaison to the Wallenberg Foundation. An external review board evaluates the project annually.

At the outset of the collaboration, each of the four theme areas identified specific tasks for joint investigation and development with parallel efforts at each of the participating schools. *Curriculum* initiatives include defining and validating the outcomes of an engineering program, early engineering experiences, disciplinary linkages, integrated design-build experiences, and CDIO skills education. *Teaching and Learning* identified concrete (hands-on) learning, problem formulation, active learning, feedback, and research into teaching and learning approaches. The *Laboratories and Workshops* group is focusing on models for building and furnishing workshops and laboratories, and research into best practices in the use of laboratories for engineering education. Finally, *Assessment* reform includes identification of clear goals and outcomes, CDIO skills assessment, creative skills assessment, and programmatic evaluation.

The proposed undergraduate engineering education features
- a curriculum organized around the disciplines and interwoven with CDIO activities
- student projects complemented by internships in industry
- multidisciplinary instruction and active and experiential group learning
- networked classroom, workshop, and laboratory settings
- robust assessment and evaluation processes.

The context for this undergraduate engineering education is a generalized description of a complete system life cycle, called in this project, *Conceive-Design-Implement-Operate*. The *Conceive* stage includes defining the need and technology, considering the enterprise strategy and regulations, developing the concept, architecture, and business case. The second stage, *Design*, focuses on creating the design, *i.e.*, the plans, drawings, and algorithms that describe what will be implemented. *Implement* refers to the transformation of the design into the product, including manufacturing, coding, test and validation. The final stage, *Operate*, uses the implemented product to deliver the intended value, including maintaining, evolving and retiring the system

Intended program outcomes have been identified for each of the four themes at both programmatic and student experience levels. (See Figure 1)

	Curriculum	Teaching and Learning	Laboratories & Workshops	Assessment
Program	Models for curriculum structure and design	Understanding and addressing barriers to student learning	Models for the design and utilization of labs/workshops	Tools and processes for program evaluation
Student Experience	Curricular materials for CDIO education	Active, experiential learning with enhanced feedback	Workshop-based educational experiences	Tools and processes for assessing student achievement

Figure 1. Intended Outcomes of Wallenberg CDIO Project

Curriculum

New curriculum models and designs are based on an organized list of learning outcomes identified as critical in the education of new engineers. Each institution conducted surveys of its faculty, students, alumni, and industrial representatives to validate the importance of these outcomes. This list, now called the CDIO Syllabus, is available in English and Swedish, and can be found at http://web.mit.edu/aeroastro/www/cdio/overview.html

The Wallenberg CDIO Curriculum Theme proposed a curriculum model in which
- disciplines are the organizing principle interwoven with design-build experiences
- design-build experiences motivate and reinforce learning and teach system building
- clear connections of learning to utility exist throughout the curriculum
- rigor and breadth of coverage are preserved
- students are well prepared to be leading engineers as well as strategic researchers

The integration of these features into existing and newly developed curriculum is left to each institution. Three integration models are proposed for local adaptation. A *block* model fully integrates disciplinary content and CDIO skills into one or more courses. In a *linked* model, two or more subjects are taught separately and concurrently, and at some point merged into one with CDIO skills as the main link. In an *umbrella* integration model, subjects and courses are taught separately, and are connected to some coordinating CDIO activity.

In the design of new curriculum, each institution is also focusing on its introductory courses. These initial experiences are designed to motivate students to study engineering, to provide personal experiences that foster deeper understanding of fundamentals, and to provide early exposure to system building. Chalmers has revised its *Introduction to Mechanical Engineering*, KTH its *Perspectives on Vehicle Engineering*, and MIT its

Introduction to Aerospace and Design. LiU has developed a new introductory course for its program in electrical engineering.

At the same time, each partner is working on one or more projects that enhance disciplinary linkages, including *Project Bruno* and a mechatronics course at Chalmers, a solar-powered aircraft at KTH, an electronics course at LiU, and an electric aircraft in a *Unified Engineering* course at MIT.

Finally, the Curriculum Theme is taking the lead in the design and development of Educational Resource Modules to serve as teaching and learning resources for integrating CDIO skills education into the curriculum. In the current year, four guides are planned in the areas of oral and written communication, communication in foreign languages, teamwork, and professional ethics. Two partner institutions are collaborating on each of the different guides. About ten additional guides will be developed in subsequent years of the collaboration.

Teaching and Learning

The main goal of the Teaching and Learning Theme is to increase student learning through
- problem formulation
- increased active learning experiences
- immediate feedback
- improved instructor skills

In the first year, each institution conducted interviews and surveys of their respective instructional staffs to determine which teaching methods were being used. In addition to more traditional methods of lecture, recitation, and problem sets, instructors promote learning through student presentations, teamwork, laboratory exercises, hands-on projects, and design-build experiences.

As a result of the Wallenberg CDIO partnership, instructors are engaged in joint projects to improve teaching and learning. For example, instructors at all four institutions are using *muddiest-part-of-the-lecture* cards[2] to encourage interaction in lecture-based classes and improve immediate feedback of students' conceptual understanding. Other methods are being investigated in one or two of the partner programs and will serve as models for the others. For example, LiU and MIT are working with personal response systems[3] and other new technologies both for independent study and class interaction.

In the next three years of the partnership, the Teaching and Learning Theme plans to
- organize workshops for faculty and students
- publish technical briefs on innovative teaching methods
- expand the use of electronic response systems
- continue to develop problem formulation and case study approaches
- investigate and test new instructional technologies

Workshops and Laboratories

The main objectives of the Workshops and Laboratories Theme are to
- develop the infrastructure and facilities to support educational initiatives
- introduce design-build experiences within existing courses
- promote active, team-based, hands-on project work

First-year projects were largely devoted to single-institution endeavors. For example, Chalmers designed a new physical prototyping workshop and studio, KTH introduced a new creativity lab/workshop in its redesigned aeronautics and lightweight structures courses, LiU introduced labs and workshops in its electronics and technology courses, and MIT built its *Learning Laboratory for Complex Systems.*

In addition, the Workshops and Laboratories Theme identified twelve different modes of instruction for effective use of laboratories in engineering education. These varied uses help to determine the requirements of laboratory spaces.
- *Class Lab Mode*: occasional use, short duration, storable
- *Large Systems Mode*: year-long project, design intensive, dedicated space, product thrust, close connectivity to outside
- *Design Product Mode*: large-scale project, term length, virtual design, dedicated space, breakout-report spaces
- *Tinkering Mode*: occasional, temporary work space
- *Experiment Mode*: desktop project, one to two terms, student developed
- *Research Design Support Mode*: in and out capacity, temporary team design space, weeks to months in duration
- *Graduate Thesis Mode*: one or more years, equipment needs, dedicated space, in and out capacity
- *Large Student-Project Mode*: large-scale project, dedicated space, large physical components, after hours
- *Linked Projects Mode*: multidisciplinary, one term or less, multi-use lab experiments, joint labs and designs
- *Teaching in Labs Mode*: occasional, presentation area, demonstrations
- *Income-Generating External Mode*: ongoing, in and out testing, days or weeks duration, dedicated space
- *Outreach Mode:* weekly, accommodate visits, lectures, presentations

In the next three years, the Laboratory and Workshops Theme plan to outfit and operate the labs designed in the first year, create new courses with design-build opportunities, expand the current laboratories and workshops, coordinate with other educational projects and development efforts, and support capstone design experiences.

Assessment

In the first year, the Assessment Theme engaged in activities in four main areas: creating learning objectives, assessing CDIO skills, course evaluation, and program evaluation. Chalmers, KTH, and LiU held workshops on writing and classifying learning objectives for

mathematics and engineering faculty. The assessment of CDIO skills focused on communication skills, creative and affective skills, and alternative assessments in mathematics. All four institutions examined and described its procedures for end-of-course evaluations by students, and LiU and MIT initiated Web-based course evaluations. Finally, in the area of program evaluation, LiU implemented an approach called *The Balanced Scorecard* [4], and MIT evaluated its program using ABET's *EC 2000*.[5]

In the next years of the Wallenberg CDIO Project, the Assessment Theme plans to
- assess deeper technical understanding in technical courses
- develop a suite of tools for assessing students and evaluating programs
- assess CDIO personal, interpersonal, and system skills in design-build courses
- benchmark best practice in assessing non-technical learning outcomes
- conduct surveys of student perspectives at entry and exit points of programs
- measure and document achievement of learning outcomes at exit from programs
- compare self-assessment with demonstrated performance data
- conduct surveys of instructor perspectives on courses and programs
- identify best practices for gathering data about instructor satisfaction, professional development needs, and opinions

Summary

In June 2001, a team of three external evaluators conducted a review of the first year of the Wallenberg CDIO Project. The review was held at MIT with all partners participating in the presentations and discussions. Reviewers said that the project had made some important contributions and strongly recommended that it continue for three more years.

> "The committee was delighted to find that the program is well underway and has achieved an impressive set of accomplishments during its first nine months of activity. All six specific elements planned for the first year have been executed well. The cordial and effective collegiality demonstrated by the faculty and the staff of the four universities who are involved with this program is refreshing. They act as a high performance team with common goals and a genuine sense of enthusiasm for their work."
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> - External Review Committee --June 2001

The international collaboration of the Wallenberg CDIO Project has resulted in a true partnership of professionals committed to the reform of engineering education. It has made possible the learning and sharing of ideas, projects, and materials bridging programs, institutions, languages, and national boundaries.

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