2nd International CDIO Conference
Linkoping University
Linkoping, Sweden
13 to 14 June 2006

USING ASSESSMENT TO INITIATE AND SUSTAIN CDIO PROGRAMS: UNITED STATES NAVAL ACADEMY (USNA) CASE STUDY

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ABSTRACT

The Conceive-Design-Implement-Operate (CDIO) engineering educational strategy has been adopted by a number of universities in the USA, Europe, Canada, South Africa, Asia and the South Pacific. These universities are using CDIO as the framework for undergraduate engineering curricular planning and outcomes-based assessment. The CDIO Initiative's goal is to educate future engineers in the fundamentals of engineering skills within a context of conceiving, designing, implementing and operating products and systems. The Department of Aerospace Engineering at the United States Naval Academy joined the CDIO Initiative in July 2003. The Naval Academy already emphasized many of the skills in the CDIO Syllabus, such as ethics, leadership, teamwork, systems thinking, and communications that are part of design-build projects, integral components of a CDIO program. What was lacking was the overall framework for developing a curriculum consistent with our goals and one that could be used to guide outcomes assessment. The CDIO Initiative provides us with the overall framework and assessment tools necessary for the successful development and continuous improvement of our program. The Aerospace Engineering program at the United States Naval Academy has used assessment to guide its evolution from initiation to institutionalization. At the program level evaluation we used our CDIO Compliance results and the CDIO Implementation Model as bases for the ABET Program Self-Study Report. At the time of our out ABET visit in 2005, our self assessment of progress towards full implementation of the CDIO model was 36 out of 48, an increase from our score of 13 in 2003. Our programs strengths were Standards 1, 2, 4, 5, and 9 and our weaknesses were Standards 3, 8, 10, 11, and 12.

INTRODUCTION

In 2001, with support from the Knut and Alice Wallenberg Foundation, the Royal Institute of Technology (KTH), Linköping University and Chalmers University of Technology of Sweden, and the Massachusetts Institute of Technology (MIT) of the USA, launched the CDIO Initiative to improve undergraduate engineering education in their countries and, eventually, worldwide. The Initiative is an open-architecture endeavour that is designed to be adaptable and adoptable by any undergraduate engineering program. Now in 2005, CDIO is a closely coordinated program with parallel efforts at participating schools in the USA, Europe, Canada, South Africa, Asia, and the South Pacific. The Initiative's vision is to provide students with an education that stresses engineering fundamentals that are set in the context of Conceiving - Designing - Implementing - Operating (CDIO) real-world systems and products [1].

The CDIO (Conceive-Design-Implement-Operation) project learning assessment model is based on the principle that product and system lifecycle development and deployment are the context of Engineering Education. Its mission is to graduate engineers able to Conceive-Design-Implement-Operate complex value-added engineering products and systems in modern team-based environments so as to appreciate engineering processes and contribute to the development of engineering products while working in engineering organizations. As a result, intended attributes of CDIO graduates include understanding disciplinary fundamentals, understanding design and manufacturing, possessing a multi-disciplinary system perspective, exhibiting good communication skills, and having high ethical standards.

Of course, each CDIO program develops expected student learning outcomes that are consistent with the program mission and are validated by program stakeholders. Typically, program outcomes include technical knowledge and reasoning, personal and professional skills and attributes, interpersonal skills such as teamwork and communication, and conceiving, designing, implementing and operating systems in the enterprise and societal context.

USNA ADOPTION OF CDIO

The Department of Aerospace Engineering at the United States Naval Academy joined the CDIO Initiative in July 2003. The CDIO Initiative provides us with the framework and tools necessary to make and assess changes in our program. Before describing why and how we adapted CDIO to our program it is necessary to understand the mission of the United States Naval Academy

The mission of the United States Naval Academy is to:

> Develop midshipmen morally, mentally and physically and to imbue them with the highest ideals of duty, honor and loyalty in order to provide graduates who are dedicated to a career of naval service and have potential for future development in mind and character to assume the highest responsibilities of command, citizenship and government.

The Naval Academy produces officers who serve in the United States Navy and Marine Corps. Therefore, the goals and outcomes of all the academic programs, including the Aerospace Engineering program, support the Naval Academy mission under the leadership of the Academic Dean and Provost. The institution has developed a set of strategic educational outcomes that describe the results it wishes to produce in the graduates. Upon graduation of the midshipmen, the Naval Academy expects to have developed naval and marine corps officers who are, for example:

- Courageous leaders who take responsibility for their personal and professional decisions and actions
- Role models of ethical behaviour and moral conduct
- Exemplars of academic, technical and tactical competence
- Individuals with a passion and commitment to lifelong learning and physical fitness
- Highly effective communicators
- Leaders who recognize and value individual excellence regardless of gender or cultural and ethnic background
- Able to understand and integrate geopolitical complexities in their decision making across the spectrum of military operations

The mission of the Aerospace Engineering Department must follow from the mission of the Naval Academy, while at the same time emphasizing the role of the aerospace engineering major. Our departmental mission and vision are a direct result of our participation in CDIO. Our mission is to: Provide the Navy and Marine Corps with engineering graduates capable of growing to fill engineering, management and leadership roles in the Navy, government and industry, maturing their fascination with Air and Space systems. Our departmental vision follows our mission: Mission fulfilment requires a program

wherein Midshipmen Conceive – Design – Implement – Operate complex mission-effective aerospace systems in a modern team-based environment.

Our primary interest in CDIO initially was its approach to program assessment that is tied to the CDIO syllabus. We felt that this approach would of great assistance in meeting the new accreditation standards set forth by the Accreditation Board of Engineering and Technology (ABET). However, as we learned more about CDIO we were convinced that CDIO was right for us for many reasons, beyond our initial interest in the assessment process. The primary reasons for adopting the CDIO Initiative in to the Aerospace Engineering program at the Naval Academy were:

- Our desire to go beyond "paper designs" in capstone design courses
- The strong focus at the Naval Academy on operations – our graduates become operators of systems
- CDIO provides us with the structure to make necessary changes in our program
- CDIO provides us with lessons learned from the original four schools to help guide our design and implementation of a renewed Aerospace Engineering Department.

Prior to adopting CDIO our faculty identified the need to move from conceptual designs in our capstone design courses to design-build-fly (DBF) projects. Our students wanted to do more than just learn abut spacecraft and airplanes – they wanted to build and fly them. This led to the formal creation of the DBF (Figure1) program for our aeronautics students where they build small, unmanned aerial vehicles (UAVs) and the Small Satellite Program (SSP) for our astronautics students (Figure 2).

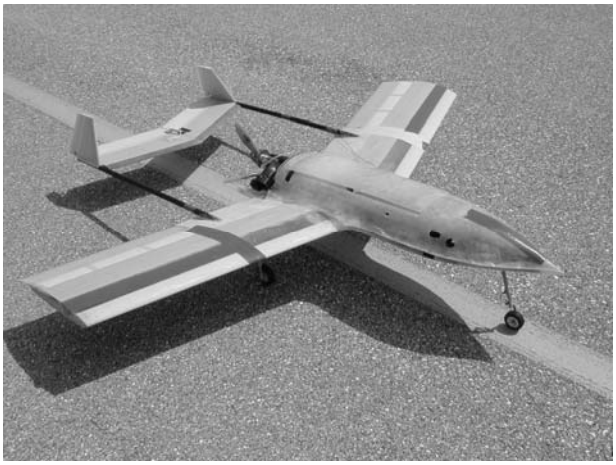

Figure 1: DBF UAV – 2004

Figure 2: SSP Satellite – PCSa

Once we decided to adopt the CDIO syllabus, the next question was, how do we do we gain support from the administration, the program leaders, and the faculty? Once we completed the CDIO Syllabus and looked at our existing program, it was clear we valued topics in the CDIO Syllabus, but we were not teaching the topics. This provided the motivation for change and made the job of convincing our faculty to adopt the CDIO Syllabus. The survey of our key constituents further solidified the need for change and the advantages of the CDIO Syllabus. We were on our way!

CDIO ASSESSMENT

The Student Learning Assessment Model (Figure 3) is used to guide CDIO practice. This model provides an approach to student learning assessment that is based on the CDIO standards and the local program context. The model may be used at the course, program or institutional level. It describes four elements of student learning assessment: learning objectives, curriculum and instruction, assessment of student learning, and use of

assessment results. The model highlights the importance of aligning teaching, learning, and assessment with the CDIO and local program's intended learning outcomes, as well as the use of assessment results to improve the processes of teaching, learning, and assessment.

The CDIO assessment model begins with a consideration of student learning outcomes relevant to a local program using the CDIO curriculum as a guide. Next, the outcomes are integrated into the local curriculum and instructional methods and materials. Student learning assessment is embedded in the curriculum and instructional methods in order to ensure their authenticity. Finally, clear procedures are established to ensure the use of assessment information for program improvement.

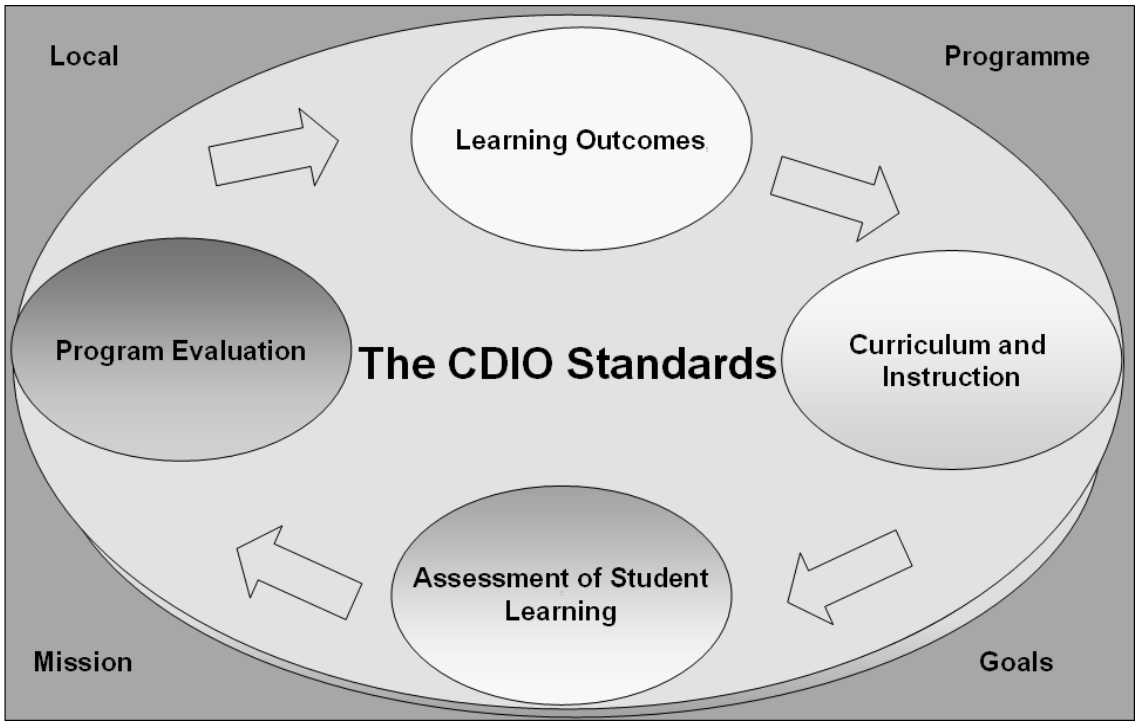

Figure 3: CDIO Student Learning Assessment Model

Assessment of student learning begins with the specification of the course learning objectives, i.e., the knowledge, skills, and attitudes that students will develop as a result of a program of instruction, including the key CDIO personal, interpersonal, and product and system building skills. Once the objectives are clearly stated, the instructional curriculum is designed around them and teaching and learning experiences are created to facilitate their accomplishment by students.

Just as different categories of learning objectives require different teaching methods and learning experiences, they also require different assessment methods in order to ensure the reliability and validity of the assessment data and to accommodate a broad range of student learning styles. Assessment methods should include both direct and indirect measures of student learning that are appropriate to the type of learning intended and to the nature of the learning activities offered to help students achieve the desired learning outcomes.

A CDIO program uses a variety of evaluation methods to determine whether or not students have acquired the knowledge, skills, and values specified in the CDIO Syllabus. The variety of methods available to gather and evaluate student learning include written and oral tests as well as rating scales (i.e., rubrics) for evaluating student performance, journals of student reflections, portfolios of student work over time, capstone projects (e.g., design/build efforts), and faculty, peer, employer, and student qualitative self-assessments. For example, learning objectives related to disciplinary knowledge may be assessed with oral and written tests. Those related to personal and interpersonal skills might include

journals of student reflection and faculty, peer, employer, and student qualitative self-assessments. While those related to design-build skills may be better measured with recorded observations of student performance using a set of evaluation criteria in the form of a scoring rubric.

As essential element of the assessment model is the use of assessment results to improve the teaching, learning, and assessment processes. That is, the quality of student performance provides information for modifying learning goals and objectives, planning subsequent course offerings, refining course syllabi, and improving assessment methods.

ASSESSMENT AT USNA

Assessment at the United States Naval Academy is based on a model that has many of the same components as the CDIO model. The USNA mission sets our local program context and departmental missions as described above. Learning outcomes, program curricula and course syllabi, assessment processes, and the use of assessment results are all developed and managed by academic departments. In addition, there is a Faculty Senate Assessment Committee that manages institution-wide assessment of the USNA learning goals of effective communication, critical and analytical thinking, and geopolitical understanding.

The Department of Aerospace Engineering uses many different assessment methods to determine how successful their program is in fostering desired student learning outcomes. Historically, the department relied on written exams to evaluate the technical knowledge of our students. Additionally, we relied on external reviews by government and industry of the student's capstone design projects and the overall Aerospace Engineering Program. Since joining the CDIO Initiative, we have added several assessment tools to provide direction for our program improvement, while retaining the external reviews and exams.

Our first step was to have each faculty member write a "Faculty Reflective Memo" at the end of each term for each course taught. In the memo, the faculty member addresses adequacy of, and ability to meet, all course objectives, preparedness of students for the courses, results of changes made in the course for that term, actual performance of students, and recommended changes for future offerings. After all the reflective memos are collected, and before the start of the next term, the department meets as a group to review each course and try to identify trends within the overall program. When appropriate, changes are made to individual courses or the overall program.

The department also initiated entry and exit surveys for all students in the program. The entry survey focuses on a self-evaluation of the students regarding their preparedness for the program and also their expectations for the program. This survey is administered at the start of the second year, shortly after the students choose their majors. The students are asked to rate themselves with respect to several of the CDIO skills. The exit survey is administered during their final term and asks the students to evaluate their technical, personal, and interpersonal skills; their satisfaction of the overall program; and recommendations for improving the program.

This combination of evaluating individual's technical skills and knowledge using exams, internal course and program review using the reflective memos and semi-annual curriculum reviews, and external review by government and industry has helped us identify several weaknesses and our program and make the appropriate changes to improve the program.

In January 2004, the twelve schools/programs then involved in the CDIO Initiative adopted 12 standards that describe CDIO programs. These guiding principles were developed in response to administrators, 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 and multidisciplinary 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. It is the stated goal of the Aerospace Engineering Department to comply with all twelve standards.

Our self-assessment of progress toward full implementation of the CDIO model is therefore a score of 36 out of 48, summarized in Table 1. This contrasts with a compliance score of 13 in the summer of 2003 when we joined the consortium. Each standard is self-assessed against a five-point scale (0-4):

0. No initial program-level plan or pilot implementation
1. Initial program-level plan and pilot implementation at the course or program level
2. Well-developed program-level plan and prototype implementation at course and program levels
3. Complete and adopted program-level plan and implementation of the plan at course and program levels underway
4. Complete and adopted program-level plan and comprehensive implementation at course and program levels, with continuous improvement processes in place

It's worthwhile to note that this scale, as articulated, doesn't represent linear progress to task; the increment between 2 and 3 representing a greater practical step than the other increments.

Table 1. CDIO Self-Assessment Score

	Standard	**Summer 2005**	**Summer 2003**
1	CDIO context	4	1
2	Syllabus	4	1
3	Curriculum	2	1
4	Intro Course	4	1
5	Design-Build	4	1
6	Workspaces	3	2
7	Integrated Learning	3	1
8	Active Learning	2	1
9	Faculty CDIO skills	4	1
10	Faculty T&L skills	2	1
11	Skills Assessment	2	1
12	Program Evaluation	2	1
	Total	**36**	**13**

Although the results of our ABET evaluation won't be available until summer of 2006, our CDIO Self-Assessment provided us with the basis for our ABET Self-Study and helped us demonstrate our process for continuous program improvement.

ADVICE FOR CDIO ADOPTERS

In conclusion, here is advice for those who wish to adopt the CDIO model to their programs:

0. Evaluate your program. What are your strengths and weaknesses relative to the CDIO Syllabus?

1. Identify some early successes
2. easy to implement
3. quick payoff
4. visible results
5. Generate buy-in from faculty
6. give them tools to help with changes
7. reward faculty who embrace CDIO (P&T)
8. give them ownership in project
9. Be ready to assess results and make changes
10. Identify resources needed before you embark on large changes – especially project-based courses

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