

Exploration and Practice of CDIO Engineering Education Mode

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Abstract. CDIO engineering education model is new achievement in international engineering education reform in recent years. It advocates learning by doing, industry cooperation and internationalization, has strong guidance in engineering teaching reform. Many universities around the world implemented CDIO model and achieved remarkable results. In order to comply with the remarkable teacher training program requirement advanced by the Ministry of Education and train "Double Type" vocational teachers in both engineer and teaching mentor, the CDIO engineering education model has been introduced in Network Engineering Design and Management courses to improve ability, innovation and teamwork of students. This paper introduces the concept of CDIO engineering education and its application in teaching theory, practice and curriculum evaluation, providing a reference for application of the model to other courses.

Introduction

In recent years, in order to improve students' innovative ability and engineering practice ability, every country all over the world is busy with promoting engineering education reform and exploring the training model for the development of innovative engineering and technical professionals. CDIO engineering education model is first developed by the Massachusetts Institute of technology and a few Swedish Universities in 2004 with the support from the Wallenberg Foundation after four years of cross-national studies and tests, which represents one of the latest achievements in terms of international engineering education. The advance and feasibility of CDIO engineering education has been proved by education reform practice domestically and internationally, and such education has imposed a significantly positive role on the field of engineering education in China^[1], and many scholars have published a number of valuable papers. The founder of CDIO, professor E.F. Crawley from the Massachusetts Institute of technology^[2], carefully studied the curriculum of CDIO, and pointed out that the main value of CDIO course lies in that it serves as a model that could be widely promoted to engineering courses designed for any universities, with specific learning objectives satisfactorily met. Literature^[3] mentioned that the application of education ideas related to CDIO and the use of its curriculum in the Department of Aeronautics and Astronautics, the Massachusetts Institute of technology, had promoted wide achievements. Literature^[4] summarized the good results when CDIO engineering education model has been successfully applied to courses such as "Innovations of Information and Communication Technology". In 2008, the Ministry of Education of the People's Republic of China approved the establishment of the project "The research and practice of CDIO engineering education model in China", and 39 colleges and universities became pilot schools. Shantou University is among such pilot schools. It proposed a new EIP-CDIO engineering education philosophy, and advocated the

use of engineering design as the guidance, and the cultivation of personal ability, group ability and system control ability as the major objectives. Also, the demonstration of ethics, integrity and professionalism was a must, and all trained engineers should be professional, honest and responsible^[5]. On the basis of CDIO, Dalian Neusoft University of Information reformed it with Chinese characteristics, creatively established eight TOPCARES-CDIO index systems that are used to assess eight abilities. Actually, every letter of TOPCARES represents a specific ability. For example, T refers to technical knowledge and reasoning, and O refers to open thinking and innovation. Also, students were required to apply gained abilities onto different learning aspects of their four-year college life^[6]. Literature^[7] discussed the application of CDIO model in order to train excellent and comprehensive software engineers. It could be concluded through our survey of domestic papers on CDIO model that the overall emphasis is on the training of excellent software engineers. However, studies that involve the training of these engineers' professional ability are still limited. Therefore, in addition to giving a brief introduction regarding the ideas of CDIO engineering education model, this present study provides a detailed description in term of its application in the course "Network engineering design and management" in aspects of theory teaching, practical teaching and curriculum evaluation, when the course is designed for students (normal) major in computer science and technology.

The ideas of CDIO Engineering education

CDIO engineering education model, commonly referred to as CDIO model, explores the question of engineering education from two fundamental issues, namely, "what kind of people to train?" and "how to train them?".

CDIO connotation

CDIO is the abbreviation of four words, namely, conceive, design, implement and operate. With the life cycle of R & D of associated engineering projects as its carrier (including products, production processes and systems), through a systematic production design that aims to train students' technical expertise, professional and personal ability, teamwork spirit and communication skills, CDIO strives to develop an enterprise's production system capability in terms of conceive, design, implement and operate ability when it is under the influence of the business and social environment. In other words, CDIO is a centralized summary and abstract expression of ideas related to learning-by-doing and project-based education and learning (PBL). Actually, the ideas of CDIO engineering education not only inherit and develop from the ideas of engineering education reform that have been developed in the Europe and America for more than two decades, but also have been further improved in order to increase feasibility, with 12 criteria specifically proposed, such as ability development in a systematic way, guidance implementation in a comprehensive way, procedure implementation in a complete way, and result evaluation in a strict way and so on^[8].

CDIO syllabus

With conceive, design, implement and operate as the main line, CDIO syllabus divides the ability of engineering graduates as four categories, namely, engineering basic knowledge, personal ability, team work and communication ability, and engineering system ability under the influence of the business and social environment. Also, the basic knowledge and skills an engineer should possess are described in details. The vision of CDIO is to train engineers with professional skills, social awareness and entrepreneurial acumen. Therefore, CDIO model is used not only to train technical experts, but also to train innovative engineering and technical professionals who could systematically develop new products in the presence of modern organizations and open market operations, and are with strong social responsibility.

CDIO standard

Table 1 shows the 12 criteria that provide detailed descriptions of the basic features of CDIO, including six major aspects: CDIO background (the standard 1), syllabus development (the standard 2, 3 and 4) design, experience and work environment (the standard 5 and 6), teaching and learning

methods (the standard 7 and 8), the improvement of teachers' skills (the standard 9 and 10), as well as relevant assessment and evaluation criteria (the standard 11 and 12). Among these 12 criteria, seven of them (the standard 1, 2, 3, 5, 7, 9 and 11) represent the most basic and essential ones, which separate CDIO from other educational mode. The rest five criteria severe as complementary ones that could enrich CDIO content.

TABLE 1. TWELVE STANDARDS OF CDIO

1. CDIO as Context	7. Integrated Learning Experiences
2. CDIO Syllabus Outcomes	8. Active Learning
3. Integrated Curriculum	9. Enhancement of Faculty CDIO Skills
4. Introduction to Engineering	10. Enhancement of Faculty Teaching Skills
5. Design-Build Experiences	11. CDIO Skills Assessment
6. CDIO Workspaces	12. CDIO Program Evaluation

Course teaching reform based on the core ideas of CDIO engineering education

In addition to the course “Computer Network”, “Network Engineering Design And Management” is another compulsory course for students at our university who are major in computer science and technology. By learning this course, students are expected to learn the basic concepts of network engineering projects, and to understand network requirements analysis, logical network design, physical network design and integrated wiring construction. Also, they are expected to become familiar with switches, routers, firewalls, server configuration, network engineering testing and maintenance management. In order to comply with the requirements of “Excellent Teacher Training Program” put forward by the Ministry of Education of the People’s Republic of China in 2014, such as the training of Double-professionally-titled Teachers who are excellent engineers and teachers simultaneously, and the improvement of students’ practical ability and engineering practice ability, CDIO training model is introduced throughout the course “Network engineering design and management” in terms of course teaching, reform in teaching methods and curriculum evaluation, with good results accomplished. The implementation process is shown as following:

The improvement of course syllabus

Course syllabus provides an important basis for any teaching courses, and there is no exception for the syllabus of CDIO based courses, which puts an emphasis not only on the mastery of knowledge, but also on the development of practical ability and engineering practice ability. According to the standard 2 of CDIO model, project team members and industry experts should work together to obtain work tasks related to the professional field of “Network Engineering Design And Management” by means of group interview and guidance interview. Meanwhile, task analysis table related to such professional field should be built. According to this task analysis table, all engineering practice abilities that should be trained according to the objectives of this course are defined one by one, which could then help to improve course syllabus of “Network Engineering Design And Management”. Such syllabus should not only provides a brief introduction regarding course nature, course objectives in terms of knowledge, ability and emotion development, but also itemizes project names and work that needs to be done for each project, such as a list of tasks for each project, teaching requirements for ability training and quality training, students’ tasks (e.g., self-learning, assignment, class discussion), and evaluation mode.

Project selection and breakdown

Project selection: In order to better implement the idea of learning-by-doing advocated by CDIO engineering teaching model, the course “Network Engineering Design And Management” requires teachers and professional experts to select several actual or simulated projects according to course syllabus and specialty characteristics that are with proper scale and moderate difficulty. Also, students should be familiar with the application scenarios of such projects, and they should learn how to work in cooperation. Therefore, during the process of project practice, students could not only learn the knowledge, but also have their knowledge expanded, as well as their collaboration

and innovation ability developed. According to project selection principles, the actual network project, “Hi-Tech Manufacturing Base of Xi’an KaiYuan Electronic Industrial Co., Ltd.” is chosen as a teaching demonstration project. Also, the campus network project that students are familiar with is chosen as a comprehensive training project. By doing so, large-scale experiments of the course are established. Due to the scale of the teaching demonstration project, the current project is further divided into ten subprojects as shown in Table 2, among which project 1 and 2 are more theory-based and held in a multimedia classroom; project 3 and 4 represent a combination of theory and practice, and are held in a classroom and network laboratory, respectively; project 5 and 6 put an emphasis on the actual practice. In order to enhance students’ practical ability, these projects are held in a network laboratory. No matter whether it belongs to the type of KaiYuan electronic network projects or the type of campus network projects, the life cycle of R & D of the chosen engineering project is regarded as the carrier, including C-D-I-O (conceive-design-implement-operate) four stages, for which project 2 belongs to the conceive stage, project 3 to 4 belong to the design stage, project 5 to 9 belong to implement stage, and project 10 (the operation and test of the entire network project) belongs to the operation stage. Clearly, such stages represent standard number one of CDIO model.

Project breakdown: After the project has been chosen, the first step is to carry out reasonable project breakdown so that teaching content and teaching objectives could be subtly merged among tasks, and the entire teaching process could be driven by learning tasks as shown in Table 2. For the course “Network Engineering Design And Management”, we do not follow a linear teaching pattern according to the fixed order of all chapters. Instead, we adjust the teaching content according to the needs of the project, and organize the teaching content based on specific teaching tasks. During the process of project breakdown, namely, project-tasks-knowledge points, teachers should straight out the interrelationship among different knowledge points, and optimize course content so that it could become easier for students to understand those abstract and difficult concepts. Also, by implementing the methods of active learning or collaborative learning, students could study in an active manner with high interest and enthusiasm.

TABLE2. THE BREAKDOWN OF PROJECT TASKS ASSOCIATED WITH THE COURSE “NETWORK ENGINEERING DESIGN AND MANAGEMENT”

Project	Tasks
Project 1. Knowing network engineering	An understanding of network engineering and network generic cabling system
Project 2. Network requirement analysis	Business requirement, user requirement, computer platform requirement, network and management requirement, and the writing of network requirement analysis report
Project 3. Logic network design	Network structure design, the selection of physical layer technologies, the selection of LAN technology, the selection of WAN technology, IP address and DNS design, routing protocol selection, network security design, network management design, and the report of logical network design
Project 4. Physical network design	Design of work area, design of wiring subsystems, design of backbone subsystems, design of telecommunication rooms, design of device rooms, design of wire inlet rooms, design of building subsystem, design of network computer rooms, and the report of physical network design
Project 5. The construction of network generic cabling system	The construction of work area, the construction of wiring subsystems, the construction of backbone subsystems, the construction of telecommunication room, the construction of device room, and the construction of wire inlet rooms and building subsystems
Project 6. Switch configuration	Access layer switch configuration, convergence layer switch configuration, and core layer switch configuration
Projection 7. Router configuration	Static routing protocol configuration, dynamic routing protocol configuration, PPP configuration, access control list configuration, NAT configuration, and wireless LAN configuration
Project 8. Network security configuration	Firewall configuration and VPN configuration
Project 9. Server configuration	DNS server configuration, DHCP server configuration, WEB server configuration, and FTP server configuration
Project 10. Test and acceptance testing of network engineering	Test of network engineering, and acceptance testing of network engineering.

Group division

In order to implement the idea of learning-by-doing, collaborative learning style is encouraged. For each project, 2-4 students work together as a group. For the first class, project tasks are laid out, and the specific requirements and the completion time of the project are also made clear. During the process of achieving project objectives, the project manager (the leader) is responsible for group

study, group discussion, and the implementation of the project. Meanwhile, the teachers will provide guidance on certain aspects. Students are divided into 10 groups according to heterogeneous grouping method. Teachers who engage in the course teaching first divide students into subgroups according to their interests. On the basis of such rough group, students are coordinated and assigned to different subgroups according to their personality, academic achievement and practical ability. As a result, the same subgroup would have students with both excellent and poor academic achievements, with both introverted and extroverted personality, with both strong and weak practical ability, and with both male and female students so that such differences could be found in every subgroup.

Theory teaching

In order to better implement the idea of learning-by-doing advocated by CDIO engineering teaching model, the theory teaching part of the course “Network Engineering Design And Management” uses flipped classrooms. Also, its associated network course has been developed, with information such as course syllabus, lecture plan, teaching courseware, educational video, teaching case, teaching design, to-do lists, assignments and experimental guiding books available online. Students are asked to self-study according to the study objectives and learning tasks provided by the to-do lists prior to the course (they also need to watch educational micro-videos and study relevant learning materials from the version of the network course), and to complete the tasks according to the to-do lists. Meanwhile, through Teacher Q & A part of the network course, students could let their teachers know what problems they have met. Also, through Online Communication part of the network course, students could exchange information or have a discussion with their teachers or other students. In addition, students could record their learning process online, submit their assignments as well as lab reports online, test their knowledge with online quiz, and study as a cooperative group. On the other hand, for the classroom section, teachers could guide the process of internalizing knowledge through the completion of assignments, collaborative inquiry, online testing, work display, and one-to-one personalized guidance. By doing so, students could learn to discover, analyze and solves problems during learning-by-doing process. Also, it has been proved useful to implement practical practice in order to guide students’ learning process so that they could develop abilities and skills in aspects of network construction, utilization and management. When student have developed active learning habits (the standard 8), teachers might also better understand students’ learning progress. Also, through the design and making of micro-videos related to theory and practice, and the completion of the design, implement and operation of network engineering project, teachers’ CDIO ability has also been dramatically enhanced (the standard 9). Additionally, activities such as the design and writing of the teaching plan and to-do lists, online Q&A practice, and one-to-one personalized guidance have also improved teachers’ teaching ability (the standard 10).

Practical teaching

The practical teaching part of the course “Network Engineering Design And Management” consists of 32 class hours, which is held in a network laboratory with more than 2 million RMB invested. This network laboratory has 30 Lenovo computers and 10 mobile learning terminals. Other devices include projector and interactive electronic whiteboard. As shown in Figure 2, the training devices of network generic cabling system, the training equipment of network generic cabling system, the training devices of generic cabling system used for the purpose of fault detection, optical access networking equipment, optical fiber fusion splicer, the training devices of all-optical generic cabling system, the router, switch, firewall, wireless access point (AP) and wireless controller (AC) are all included. There are a total of 10 experimental groups. For each group, 3 computers, 2 access switches, and 3 layer-3 switches function as the sink-layer switch and the core-layer switch, respectively. In addition, 1 firewall, 3 routers, 1 AC and 2 AP could help to complete the design of generic cabling system, the construction of the entire engineering project, and the setup of relevant experiments with the router, switch, network security, server and wireless network all configured. Prior to each experiment, students are required to study relevant videos via

the network course, and download experimental guiding books via laptop, mobile phone, iPad or other mobile devices. After the completion of the content of basic experiments, students also need to finish the content of extending experiments. Every experiment has corresponding evaluation scale, and the performance of each student is evaluated according to the completion status of each experiment. This part is in line with CDIO standard 6.

In order to improve students' practical ability, the final exam tests students' professional skills with contest method. For students from class 2012 who major in computer science and technology, all contest questions are shown in Figure 1 and 2. These questions are based on contest questions related to network generic cabling system when an unnamed province has hosted such a skill competition, with the content of network device configuration and server configuration also included. Students are asked to work as a group, and finish 15 tasks through cooperative learning, including the statistical table of point-to-point network information, the design and diagram of network generic cabling system, the design and working drawing of network generic cabling system, the statistical table of compiled materials, the production of network jumper wire and relevant testing, the construction within work areas, wiring subsystem installation/trunking installation and generic cabling, the construction of telecommunication rooms, the construction of backbone subsystem, terminal connections among devices via complex test links, terminal connections among devices via complex network wiring, the production of fiber jumper wire, network device configuration, server configuration, and the writing of project completion report. By doing so, theory teaching and practical teaching has been tightly integrated, and students have achieved mastery through a comprehensive study of the subject. The content of practical skill test includes the core ideas of CDIO model (i.e., conceive, design, implement and operate), which aims to enhance students' engineering ability, and manifests the requirements of CDIO standard 5 as shown in Table 1 (design-build experience). Also, it aims to meet the needs of double-professionally-titled teachers and application-type network talents.

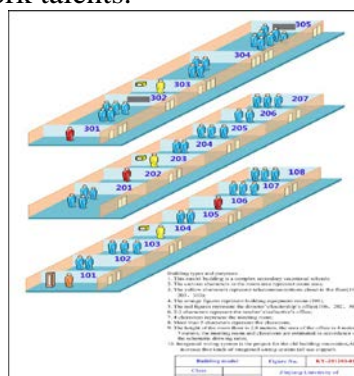


Figure 1. Building model figure

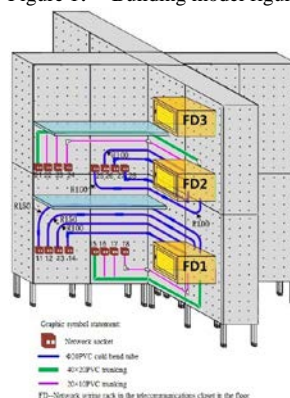


Figure2. Integrated wiring construction sketch

The reform of curriculum evaluation methods

In order to accurately determine the extent of a student's learning effort and performance, in addition to appropriate assessment methods, a detailed assessment content and evaluation criteria for each assessment method should also be provided. Also, the assessment content and expected

capability indexes should be compared, and the significance of contribution degree of each factor should be determined. The course “Network Engineering Design And Management” uses a diversified evaluation method that combines formative assessment and summative assessment. In addition to traditional theory-related exams, students are also required to take practical skill tests that evaluate their practical ability and group cooperative ability. The evaluation scale is designed for each experiment. For example, Ratings table of PVC pipe line installation mentioned in figure 2 as shown in Table 4. The evaluation subjects include all teachers, students and project groups involved. Students are encouraged to objectively analyze and evaluate their own and other groups’ performance. Through self-reflection, students also gain an understanding of their own learning processes. Meanwhile, teachers are encouraged to use the assessment results to help improve the processes of teaching and learning. Clearly, such practice has demonstrated CDIO standard 11 (CDIO ability assessment) and CDIO standard 12 (CDIO project assessment) as shown in table 1.

TABLE 3. CURRICULUM EVALUATION WAY’S CONTRIBUTION TO THE EXPECTED EFFECT OF LEARNING THE TARGET WEIGHT DISTRIBUTION

Formative assessment				Summative evaluation		Overall performance
<i>Performance at ordinary times</i>	<i>Online learning</i>	<i>Homework tasks list</i>	<i>The experiment</i>	<i>Skills test</i>	<i>The theory test</i>	
5%	5%	10%	10%	20%	50%	

TABLE 4. PVC CONDUIT INSTALLATION EVALUATION

Evaluation content	Rank	Score	Evaluation standard
Route 11	0, 5, 10, 15, 20, 25		Each cable wiring routing 25 points, if there is one place is not complete, all points of the routing will be deducted directly. Among them: line pipe installation position, horizontal vertical correctly(10points); Conform to the requirements, joint bending radius is less than 1 mm (10points), otherwise the zero points; Wiring correct and reasonable reserved length(5points)。
Route 12	0, 5, 10, 15, 20, 25		
Route 13	0, 5, 10, 15, 20, 25		
Route 14	0, 5, 10, 15, 20, 25		
Total score			

Discussion

In recent years, countries around the world are actively promoting the reform of engineering education, and exploring the training model of innovative engineering and technical professionals. Since curriculum reform is the key to education reform, this paper discusses possible curriculum and education reform approaches for the course “Network Engineering Design And Management” based on CDIO engineering teaching model, and from the aspects of theory teaching, practical teaching and curriculum evaluation, with the ideas of learning-by-doing and project-based learning specifically advocated. Practice shows that CDIO model is helpful for the development of students’ practical ability, and the enhancement of individual innovative ability as well as group cooperative ability. Meanwhile, our society’s needs of double-professionally-titled teachers and application-type network talents could be met. We hope that our study could also be proved helpful for subsequent practitioners of CDIO.

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