# Development of Design Directed Engineering Curriculum based on the CDIO Framework

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**Abstract**
As economic reform in China has made significant progress in the last 25 years, there is an urgent need to reform higher education system to better serve increasing needs of society and industry. College of Engineering at Shantou University adopted CDIO education framework to re-design engineering programs. A design directed engineering education approach based on CDIO has been developed to re-design curricula and course contents. Since this is a college wide implementation of a new engineering education paradigm, detailed steps have been taken to ensure smooth transition from the current curricular to the new curricula. This paper discusses the implementation process and progress as well as potential challenges.

## Introduction

Over 2,000 universities in China graduate over 500,000 new engineers annually. Recent rapid economic expansion in China has created a number of new enterprises, and these companies have absorbed most of the recent engineering graduates. For the increasing number of multinational firms established in China, recruitment of qualified engineers has been considered critically important. According to research by the McKinsey Global Institute [1], these multinationals have been experiencing challenges in recruiting engineers and other professionals in China. The report identified a number of issues, one of which is that Chinese educational system is "biased toward theory" where "Chinese engineering students received relatively little practical experience in projects or teamwork compared with engineering graduates in Europe and North America". In the last few years, major efforts have been made to reform engineering education both at the Ministry of Education and at universities.

Before the cultural revolution, the Chinese education system was designed more for the planned economy. Engineering programs were, therefore, narrowly focused with significant engineering science content and detailed specialized courses. Engineering students graduated from this kind of program readily worked at jobs on which the programs were based. Engineering graduates were provided with employment, based on their specialty and family location as well as other government considerations. With the planned economy and lifelong employment of almost all Government Corporations, such programs served the purpose of supplying engineering graduates to sustain the operations of crown corporations.

Since Chinese economic reform was launched in 1978, many private enterprises and crown corporations that have gone public require different kinds of engineers with broader based engineering training who can adapt to the changing needs of both companies and their customers. Graduating students are no longer provided with jobs, and they have to compete with others in the open job market. It is becoming increasingly clear that broad based engineering education with both strong theoretical and practical knowledge, as well as other skills, such as teamwork, leadership, communications, project management, knowledge of technology, appreciation of society, etc., are essential in engineering education reform. No private firms can offer lifelong employment, and individuals may have to change jobs a few times before retirement. Therefore, educational background, various software skills and interview skills have become critically important for those who are competing with many others for one job.

In the last few years, the importance of engineering education has been recognized by the leadership at various levels of educational systems. In North America, universities are autonomous, with protection by law for academic freedom and governance. For those professionally accredited engineering programs, professional bodies control the accreditation process to ensure that graduating engineers meet the minimum requirements for registration as a professional engineer after a few years of practice and passing the ethics exams.

In China, the Ministry of Education and provincial governments are formally in charge of the educational system, with authority ranging from degree granting status to quality control and textbook development. The quality control of engineering programs has been largely left to the government, since formal engineering accreditation by an independent body has yet to be established. One of the major advantages with the current Chinese educational system is that radical reform of engineering programs can take place relatively easier than in North America. Therefore, a relatively efficient approach has been adopted by Shantou University to develop new curricula for all engineering and computer science programs based on the CDIO education framework.

**Engineering Education Reform at Shantou University**

Shantou University was founded jointly by the Guangdong Province of China and the Li Ka-Shing Foundation in Hong Kong in 1981, when economic reform in China had just begun. The College of Engineering at Shantou University consists of four departments, offering five engineering programs: Civil Engineering, Computer Science and Engineering, Electronic Engineering, Electric Communication Engineering, and Manufacturing Engineering (formally Design, Manufacturing and Automation Engineering in Chinese). Shantou University has been taking various initiatives in education reform, ranging from English enhancement to full credit systems. Therefore, both academic staff and students are more open to changes than many traditional universities in China.

One of the main objectives for engineering program reform is accreditation by the US's ABET 2000 and the Canadian Engineering Accreditation Board as soon as possible. To make all the engineering programs ready for accreditation within a five-year timeline, it is not practical to follow a well-established approach that normally requires a relatively long time to complete changes in the entire curricula. The College of Engineering has decided to adopt the CDIO initiative and redevelop new curricula for all five programs based on the CDIO framework, because it provides a holistic and systematic educational model and the complete implementation of the CDIO education framework will provide the necessary assurance to meet US/Canada engineering accreditation needs. In addition, it is believed that design directed engineering education, based on CDIO, provides rationale, methodology, resources and tools to develop the new engineering education paradigm in China, in order to produce a new generation of engineers who will meet the demands of both Chinese local enterprises and multinational corporations. While the curriculum redesign is still in progress, this article reports the process, experiences and difficulties in the development of the new engineering curricula, using the Manufacturing Engineering and Civil Engineering programs as examples.

**Design Directed Engineering Program based on the CDIO Framework**

In the Chinese educational system, with strong administrative influence, it is much easier to establish a consensus in developing new curricula based on the CDIO framework. To develop new engineering curricula for all engineering programs in a relatively short time, an approach with the following steps has been developed:

1. Introduce CDIO to academic staff.
2. Help academic staff become familiar with the CDIO education framework and the associated standards through training and workshops.
3. Prepare students for program reform and changes.
4. Analyze individual course content against the CDIO syllabus with Introduction, Teaching and Utilization.
5. Select and train champions.
6. Redesign curricula for all the engineering programs.
7. Design new course content.
8. Renovate laboratories and workspace, as well as upgrade experimental facilities.
9. Select two courses from each program for pilot implementation.
10. Revise the new programs and make changes based on feedback from experience of the pilot courses.

To prepare academic staff for adopting CDIO in creating new engineering curricula, the first step was to reach a consensus within the College Administrative Council. A series of meetings and discussions were carried out to discuss the development and implementation process. Then, a faculty council meeting with all academic staff was called to discuss this new initiative. Each department also called a series of meetings to reach a consensus on adoption of CDIO for developing new engineering curricula.

This initiative soon became known to most engineering students. Some students were excited about this major change: others expressed concern for the potential impact on their studies. In parallel to the implementation process, we created the World Engineer Forum to discuss various topics that are important to engineering students and academic staff. The first forum was on engineering education. This three-hour session was used to explain to students the reasons for such changes and how this new initiative would impact on their studies and career development. Students became very supportive. For example, students currently in their junior and senior years will not have an opportunity to experience this change. Many students, therefore, demanded the implementation of as many courses as possible and as soon as possible so that they could learn in the different paradigm.

All engineering academic staff who were currently teaching engineering courses were provided with a copy of the CDIO syllabus in Chinese and were asked to provide analyses of their course content and the learned knowledge and skills. Each of the syllabus competency items was analyzed to against the learned knowledge and skills of a course by the course instructor in terms of Introduction, Teaching and Utilization of a particular competency item. All of the course analyses were then collected to determine the differences between the current programs and the CDIO syllabus. This exercise accomplished two things: 1) determination of what was being taught in the current programs; and, 2) understanding of the CDIO syllabus and its meaning, as well as a more in-depth knowledge of CDIO. In fact, this was also a training and learning process and has proven to be worthwhile.

Champions were selected from each department to form a CDIO panel for developing the implementation plan, ranging from training workshops to course outline format issues. Several training workshops and faculty council meetings were organized to introduce CDIO and associated documents. As one individual had previously attended a CDIO workshop and two others were familiar with the contents, the workshop and initial implementation process seems to have gone well.

The new engineering curricula have been designed based on an engineering design directed approach. Engineering design, in a broad sense, is considered the essence of engineering. The proposed engineering design directed CDIO program will use engineering design as the theme to integrate all courses, as shown in Figure 1.

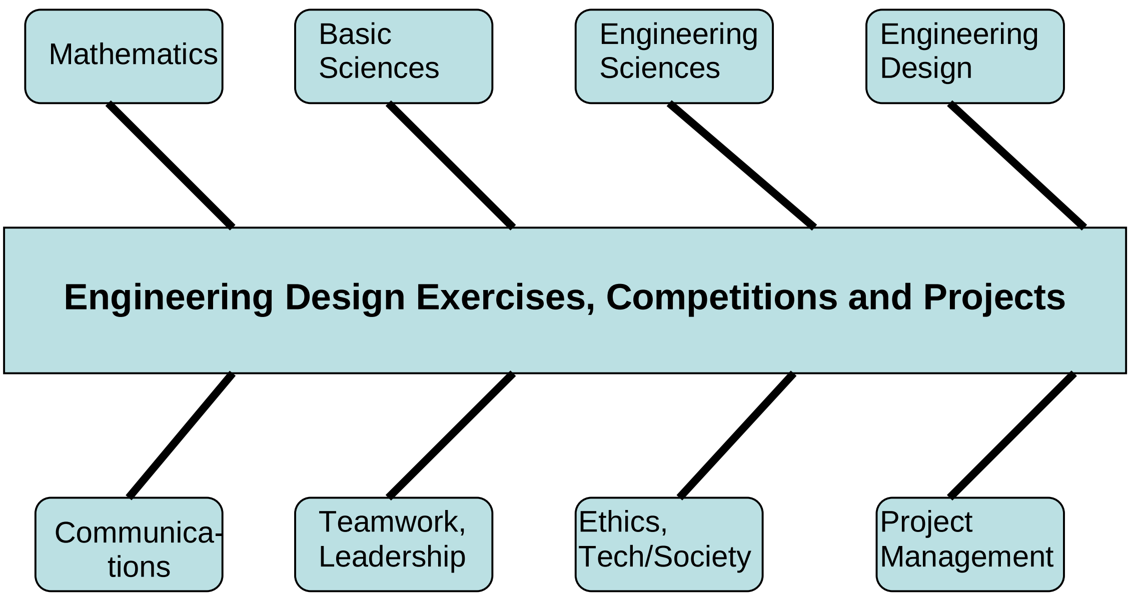


Figure 1. Design Directed CDIO Implementation

Figure 1 shows that the design directed engineering programs based on CDIO will integrate all engineering and non-engineering knowledge and skills. In addition to the previously existing final year design project, at least four design projects will be introduced in each of the five programs. These design projects will be distributed throughout the four-year programs to allow the students to gradually go to greater depth in each stage. Table 1 shows the projects and their emphases for the Manufacturing Engineering program.

Table 1. Planned projects in the curriculum of the Manufacturing Engineering program

| Project | stage | Project specifications |
|---|---|---|
| Introduction to Engineering | Year 1 Semester 1 | 4 design mini-projects to stimulate the students' interest and creativity, to expose the students to the process of knowledge creation and development, to give the students a sense of responsibility in social and historical contexts |
| Engineering Design & Communication | Year 2 Semester 1 | To introduce the students to the design process, design process management, task decomposition and cooperation and team spirit |
| Mechatronic System Design & Prototyping I | Year 2 Semester 2 | Market survey, product definition (functional analyses), feasibility analyses and conceptual design |
| Mechatronic System Design & Prototyping II | Year 3 Semester 2 | Detailed design including specifications, forms, tolerances, materials, etc. |
| Mechatronic System Design & Prototyping III | Year 3 Semester 2a (a mini 6-week semester after Semester 2) | Prototyping and validation including fabrication, inspection, assembly, testing, operating processes, etc. |
| Final Year Design Project | Year 4 Semesters 1 & 2 | Open-ended design projects coming from industry or faculty R&D programs, students will be required to complete the project from the planning and definition stage to the implementation stage. |

As can be seen, design projects are staged in accordance with the students' development in learned knowledge and skills in their programs. The design directed curriculum puts the students in a design environment where they learn engineering science and technology and when they need to use them. In addition, they are required to work as design team, exercise their communication, project management, leadership and other skills. Specifications for life cycle engineering requirements and environmental considerations give students the opportunity to relate their design activities and decisions to social and professional responsibilities. This approach is a major improvement from the traditional one, which provides the students with all the engineering science and technology materials but where most students have little or no ‘engineering appreciation’. An analogy may depict the situation clearer: imagine that “the technology and practice are the vocabulary of engineering, the design process as composition and engineering science as the grammar” [2]. Preparation of compositions puts the grammar and vocabulary in the right context and make the learning much easier and fun. Of course, any composition assignment uses only limited vocabulary and grammar. Rigorous training in these areas is necessary.

For the Civil Engineering program, the design processes are arranged in a more discrete fashion. This is due to the diversity of the different fields in civil engineering: material science, structural engineering, transportation engineering, geotechnic engineering, etc. Each project is designed with emphasis on a specific field. Table 2 shows the project plan.

Table 2. Planned projects in the curriculum of the Civil Engineering program

| Project | stage | Project specifications |
|---|---|---|
| Introduction to Engineering | Year 1 Semester 1 | 4 design mini-projects to stimulate the students’ interest and creativity, to expose the students to the process of knowledge creation and development, to give the students a sense of responsibility in social and historical contexts |
| Sustainable Development Civil Engineering I (Sustainable Development Civil Engineering Materials) | Year 2 Semester 1 | The students need to learn the fundamentals of construction materials; then work in groups to make mix designs of Portland cement concrete for specific purposes, to realize the mix, to test and validate the design, to present to the class, and to discuss and defend their ideas. |
| Sustainable Development Civil Engineering II (Human Habitat and Green Construction) | Year 2 Semester 2 | Team project work. Enhance communication abilities |
| Engineering System Design | Year 3 Semester 2 | Whole cohort (about 50 people) of students work as a team to design a civil system, such as an arterial road system or a new city district |
| Structural and Geotechnic Engineering Design | Year 3 Semester 2 | Two structural teams and two geotechnic teams work together to design a given system |
| Final Year Design Project | Year 4 Semesters 1 & 2 | Work on a major construction development project, such as Shantou Metro system |

Teamwork and communication are always required throughout all projects. ~~The~~ Personal, inter-personal and CDIO capabilities, as specified in the CDIO syllabus [3], are addressed where appropriate in the processes and assessments of the projects' implementation.

In order to introduce the new design projects, radical adjustments have been made to the existing curricula. Twenty to thirty percent of existing contact hours between academic staff and students have been cut. Some courses have been merged or may even be phased out.

Most of the details of the projects are still under design. This is partially because the stakeholders' survey is yet complete. The survey results are needed to set up the educational benchmarks and to validate the educational objectives, as stipulated by CDIO Standards [4].

The development of course content is in progress. To further enhance faculty understanding of CDIO and the associated processes and standards as well as enthusiasm in the process, faculty members are involved in reformatting the course syllabi. A course syllabus template has been created for all courses. Two major changes have been introduced into the template. One is changing the former content oriented syllabus into an outcome oriented syllabus. For each item listed in the syllabus, the expected learning outcome is marked with the six levels of Bloom's taxonomy of cognitive domain [5]. The second change is the introduction of a table specifying the 14 CDIO syllabus second level 2.1 – 4.6 objectives, similar to Figure 2 in reference [6]. The table is filled with the training/utilization expectations for each objective. This serves three purposes:

1. All teaching staff have to make some effort~~s~~ to understand the CDIO initiative and its syllabus.
2. The filled table works as a kind of 'promise' for what a specific course is to contribute to the program's CDIO initiative.
3. The collection of all syllabi in a program's curriculum would easily enable an overall check of CDIO practices within the program's activities.

Laboratories and workshops are indispensable components that support the CDIO initiative. Apart from the existing 24 laboratories open to all project students, an integrated Student Innovation and Project Centre in the College of Engineering is being developed to provide students with the necessary infrastructure and facilities to work their projects. The over 400m$^2$ space will house facilities ranging from physical prototyping to civil, mechanical, electric and electronic, computational and communicational hardware and software. An estimated 11 million RMB (about $1.4 million US) engineering complex renovation and laboratory equipment upgrading project is also underway. These efforts will provide students and staff with a new facility to implement the new CDIO based engineering curricula.

The new curricula will be implemented for students enrolled in Fall 2006. There have already been some trial runs of design projects working within discrete courses. For example, in a Civil Engineering course, instead of assigning the students with a given mix and asking them to make the specimen and crush them, Construction Material lab practice has required the students to design their own mix to fit a specific purpose, like acid resisting, and to validate their designs. The students have come up with some very unique designs of which the instructor was unaware. In this particular course, the students are also asked to read journal papers and make summaries relating to their material design project. Such practices have changed the mindset of the students, who now even actively request for changes in other courses. These initial responses provided endorsement from students. Hence, it is expected that more positive responses will come from students once the new courses are introduced in the fall of 2006.

Though the CDIO framework has been set up and is expected to be in operation soon, the real challenges will occur upon full implementation of the CDIO programs. Two major problems are anticipated:

1. Lack of experience in running and managing the design directed education practice. The balance between rigorous training and hands-on experience can easily be lost. This problem can, of course, be solved through practice and exploration, provided that all faculty members believe in the initiative and commit themselves to it.
2. There will be some unwillingness, inertia, doubt or resistance from faculty members. The initiative must finally be implemented in courses and projects; and, the motivation and responsibility of faculty are crucial. Therefore, there have to be some pioneers piloting the initiative and leading the implementation process. To this end, two courses per program have been selected to pilot the initiative at the course level. The results will be summarized by the end of June 2006.

**Conclusion**

The College of Engineering at Shantou University is the first institution in China to develop new engineering programs based on the CDIO education framework. Since November 2005 (in less than 6 months), progress has been made on various fronts. New curricula for all engineering programs including Civil Engineering, Computer Science and Engineering, Electric Communication Engineering, Design, Manufacturing and Automation Engineering (equivalent to Manufacturing Engineering programs in North America), and Electronics Engineering have been developed. Detailed course content is being developed. Workspace improvements, including development of new design project spaces and upgrading of laboratory facilities, are underway. Two pilot courses from each of the engineering programs have been selected to implement the new curricula, and the implementation results are expected in end of June 2006. Between June and September 2006, minor changes will be made in the new curricula and course content, in order to be ready to offer the new curricula in Fall 2006.

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