How to Successfully Promote CDIO Reform in Undergraduate Engineering Education

——A Case Study on the Beijing Institute of Petrochemical Technology

Wen-li GUO[1], Bo MENG[2], Hong-Mei JIN[3]
([1]The Office of President, [2,3]Academic Affairs Office, Beijing Institute of Petrochemical Technology, Beijing, 102617)

ABSTRACT
An urgent issue in engineering education is not so much whether to reform, but rather how to reform. In recent years, much attention has been focused on the concept of the engineering education community on the CDIO (conceive, design, implement, and operate) theory study in China. There was a shortage of awareness of how to succeed in undergraduate engineering education and reform the system for implementing CDIO strategic research. Since 2009, this study has investigated the specific case of Beijing Institute of Petrochemical Technology CDIO reform in an attempt to fill this gap. The major issues focused on: (1) how the CDIO idea was spread and succeeded at the school; (2) how the idea based on the CDIO project-based learning in practice was proceeded; (3) how the CDIO concept-based curriculum reform was implemented in practice; (4) the selection of reform strategies; (5) the driving force of the reform; and (6) the key characteristics of successful reforms. The CDIO reform model summarized in this article provides cases from China for international engineering education practice and further enriches the theoretical discussion on the success of the reform of undergraduate engineering education.

Keywords: engineering education, CDIO, reform strategy, project-based learning, standards 6

I. Introduction

Since 2006, the Royal Academy of Engineering has published a series of reports, which indicated that "the most pressing issues in engineering education is not whether to reform, but how to reform." [1] This statement can also be applied to the CDIO reform of Chinese universities. As one of the patterns of international engineering education, the ideas of CDIO has a substantial influence on the ongoing engineering educational reform in China. The applications of CDIO framework in Chinese universities, such as Shantou Universities [2], have been proved to be very successful. However, the theoretical research and practices of the idea in terms of the reform itself are still elusive. Most of the previous literature focused on the theoretical exposition on the idea of CDIO or limited to the simple application of CDIO in a specific course.[3-4] The research on how to promote reform was occasionally reported, which has seriously hampered the effectiveness and progress of CDIO reform in Chinese universities.
The current study was based on the analysis on the reform process of CDIO in the Beijing Institute of Petrochemical Technology (BIPT). By applying the research framework of the Royal Academy of Engineering, the purpose of this research was to discuss how to realize the positive change in

---

1.Crawley, Edward F. "Rethinking engineering education: the CDIO approach". Vol. 133. Springer Science Business Media, LLC, 2007.
2. P.H. Gu, M. F. Shen, S. P. Li, Z. M. Zhuang, X. H. Lu, G. J. Xiong. "From CDIO to EIP-CDIO: A Probe into the Mode of Talent Cultivation in Shantou University," Researches in Higher Education of Engineering, vol.1, 2008, pp.12-19.
3. X. Y. Gu, "Connecting Abstract Theories with Concrete Engineering Skills in the CDIO Learning Cycle",. Researches in Higher Education of Engineering, vol.1, 2009, pp.11-23.
4. T. B. Wang, W. D. Cheng. "Study and Practice on Innovative Engineering Talent Cultivation Model Based on CDIO", Researches in Higher Education of Engineering, vol.1, 2010, pp.35-31.

undergraduate engineering education, especially on the study of occurring, developing, and the continuity of engineering education reform in Chinese universities.

II. The Background and Driving Force of Reform

A. *The Reform Background*

Beijing Institute of Petrochemical Technology (BIPT) is a regular institution of higher education, and administrated mainly by Beijing Municipal Government. BIPT was founded in1978 within the large state enterprises-Yanshan Petrochemical Company. Since its initiation, the BIPT has established a multi-disciplinary academic structure and emphasized on the undergraduate education.

The mission of BIPT has oriented to cultivate qualified high-level engineers on the first production line. In addition, by using the production workshop as a special type of teaching sites, BIPT also tried to improve the students' ability in the interaction of theoretical teaching and practical training.[5]

Currently the university has 797 full-time teaching staff and 7,600 undergraduate and graduate students. The major areas of study focused on electronic information, clean energy, optical-mechanical-electronic integration, new materials, environmental protection and resources, etc. The university has substantially adjusted and optimized its academic structure and established 9 colleges. The university offers 27 Bachelor’s Degree programs (of which 17 are engineering programs) and 2 engineering Master’s Degree.

B. *The Driving Force of the Reform*

The first and the most direct driving force for reform was from the university president and other senior administrator who concerned with the personnel training quality and felt a sense of urgency to compete for similar institutions. For example, “The engineering-oriented practice teaching system is not in place,” “The theory and practice are out of contacted in engineering personnel training,” “Engineering graduates are lack of engineering practice, teamwork, and the ability to use multi-disciplinary knowledge to solve practical engineering problems etc. ”

Furthermore, some other issues, such as how to make a connection for the following categories: basic engineering knowledge, personal skills, interpersonal and team skills, and the ability of engineering systems may be also in problematic. In the university level, the administration staff realized the shortage of above. On the department level, faculties also have a consensus that the existing undergraduate engineering curriculum and its teaching methods are unable to meet the demands of changing social and economic development.

In order to resolve these problems, senior administrator and the Academic Affairs Office proposed a series engineering education reform strategies planning to “strengthen the practice teaching “since 2008. It was obviously that one of the strategy repeatedly and strongly advocated by the senior administrators is CDIO.

The hope of deepen-seated impetus for reform will provide for a first-class application undergraduate engineering education in Beijing. Furthermore, our personnel training will be well respected and enjoys a wide reputation at home and abroad. We believed that education is not only to give students rigorous knowledge or practical skill training, but also to share experiences with students on deep understanding in a field of applied science or engineering technology. BIPT can enable students to develop a rigorous and realistic professionalism and improve their thinking ability and problem solving skills.

---

5. W. L. Guo, “Transformation and Construction: Training Mode Reform of Application Oriented Engineering Talents in Local Universities with Industry Background.” Researches in Higher Education of Engineering, vol.4, 2012, pp.25-33.

The CDIO initiative has been the latest achievement in international engineering education reform over the past two decades. The vision statement for CDIO states, —The CDIO Initiative offers an education stressing engineering fundamentals, sets in the context of the Conceiving-Designing-Implementing-Operating process, which engineers use to create systems and products. This was not only in excellent agreement with the mission and orientation of talent cultivation of BIPT, but also highlights the long-stand characteristics of Engineering Practice of BIPT.

III. Reform Process

On December 14-15, 2008, the 2008 National Pilot Working Conference of CDIO Model was jointly held by the Ministry of Education of the People's Republic of China and Shantou University. More than 10 deans and teachers of BIPT from the school of chemical engineering, school of mechanical engineering, and school of information engineering were attending the meeting. And chemical specialty of BIPT was selected as the first batch pilot universities of CDIO engineering education reform thereafter, which greatly inspired our teachers and students to study and practice the CDIO idea.

Since then, our faculty have participated in the following 2011, 2012, and 2013 Annual National Working Conference of CDIO, which deepen our understanding of the CDIO initiative.

As the CDIO syllabus provides a new vision for engineering education for our teachers, the staff and teachers began to initiatively reflect and reconstruct the existing curriculum and teaching methodology referred to CDIO's.

In 2008, the reform was initiated by some specialties from school of chemical engineering, school of information engineering, and school of mechanical engineering.

Although the degree of reform was largely differed among the colleges, the direction and content of the reform were similar, i.e., focused on adjusting and reconstructing the existing curriculum and teaching methods, based on CDIO idea.

These reforms include:

- Enhancing the credit proportion of practice teaching in the overall training programs, so as to reach 40%;
- Through a series of " design " to combine theory of teaching the practice;
- Introducing practical project into the curriculum to improve students' early research training;
- Expanding the opening of laboratory and the establishment of comprehensive and designing experiment.

On April 24, 2010, 15 teachers from BIPT attended the 2010 National Pilot Working Conference of CDIO Model. As one of the national 10 Characteristic Specialties, the Machine-Electronic Engineering Specialty of BIPT presented a brief description of their experience and practice in promoting the CDIO reform and attracted great concern from similar institutions.

In June, 2010, by carrying out of the Plan for Education and Training outstanding Engineers, BIPT became the first batch of pilot universities. We carefully designed the engineering educational reform strategies in the next step, proposing to further deepen the win-win cooperation between school and enterprise. The strategies also emphasized that the actual project should be serving as the educational background, focusing on improving students' awareness of engineering and ability of engineering practice, so as to training high-level qualified engineers.

Driven largely by the Implement of Plan for Education and Training outstanding Engineers, the CDIO reform in BIPT has initiated a new era.

IV. The Measurements of CDIO Reform in BIPT

A. *To inspire the interest and guiding by project and to improve students' practical experience and ability to innovate*

According to the characteristics of our students, the cultivation of students' innovative ability should start from the practical problems students are interested.

Based on the projects such as Undergraduate Research Training (URT) program, subject contest etc., regarding students as main body, we encouraged students to find their own issues, establish their own group teams and choose their own mentor.

Under the guidance of mentor and with the help of Internet and other modern advanced teaching tools, our students could easily realize the goal of "learning by doing" and "learning by playing." We further emphasized the importance of making students learn knowledge, improve ability, and train innovation ability in the process of research and teamwork.

Through personal involvement, students acknowledged that the projects such as URT will have a great help to enhance their ability to learn, develop, and communicate.

For example, Weiliang Zeng, a student in G043 class, held that URT project was not only a test of the original knowledge, but also an opportunity to improve our ability. In the experimental design process, we have postulated meticulous division of labor for each item of work. Meanwhile, Zeng also mentioned that we also learnt from each other and worked together. The URT project helped me establishing self-confidence on my own ability to work and improve my practical ability, so I fully appreciated the difficulties in the exploration process of creative and the joy of success.

On this point of view, we proposed that we need to combine the innovative courses learning with the innovative projects training and register the selection of the courses with the selection of the projects, so as to translate the core of innovation training from the classroom teaching to the "interest-driven, project-guided, team-learning mode."

In the aspect of training students' innovative ability, we set up courses such as "Creative Thinking for Students Training," "Create Engineering and Practices," "Robot Technology," and many other elective courses. Furthermore, we incorporated the innovation projects of different training bases with these courses and stimulated innovative activities, so that students from different specialties can collaborate in the "problem solving" team. All of subject contest modules and elective courses were documented into student score management system. Our purpose was to improve the teaching effectiveness of innovative elective courses by the way of students' Self-regulated Learning.

B. *To focus on the cultivation of engineering capability and to reconstruction of curriculum system for engineers on the first production line*

By examining the existing problems of Chinese engineer education and using CDIO Syllabus and engineering education development experience of other countries as the reference, the Electric Engineering and Automation spatiality part of BIPT proposed a "DRIVE" competency mode for engineers on the first production line. "DRIVE" represents an abbreviation of Devotion-Rule-Integrity-Value-Exploration, which means an internal driving force of engenderers in pursuing excellence. It was used as the common training standard of all specialties in BIPT.

On this basis, Dai et al. (2011) creatively constructed a "training standards-curriculum," "curriculum objectives-teaching link," and a secondary realization matrix, which orderly decomposed the training objectives of engineer ability to each training stage and the whole curriculum system. They further reconstructed an engineering-oriented curriculum system for the training of engineers on the first production line.[6]

The secondary realization matrix standardized syllabus for each course and provided effective guidance for teacher with the setting of curriculum teaching program. Under the guidance of Secondary realization matrix, teachers from university and professionals from enterprise could discuss the syllabus of core course together, select an appropriate teaching content, and design reasonable teaching organizations and teaching methods aiming to training standards of knowledge, ability, and quality.

It has been proved that the implementation of this reform has greatly improved students' professional competence, engineering practice ability, and overall quality etc., so they were warmly welcomed by the employer.

Under the guiding of CDIO idea, the Chemical Engineering and Technology specialty of BIPT combined theory of teaching and practice teaching with "four design" and "three practices." More specifically speaking, the "Four Design" included basic design, professional design, the plant design, and the product and process design; "three practices" included initial practice, vocational practice, and professional practice. "Three practices" were interspersed among "Four Design." As a result of the reform, they reconstructed their curricular system and formed a training model with characteristics of "design."

C. ***To establish "Simulate Factory" and to construct real engineering education environment***

In order to effectively improve the students' engineering practice ability, teachers from university and professionals from enterprise exchanged their ideas, and established a batch of "Simulate Factory" labs which consisted of industrial equipment and production equipment. These labs are in close connection with our training standard, integration, systematization, and complexity of engineering.

"Simulate factory" style lab inside the campus

Real engineering practice base outside the campus

Typical business workshop

Figure 1. Real engineering environment combining campus elements and out-of-campus elements

These laboratories and practice teaching bases on campus based on product-oriented projects was used to enable students to receive engineering training on the basis of the product life cycle. The facilities could also be used to improve students' capabilities of product design, processing, and found in modern industrial techniques to solve engineering problems.[7]

---

6. B. Dai, W. G. Ji, J. D. Liu, L. X. Zhang, N. Liu. "Constructing Professional Talent Training Engineering Ability Quality Training as Model by Main", Researches in Higher Education of Engineering, vol.6, 2011, pp. 136-140+168.

7. B. Wu, J. L. Sui, X. F. Yan, H. L. Liu, B. S. Wang, Q. Chen, J. G. Zhang,Y. H. Yang. "Construction and practice of the extramural base of training talents with engineering characteristics." Experimental Technology and Management. vol.27, No.1, 2010, pp.9-13.

In the completion of the regular teaching tasks, these practice teaching bases on campus could also serve as a training base for the students' innovation ability and entrepreneurship, where the real issues faced by enterprises and the problems found in student internships corporation were used as a students' extracurricular engineering training and research training projects.
A lot of students' research results were presented as the demonstration projects for the national innovation and entrepreneurship research program, student technology competition program, student innovative training program, and demonstrate the work of the International Conference of CDIO engineering education etc.

V. Effects and sustainability of the CDIO reform in BIPT

A. *Effects of the reform*

When CDIO reform implementation was completed, there was a strong evidence supporting that the students' engineering practice ability, performance, and quality of training had been substantially improved.
There was a large and wide range of innovation and entrepreneurship training projects and academic competitions, in which our students participated. As an illustration, in 2006, approximately 490 students (7.4 percent of the total students) in BIPT participated in various academic competitions and innovation and entrepreneurship training programs at all levels. They were recognized by 76 provincial, ministerial or even higher awards. After the implementation of this project, in 2011 more than 2100 people (29.2% percent of the total students) participated in various competitions and research innovation and entrepreneurship training programs at all levels, and more than 260 students obtained above provincial and ministerial awards.

More and more students would like to involve in the training of the project practices and engineering studies. The number of participants and the proportion of contest winners significantly increased.
Students participating in relevant engineering design contest demonstrated remarkable achievements. In the year of 2011 and 2012, six teams of our school won 2 first prize, second prize, and third prize, respectively. The BIPT had won 1 best award for energy-saving design items in "Mitsui Chemicals Cup" National Chemical Engineering Design Contest. In the 6th Capital University Mechanical Innovation Design Competition of 2012, our school had 60 students participated in the municipal race. We won 1 first prize, 8 second prize, and 3 third prize, respectively. The quantity of participating students and average level of participating achievement consolidated the prestigious successes of our school in these years. In an Undergraduate Electronic Design Contest of Beijing of 2012, our students shared 4 of the first prize and 5 of second prize, respectively. Our first prize number was second only to that of Beijing University of Posts.
The excellent evaluations for our graduates by the employer significantly increased. The service capabilities for Beijing's economic and social development and for the petroleum and petrochemical industries of our institute extensively enhanced.
The engineering practical abilities of our students have been widely recognized by the employers. The signing contract rate of engineering graduates increased from 72.81% of 2006 to 86.8% of 2012. The signing contract rate of students majored in energy and power engineering and automation reached to 100%. The employment of BIPT graduates in Beijing reached 75 %.
More than 63 percent of our graduates are employed for the state-owned, private, and foreign-funded enterprises. The major fields are electronic information (IT), equipment

manufacturing, chemical and pharmaceutical, new energy, new materials, services, and other areas, covering the main areas of capital's economic transformation and industrial restructuring.

A number of high-quality application-oriented creative talents also emerged in the graduates of BIPT. For example, Zengguang Gao (2010 high honor graduate majoring in computer science and technology), the current SINA of Telecom OSS Center research and development engineer in Beijing, developed resource data verification tools and resource projects. His contribution made Beijing data quality greatly improved, which was vigorously promoted by Beijing Mobile Group company’s 10 other resource projects.

B. *The sustainability of the reform*

Since 2008, CDIO reform of BIPT has been implemented for nearly six years. How about the sustainability of the reform in the foreseeable future? We believe that there are three factors that will directly affect the continuity of CDIO reform:

① The supports of school chief executives and senior teaching management

The initial motivating source of CDIO reform comes from school chief executives and senior teaching management. Their strong support was the decisive factor in the early success of the CDIO reform. From the school' chief executives to teaching management officer, both of them had a common understanding on the problems existing in former training model of higher engineering personnel, and agreed that the reform vision and proposed ways of CDIO reform meet the target of our school' train high-quality personnel and engineers in first line. School' senior leaders have expressed their attentions and supports to the CDIO reform in many different ways. This provides a suitable policy environment for promoting the CDIO reform.

② Strengthening and embeddness of the results of reform

Although not all teachers have widely accepted CDIO reforms, it is essential that to quickly improve the student’s quality and let CDIO reform model achieve more and more favorable reception.

Based on the success of the reform on chemical, mechanical, and information engineering college, the school leaders and the Office of Academic Affairs are planning to extend the CDIO education reform to all faculties (including liberal arts faculties and others). The amending of the training program is an opportunity for each college to strengthen and embed results of the reform into the professional personnel training programs. Through the amendments of various professional training standards and structural adjustment programs the strengthening results of the reform will allow CDIO reform keep effective continuity.

③ Establishment of the ongoing education reform supporting mechanisms

In order to motivate and guide the staff and students actively participate in CDIO engineering education reform, teachers are encouraged to combine their professional and practical courses, and implement the CDIO concept to the specific aspects of the project personnel training. The teaching administration department in conjunction with other school departments will formulate a series of security systems and mechanisms.

We should establish policies (regulations) which encourage students to participate in academic competitions, student research training (SRT), and other activities and further increase the financial supports for students to participate in various projects.

- The assessment methods need to be adjusted for school teachers in promotion, employment. The evaluation will be more focused on the ability of teachers in engineering researching, project designing, industry-university cooperation, and technical services, etc.

- The training of teachers for engineering systems and business practices should be strengthened.
- The special funds of $1 million per year to employ external personnel with extensive experience in engineering and technical as teaching personnel to work in part-time should be provided. There will be 38 enterprises senior technical and management personnel employed as a part-time teacher of the school, together with our teachers developing 15 engineering training projects and programs.
- An independent engineering education reform project research funding should be setting-up every year (e.g., $700,000 engineering students study training program funding, and $250,000 international engineering education scholarships to support students learning abroad).

In a short summary, the higher engineering education reform is not only related to the college and professional, but also to curriculum, syllabus, teacher, teaching content, teaching methods, and a series of reforms. The reform is a comprehensive integrated approach (from macro to micro level). In the future, our school will focus on the engineering education reform about practice-oriented engineering practice area, rely on the research of strategic alliances, and create the engineering education model with our school characteristics. Therefore, we need to achieve excellence in fine training of future engineers and combining CDIO engineering education reform ideas to the general layout of engineering education reform.