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, the recruitment of qualified engineers has been considered as critically important. According to research conducted by the McKinsey Global Institute, these multinationals have been experiencing challenges in recruiting qualified engineers and other professionals in China [1]. The report identified a number of issues, one of which is that the Chinese educational system is biased towards 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. With the planned economy and life-long employment of almost all State-owned corporations, such programmes served the purpose of supplying engineering graduates to sustain the operations of crown corporations.

Now, graduating students are no longer provided with jobs; 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, communication, project management, knowledge of technology, appreciation of society, etc, are essential in engineering education reform. No private firms can offer life-long employment, and individuals may have to change jobs a few times before retirement. Therefore, strong technical education, various soft skills and interview skills have become critically important for those who are competing with many others for one job.

In China, the Ministry of Education and provincial governments are formally in charge of the educational system. One of the advantages with the current Chinese educational system is that radical reform of engineering programmes can take place relatively easier than those in North America. Therefore, a relatively efficient approach has been adopted by Shantou University, Shantou, China, to develop new curricula for all engineering and computer science programmes based on the Conceive – Design – Implement – Operate (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 with a mission to reform higher education in China. The College of Engineering at Shantou University in Shantou, China, adopted a Conceive – Design – Implement – Operate (CDIO) education framework to redesign its engineering programmes. A design directed engineering education approach based on the CDIO framework has been developed in the redesign of the curricula and course contents. Since this is a college-wide implementation of a new engineering education paradigm, detailed steps have been undertaken to ensure a smooth transition from the current curricula to the new curricula. In this article, the authors discuss the implementation process and progress, as well as potential challenges.
approach that normally requires a relatively long time to complete changes in the entire curricula. Based on the successful experiences of implementation of CDIO in other institutions in the USA and Europe, the College of Engineering has decided to adopt the CDIO Initiative and redevelop new curricula for all five programmes based on the CDIO framework. The CDIO framework provides a holistic and systematic educational model. The complete implementation of the CDIO education framework will provide the necessary assurance to meet USA/Canada engineering accreditation needs. In addition, it is believed that design directed engineering education, based on CDIO, provides the rationale, methodology, resources and tools to develop the new engineering education paradigm in China in order to produce a new generation of engineers who can meet the demands of both Chinese local enterprises and multinational corporations. While the curriculum redesign is still in progress, the authors report on the process, experiences and difficulties in the development of the new engineering curricula, using the manufacturing engineering and civil engineering programmes as examples.

DESIGN DIRECTED ENGINEERING PROGRAMME BASED ON THE CDIO FRAMEWORK

To develop new engineering curricula for all engineering programmes 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 programme reform and changes;
4. Analyse individual course content against the CDIO Syllabus with introduction, teaching and utilisation;
5. Select and train champions;
6. Redesign curricula for all the engineering programmes;
7. Design new course content;
8. Renovate laboratories and workspace, as well as upgrade experimental facilities;
9. Select courses from each programme for pilot implementation;
10. Revise the new programmes and make changes based on feedback from experiences with the pilot courses.

In order to prepare academic staff for adopting CDIO in the creation of 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 the adoption of CDIO for developing new engineering curricula.

Most engineering students soon became aware of this initiative. Some students were excited about this major change, while others expressed concern for the potential impact on their studies. In parallel to the implementation process, the World Engineer Forum was created 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 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, as well as the learned knowledge and skills. Each of the Syllabus competence items was analysed against the learned knowledge and skills of a course by the course instructor in terms of introduction, teaching and utilisation of a particular competence item. All of the course analyses were then collected to determine the differences between the current programmes and the CDIO Syllabus. This exercise accomplished two things. Firstly, a determination of what was being taught in the current programmes and secondly, an understanding of the CDIO Syllabus and its meaning, as well as a more in-depth knowledge of CDIO. In fact, this formed part of the 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 organised 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 programme will utilise engineering design as the theme to integrate all courses, as shown in Figure 1, which shows that the design directed engineering programmes based on CDIO integrate all engineering and non-engineering knowledge and skills through design projects. In addition to the previously existing final year design project, several design projects will be introduced in each of the five programmes. These design projects will be distributed throughout the four-year programmes to allow students to gradually go to greater depths in each stage.

To implement the design directed approach, three levels of design projects are defined. Level 1 projects integrate most core courses of a programme. Level 2 projects integrate a group of interrelated core courses. Level 3 projects are embedded in individual courses to enhance the learning of the specific course content. A fishbone diagram is used to express the curriculum structure of each programme. Figure 2 shows the fishbone diagram for the civil engineering programme. The fishbone, ie the curriculum plan, defines only Level 1 and 2 projects. Level 3 projects are planned in individual courses.

![Figure 1: Design directed CDIO implementation.](image-url)
where needed. The design projects integrate CDIO skills with technical disciplinary content and exploit disciplinary linkages.

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]. The preparation of compositions puts the grammar and vocabulary in the right context and make learning much easier and more fun. Of course, any composition assignment uses only limited vocabulary and grammar. Rigorous training in these areas is necessary.

For the civil engineering programme, the design processes are arranged from introduction to professional designs of the different fields in civil engineering: material science, structural engineering, transportation engineering, geotechnical engineering, etc. Each project is designed with an emphasis on a specific field, but all refer back to the same initial dream home project. Table 2 shows the project plan.

Table 2: Planned projects in the curriculum of the civil engineering programme.

<table>
<thead>
<tr>
<th>Project</th>
<th>Stage</th>
<th>Project Specifications</th>
</tr>
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<tbody>
<tr>
<td>Intro. to Civil Engng. Design</td>
<td>Yr 2 Sem. 1</td>
<td>Plan roads, bridges, a school and a community library for a dream home</td>
</tr>
<tr>
<td>Sustainable Develop Civil Engng.</td>
<td>Yr 2 Sem. 2</td>
<td>Architecture design of one of the dream home facilities. Address environmental problems and sustainable development issues</td>
</tr>
<tr>
<td>Structural &amp; Geotechnic Engineering Design</td>
<td>Yr 3 Sem. 2</td>
<td>Structural designs for the dream home. Groups need to design a structure different from the one they in the architecture design stage</td>
</tr>
<tr>
<td>Engng. Systm Evalu. &amp; Constr. Mngmt Plng</td>
<td>Yr 4 Sem. 1</td>
<td>Evaluate the dream home designs regarding economic, social and environmental issues. Plan its construction</td>
</tr>
<tr>
<td>Final Year Project</td>
<td>Yr 4 Sem. 1 &amp; 2</td>
<td>Major construction development project, eg the Shantou metro system</td>
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Implementing and operating the above designs in civil engineering are impossible. However, while engaging in design, students must address economic, social and environmental problems, ie the operation issues of the CDIO Initiative.

In addition to these large scale projects (Level 1 and 2 projects), some courses operate small scale (Level 3) projects in course delivery. Such project address all the C, D, I, O issues of the CDIO Initiative.

In order to introduce the new design projects, radical adjustments have been made to the existing curricula, notably 20-30% of the existing lecturing hours by academic staffs has been cut. Some courses have been merged or may even be phased out. In order to realise this, there has to be a paradigm...
shift from faculty-centred teaching oriented to student-centred learning. More discussions are required to balance teaching and learning. Practical elements have been significantly added in the programmes to allow students to develop their ability to utilise and apply knowledge to practical problems, conduct independent thinking, enhance teamwork and communication skills, as well as project and human management skills.

The reformed plan will not be in full operation until the 2006 cohort of students reaches the designated stages. However, whenever appropriate, test runs will be carried out for students of earlier cohorts to accumulate experiences. A stakeholders’ survey has yet to be completed. The results will be used to set up the educational benchmarks and validate the educational objectives, as stipulated by the 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 reformating 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 syllabi into outcome oriented ones. For each item listed in the syllabi, the expected learning outcome is marked with Bloom’s taxonomy of the 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 ref. [6]. The table is filled with the introduction/teaching/utilisation expectations for each objective. This serves three purposes, namely:

- All teaching staff members have to undertake some effort to understanding the CDIO Initiative and its Syllabus;
- The table works as a kind of promise for what a specific course is to contribute to the programme’s CDIO Initiative;
- The collection of all syllabi in a programme’s curriculum easily enables an overall check of CDIO practices within the programme’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 space (over 400m²) 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 US$1.4 million) 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 autumn 2006. There have already been some trial runs of design projects working within discrete courses. For example, the concrete mix design as mentioned above. Students have come up with some very unique designs of which the instructor was unaware of. In this particular course, students are also asked to read journal papers and make summaries relating to their material design project. Such practices have changed the mindset of 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 autumn 2006.

Although the CDIO framework has been established and is expected to be in operation soon, the real challenges will occur upon the full implementation of the CDIO programmes. Two major problems are anticipated, specifically:

- A 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;
- There will be some unwillingness, inertia, doubt or resistance from faculty members. The initiative must finally be implemented in courses and projects. Hence, the motivation and responsibility of those faculty members implementing the initiative are crucial. Therefore, there have to be some pioneers piloting the initiative and leading the implementation process. To this end, two courses per programme have been selected to pilot the initiative at the course level.

CONCLUSION

The College of Engineering at Shantou University is the first institution in China to develop new engineering programmes based on the CDIO educational framework. Since November 2005 (less than six months), progress has been made on various fronts. New curricula for all engineering programmes, including civil engineering, computer science and engineering, electric communication engineering, design, manufacturing and automation engineering (equivalent to manufacturing engineering programmes in North America), and electronics engineering have been developed. Detailed course contents of the new curricula are being developed. Workspace improvements, including the development of new design project spaces and the upgrading of laboratory facilities, are underway. Two pilot courses from each of the five engineering programmes have been selected to implement the new curricula, and the implementation results are expected at the end of June 2006. Between June and September 2006, minor changes will be made for new curricula and course content in order to be ready to offer the new curricula in autumn 2006.

ACKNOWLEDGEMENT

The authors would like to thank their many colleagues at Shantou University for their active involvement in developing the new CDIO-based engineering programmes. The authors also wish to thank the Li Ka-Shing Foundation in Hong Kong for providing financial support to this major project.

REFERENCES

3. CDIO Adoption Centre material Appendix A. The CDIO Syllabus in Topical Form (v 4.2.3), www.CDIO.org.
5. CDIO Adoption Centre material Appendix B: Bloom’s Taxonomy of Educational Objectives, www.CDIO.org.