PRACTICE OF GRADUATION DESIGN BY APPLICATION OF CDIO CONCEPT

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ABSTRACT：Illustrated by the example of process equipment and control engineering major, this article discussed how to improve the students' comprehensive ability under the guidance of CDIO engineering educational concept during phase of graduation design. In the article, the author described how to integrate concepts such as the large-scale engineering, cultivation of comprehensive ability and close contact with industrial actual practices into each link of graduation design during the research and development of full series and all categories of "corrugated tube type half volume type heat exchanger" through the cooperation between college and enterprise. Specific practices included how to integrate the research and development of the other engineering projects into graduation design; how to combine the comprehensive professional curriculum design with the graduation design, and how to embed more tasks of practical significance into the graduation design. The results of the implementation indicate that the practice of educational reform based on CDIO concept could feasibly ensure the quality of the graduation design.

KEYWORDS: Process Equipment And Control Engineering, CDIO, Continuous Graduation Design, Cooperation Between College And Enterprises, Competencies Of Engineering Practice; Standards: 5,7

1. INTRODUCTION

CDIO engineering education mode is the newest achievement in international engineering education reform proposed by an international research organization constituted of four universities such as Massachusetts Institute of Technology, which has earned widespread acceptance by international engineering educational world. (Tao Yongfang et al.,2006) To understand its profound meaning and apply it to guide our practical work is the bounden duty of teachers in college of engineering. CDIO model has four remarkable characteristics: systematic reform on engineering education; large-scale engineering concept, emphasis on the cultivation of comprehensive quality; close contact with the industry. (Wang Gang,2009) This article focuses on the exploration and the practices in these four aspects.

To apply the CDIO concept in the cultivation plan and the teaching implementation in the engineering colleges, the educators must, to the greatest extent possible, consider the conception, design, implementation and operation of product, process or system to be the environment of engineering education. The most favourable condition for CIDO mode is the involvement of the enterprises. Last year we had cooperated with a company in Qinhuangdao Economic Development Zone on the research & development of full series and all categories of "corrugated tube type half volume type heat exchanger". Many senior students had an unforgettable experience during the graduation project design.

The project cooperated with enterprises on the research & development of full series and all categories of "corrugated tube type half volume type heat exchanger" was the all-round cooperation, which included the heat transfer calculation, process calculation, structure design; strength calculation and medium calculation (containing steam-water heat transfer calculation and water-water heat transfer calculation). Structures involved in the project included vertical and horizontal types, single hole and double hole overlapping types. Equipment involved included more than a dozen of different sizes in volume. The work of full sets of corresponding drawings was completed and the corresponding supporting soft wares were also developed. The project was, to some extent, a small-scale systematic engineering project.

Students were divided into groups to facilitate field research and discussion, and every group had 3 students. Each student was required to have his own topic. They had participated in the entire engineering process: from the heat transfer and process calculation to the structure design and the strength calculation; and from proposing manufacturing assessment and maintenance requirements to draw a set of equipment graph. The whole process of design should follow GB150, GB151 and relevant national standards and the other industrial standards.

2. GRADUATION DESIGN REFORM OF THE PROCESS EQUIPMENT AND CONTROL ENGINEERING MAJOR BY APPLICATION OF THE CDIO CONCEPT

2.1 The Concept of Systematic Engineering Educational Reform Throughout The Whole Process of Graduation Design

CDIO education mode is a systematic reform of engineering education. Engineering education changes from “science paradigm” to “engineering paradigm”, that is to say, engineering practice faced with the era of globalization should combine science and technology as well as technology and non- technology together, and emphasize practice, comprehensiveness and innovation of the engineering education. To carry out that plan, we should not follow the old way. Essential changes must be made in the topic selection and teaching requirements. We made several key substitutions, using engineering criterion to substitute the teaching standard. We adopted principles of "graduation design topic closely related to the engineering project, the teaching requirements closely related to engineering criterion, design method closely related to engineering training, design environment closely related to the engineering site”. The topics came from the engineering practices and the whole process of design followed the national standards and other industrial standards. We carried out an all-round reform in the aspects of curriculum system, teaching content, teaching method and approach, and enabled the engineering education return to engineering practices.

2.2 Large-scale Engineering Concept As The Main Line In The Task Of Graduation Design, Integrating Every Aspects Of The Profession As Basis

CDIO model interpret engineering from a more broad perspective, in which engineering is no longer limited to technology. Engineering is combined with many factors such as social development, market rules and management mode. To cultivate engineering talents from a macro and systematic perspective, the teachers should make training objective, curriculum and teaching mode under the guidance of large-scale engineering concept. The large-scale engineering idea turns specialist educational mode to the integration of "specialist and generalist" mode. Therefore, the task of graduation project adopted the large-scale engineering concept as the main line, and discipline crossing and integrating every aspects of the profession as basis. That would enable students to learn the engineering in a way that is active, practical, and multi-course organically related. The whole teaching process should not be confined to the study of the professional knowledge and technology.

In the reform of the graduation design, we adopted completely the "design institute mode "， which was practical in enterprises. The mode concentrates on the following area: taking the actual project as the background, following the actual project requirement, and finding out the demand of social development based on research in the market; solving technological problems by visiting the site to study the latest technology trend; learning actual structure design by visiting the manufactory. Tackle all the problems following the national and industrial standard while adopting the typical industrial pattern. From feasibility study to implementation of the project, the design concept of "large-scale engineering " was fully embodied.

Students in their fourth year of college have the task of the detection and control design and piping design, therefore it is difficult to complete all of these tasks during the graduation project. During the conceiving and planning of this teaching reform we had considered the heavy workload and busy schedule of students and therefore we combined course design and graduation design together: i.e. “comprehensive professional courses design” in the seventh semester and “the content of graduation design “in the eighth semester were rearranged and integrated. After the recombination, this continuous teaching approach made each part of the design process organically related and integrated. Encircling the main topic of curriculum design, detection design, control design and piping design topics could be finished. That would ensure that the students could finish the whole process of design around one topic, and complete the whole set of the equipment design. Different stages of content had a focus, but they were internally and progressively related.

The fourth year of college is a chaotic year. Various interferences have a big impact on the graduation design. Some of the students spent quite a lot of time on the graduate entrance examination or searching for a job. Graduation design is not paid enough attention. On account of this, the project research, scheme design and related experiments could be done during the spare time such as morning and evening break, weekends and holidays. Some of the topics had been delivered to the students a semester in advance. In that way, the impact of these interferences had been alleviated. That could present active learning opportunities and conditions, and then the quality of graduation design was improved.

2.3 Cultivation Of Comprehensive Quality As The Core Task In The Implementation Of The Graduation Design

CDIO model can be described to be an engineering educational approach that set project design as guidance, engineering competence cultivation as the main objective. Under this training approach, educators can combine the whole curriculum together organically and systematically throughout project design. All the content that needs to be learn and master are designed around the core project design and is implemented step by step.

The training objective of CDIO mode is comprehensive, including not only the professional technological knowledge, but also the development of various aspects of the comprehensive ability. We integrated the training objective into the whole design process; each competency requirement was implemented in specific design of each link based on the requirement of four CDIO syllabus competences. For example some small research and development program were implanted into the whole graduation design. Students had been taught in accordance with their aptitude to cultivate their individual ability of doing experiment and analysing and solving problems. These kinds of topics could help the students to cultivate individuality and comprehensive ability. The cultivation of individuality would support and guide the students to find their interests and hobbies. This actual problem-solving process is also a teaching process that is operating-friendly and has explicit objective. Common constraints have been reduced，and more individual space has been expanded. The progress of all the students were not under the same standard and model，rather, their comprehensive ability should be improved properly and constantly.

In the process of performing the "design institute model ", students solving the problems in the real sense had improved their engineering thinking. To operate large-scaled, modernized and complicated process equipment also required the students to be good at engineering thinking. The theoretical teaching in our classroom is often accustomed to scientific thinking. In general, the scientific thinking focuses on analysis and handles all kinds of problem in decomposition and refinement, and then studies them respectively; engineering thinking, however, focuses on synthesis, after going through the process of decomposing and refining of various questions , recombine and study them according to the objective requirements，so that the overall understanding of the questions are achieved. Practically, engineering problem is perplexing, and many factors often intertwined. Students must take many relative factors under comprehensive consideration. So it is very necessary for students to use engineering thinking. (Zhu Gaofeng, 2005) (Tu Shandong,2007)

Team spirit could also be developed in this design mode. This cooperation, involving peer cooperation at school, cooperation with construction unit outside school, cooperation with the technical personnel of the equipment helped students understand the importance of the inter connections of different professions and the strength of cooperation.

2.4 Close Contact With The Industry As The Means And Approach Throughout The Progress Of Graduation Design

CDIO educational model is directly related to the industrial demand. In the process of the design, many kinds of practical problems occurred. We took measures such as comparing our designs with engineering standard examples, hiring senior engineer to give lectures and to have discussions with us. The problems could be solved by the discussion and analysis by everyone in the team. Many categories of drawings, data, pictures and videos were borrowed and researched. The team made several times' visit to the pressure vessel-manufacturing factory, corrugated tube manufacturing plant and other enterprises. Those made the students explore the ways to solve the practical problem in the actual engineering site. The students researched and studied many times on site to make sure they understand the corresponding questions such as welding structure of the corrugated tube and the tubeplate and the connecting structure of the corrugated tube and the baffle. These practices indirectly enhanced students' ability of interpersonal communication and the aptitude of conception, designing, implementation; and improved their learning interest and motivation. The project design was the essence of engineering practice，and the implementation process should be closely linked to actuality. This approach had completely changed the teaching mode, which focuses on teaching only. The knowledge of students is not gained by teaching，but by learning. This teaching approach reform fully embodied the "student-centered, hands-on learning-centered, studying effect-centered" teaching concept.

2.5 Evaluate And Assess Students Based On Initiative Learning Effect And Comprehensive Learning Effect

The content of the graduation design was fundamentally different from the previous ones, so are the assessment mode and process. The assessment included professional knowledge and skills, working initiative, cooperation, innovation, responsibility, engineering consciousness, practical ability and comprehensive level of the achievement. In this design, the students were guided to deal with the practical topics in which they must find and solve problems before they had fully grasped the professional design knowledge. The corresponding assessment pattern and content are diversified. The assessment ,which embodies the entire-ranged, dynamic and comprehensive characteristics，accompanied the whole design process. The assessment included evaluating students' ability to identify problems, to ask questions, to simplify the problem and eventually to solve the problem, examining their initiative learning, hands-on learning practice, the effect of a comprehensive study, and differences and distances between the requirements of the practical engineering application and the students' final design product. Finally, comprehensive evaluation results are given according to their submitted works, oral defence as well as the effect of practical study.

3. ACHIEVEMENT

It took more than a year to complete this task, which included the preparation research and nearly two semesters of design practice. Teachers, graduate students and undergraduate students all took part in this work. A full set of drawings, data and materials had been evaluated and accepted by both the professional design organization and enterprises and had met the requirements of the enterprises. The design calculation and strength assessment were completed respectively in accordance with the national standard and industrial standard by manual calculation and SW6 software calculation of national pressure vessel calculating center. Students obtained both professional skills and software application competence.

The achievement of the teaching reform was significant in every aspect. This was the first time that we were using CDIO module to organize teaching practice. It was a trial that put CDIO syllabus and standards into practice consciously, naturally and initiatively.

3.1 Students' Engineering Competencies Were Enhanced Significantly In The Process Of Project Implementation

According to the CDIO syllabus, the engineering education is to educate the engineers and the core ability is the engineering ability. On retrospect, the essence of CDIO model train engineering students with engineering approach which can be described as project design-oriented, to enable students to have contact with the real engineering practice in the educational process. A pragmatic attitude was fostered and therefore, a genuine harvest was achieved. After completion of the project, acceptance check has been implemented by the enterprise and three students were hired. That "an education is to create value from the students" was indeed what we had experienced. Engineering capabilities were improved in the following aspects: the design process enabled the students understand explicitly the national standards and industrial standards. From the level of having heard of and witnessed to skilfully apply the standard when dealing with practical engineering problem, this was a qualitative leap. In the process of design they understood the profound meaning of the sentence that "use the standard to ensure the safety of the equipment, and use the standard to ensure the safety of user and designers of the equipment"，which was said by the experienced engineering technical personnel. Students' behaviour in the process of design also enabled the engineering consciousness remain in their mind deeply, which would be a lifelong benefit in their future work.

3.2 Project Implementation Process Cultivated Students' Spirit of Collaboration And Their Sense Of Responsibility.

This experience allowed student to play a role of prospective engineer in the approximate social environment under the guidance of CDIO system, real topics enabled the students to undergo training in the whole process of project conceiving, designing and implementing with sense of social responsibility. Students also went through the repeating process of finding out their loopholes and reconsidering the solutions for quite a lot of times. This repeating process had deepened and improved their understandings. The consensus of the students was that they should not be satisfied with simply complete the task. In order to have better achievement, they would like to explore further. The discussion, mutual questioning, cooperation would lead to new discoveries and therefore, a new harvest.

3.3 Students' Motivation For Study Was Improved In The Process Of Project Implementation

CDIO standard emphasizes learning initiative. This learning module is very attractive to the student. With interests and desire to learn initiatively, the students enjoyed the feelings of "experiencing the environment"，and they achieved the sense of responsibility and achievement in the process of project. Working with the real topic made the students understood the profession more deeply and comprehensively. As they say, they had understood what their profession was and what they would do in the future，and therefore loved the profession and were more passionate about it. The process to solve the problem also enhanced their ability and confidence, and the advantages were reflected in the subsequent job hunting. Just as Confucius says: "who likes is better than one knows, who enjoys is better than who likes." Enable the students willing to learn is our biggest motivation to work.

3.4 Teachers' Competencies Were Improved In The Process Of Project Implementation

CDIO standards emphasize the improvement of teachers' competencies. Only the good researchers could be the qualified teachers, and only who themselves engage in the study have the knowledge to teach the students. Practical teaching is more comprehensive and complex than theoretical teaching. It is easy to teach and solve theoretical problems on the blackboard，but when dealing with some specific problems in practice it will probably be quite difficult. A problem may not be perfectly solved until after more than 10 times of review over the drawings. Although the guiding teachers have engaged in the professional work since twenty or thirty years ago, who also have certain engineering experience with assessment qualifications in this area， the teachers still reaped new awards during in-depth study and discussion of some issues. As the saying goes "teaching benefits teachers as well as students, a worthwhile trip". In addition, the teachers would make their instruction more vividly and fluently and made the knowledge taught professionally by speaking of their first-hand experience. On the other hand, this unforgettable experience had also given the teachers a profound experience of the extent and depth of requirement of the CDIO and helped the teachers identified explicitly the objectives and directions in the future.

4 CONCLUSION

In June 2010, the Ministry of Education initiated “Plan of Cultivating Excellent Engineers”. We understand that there are three main features: the first is that the industry enterprises participate in the training process; the second is the school cultivate the engineering talents in accordance with the general standards and industrial standards of talents training; the third is to strengthen the students engineering ability and creative ability. Now reflecting on the work we have done, we have found that every step seems to be on the track of the CDIO mode. Our work is in consistency with the direction of CDIO concept.

In this teaching reform, we have achieved unexpected result, which have greatly exceeded our expectations. And this teaching mode is not unchangeable; it should be accommodated in accordance with the demand of the society and it should cater for the orientation and characteristics of our college. We will implement CDIO standards and requirements omni-directionally in the whole training plan of our major. We will reform and explore continuously so that the quality of our work will be improved constantly.

CDIO mode should be regarded as the guidance for our practical work. It is highly necessary to participate in the engineering project, collect engineering data, establish the concept of large-scale engineering project, make close contact with industry, highlight engineering characteristics, and cultivate engineering talents of comprehensive ability. These are the eternal missions of engineering colleges.

REFERENCES

Tao Yongfang, Shang Cunhui. (2006) Revelation of CDIO Outline of Education Innovation in Higher Engineering Course[J]. *China Higher Education Research*,11,81-83.

Tu Shandong. (2007) A Introduction of Comprehensive Engineering Education[J]. *Higher Engineering Education Research*, 02

Wang Gang. (2009) Understanding and Thinking of CDIO Engineering Education Model [J]. *China Higher Education Research.* (05):86-87.

Zhu Gaofeng. (2005) Exploring of Engineering Education in China [J]. *Higher Engineering Education Research,* 06

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用 CDIO 理念指导毕业设计改革的探索与实践
--以“过程装备与控制工程”专业为例

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摘要： 本文以“过程装备与控制工程”专业为例，探讨了在 CDIO 工程教育理念指导下毕业环节中如何提高学生的综合能力。文中介绍了校企合作进行全类别、全系列的“大波节管半容积式换热器研发设计”的研发过程中，如何把大工程理念、注重培养学生的综合素质、密切联系产业实际等做法融入到毕业设计的每个环节。具体做法还包括把其他工程实际中的研发与设计的“专题”引入到本科生毕业设计环节中来，把“专业综合课程设计”和毕业设计贯穿组合，在毕业设计环节中植入有工程实际意义的“专题设计”等项工作。实施效果表明，基于 CDIO 理念的毕业实践改革能切实保障工科毕业环节的教学质量。
关键词：过程装备与控制工程；CDIO；贯穿式毕业设计；校企合作；工程实践能力 ；
CDIO 标准 5,7

1.前言

CDIO 工程教育模式是麻省理工学院等四所大学合作的跨国研究组织在国际工程教育改革方面的最新成果，得到国际工程教育的认可[1][2]。深入理解其深刻含义，用 CDIO 模式引领我们的实际工作，是高等工科院校教师义不容辞的职责。“CDIO 模式有四个显著特点：系统的工程教育改革、具备大工程理念、注重培养综合素质、密切联系产业[2]。”本文工作也主要从这四方面进行探索与实践。

工科高校的培养计划和教学实施中渗透 CDIO 理念，就要尽最大可能把产品、过程或系统的构思、设计、实施和运行作为工程教育的环境。有企业深入参与，是实行 CDIO 模式的最有利条件。去年我们与秦皇岛经济开发区某企业合作一个较大的项目，进行全类别全系列的“大波节管半容积式换热器研发设计”。2011 届多名学生的毕业环节有了一次难忘的经历。

这次与企业合作的 “大波节管半容积式换热器研发设计”项目，属于全方位合作开发，包括传热计算、工艺计算、结构设计、强度计算，介质含汽-水传热、水-水传热，结构含立式、卧式、单孔和双孔重叠式，容积从小到大有十几种规格，绘出对应的全套图纸，还研发有对应的配套软件，也算是一个小规模的系统工程。

对学生安排是同类别 3 人一组，便于讨论和现场调研，具体要求是每人一题，从传热、工艺计算到结构设计与强度校核，提出制造检验与维修要求和绘制一套完整的设备图等全部内容。设计过程要求严格遵循 GB150、GB151 等国家标准和其他一些行业标准。

2.基于 CDIO 理念的“过程装备与控制工程”专业毕业设计改革

2.1 系统的工程教育改革理念贯穿毕设全过程

CDIO 教育模式是一项系统的工程教育改革，工程教育从“科学范式”走向“工程范式”，面向全球化时代的工程实践，应将科学与技术、技术与非技术融为一体，强调工程教育的实践性、综合性和创新性。进行这样的工作，不能墨守陈规。在选题和教学要求上都要做本质的改变。我们做了几个关键性代换，采用了“设计题目向工程项目靠近，教学要求向工程规范靠近”，“设计方法向工程实训靠近，设计环境向工程现场靠近的原则，题目来自工程实际，设计进行的全过程都按照国家标准、行业标准等工程规范进行。从课程教学体系、教学内容、方法和手段等方面进行全方位改革，让工程教育回归工程实践。

2.2 毕设任务以“大工程观”为主线，以专业综合为基础

CDIO 模式从更宽阔的视野解读工程，这个视野中的工程不再局限于技术，工程与社会发展、市场规律、管理模式等众多因素紧密结合起来，以宏观的、系统的视角考虑培养工程人才，从培养目标到课程体系、教学模式，无不在这样的理念统领下。这种大工程的理念，变专才教育为“专才+通才”、通专融合的工程教育。因此，毕设任务以“大工程观”为主线，就要以学科交叉和专业综合为基础，让学生以主动的、实践的、课程之间有机联系的方式学习工程，完成整个教学环节不能只局限于专业知识和技术的学习。

此次毕业设计改革，完全采用企业实用的“设计院模式”，即以实际工程为背景，以项目实际要求为依托，开题调研去市场了解社会发展需求；工艺问题去设备现场了解最新工艺路线；结构问题去制造厂了解实际结构设计；用国家标准、行业标准和“企业惯用模式”解决问题，从项目可行性研究到项目内容实施，充分体现社会化“大工程观”的设计理念。

构思、筹划这次教改时，考虑到此次设计的任务量很大，一些学生还要进行检测与控制设计，配管设计等专题，很难在毕设一个环节完成这么多工作，我们采用了把“专业课程设计”和“毕业设计”统一起来，即把第 7 学期的“专业综合课程设计”与第 8 学期的毕业设计的内容重新组合“延伸”和“贯穿”起来。重新组合后这种“贯穿式设计”的教学方式，将各环节有机串联，实现了设计环节的贯通，毕业设计完成主体内容，课程设计围绕主体题目，进行“检测设计”、“控制设计”和“配管设计”等专题工作。保证学生能够围绕一个设计题目，经历完整的设计过程，完成一个设备整套的设计工作。不同阶段内容上各有一个侧重专题，全程进展有层层深入的内在联系。

大四是一个混乱的学年，各种干扰对毕业环节都有一定的冲击。部分学生为考研、找工作等事耗掉了大量时间，专注于毕业设计的程度往往不够。而专题中的调研、方案设计和相关的试验都可以用早晚、周末和节假日等弹性时间来完成，有些题目还可以提前一学期告诉学生，如此可缓解这些干扰的冲击，创造出主动性学习的机会和条件，进而提高毕业设计的质量。

2.3 毕设执行过程以培养综合素质为核心任务

CDIO 可以说是一种以工程项目设计为导向、工程能力培养为主要目标的工程教育模式。按这种培养模式，可以通过项目设计将整个课程体系有机而系统地结合起来，所有需要学习和掌握的内容都围绕项目设计这个核心，分层次一步步实施。

CDIO 模式的培养目标又是全方位的，不仅包括专业技术知识，还有各方面的综合能力的培养。我们把培养目标融入到整个设计过程，按 CDIO 四大层次的能力要求，每个能力点具体落实到各环节的设计进行中。如在毕设大题目中植入工程实际中的一些小型研发专题，因材施教地培养学生个体实验动手能力和分析问题解决问题的能力。这类“专题”有益于培养学生的个性和综合能力。个性化培养要对学生的兴趣和爱好给予支持和引导,解决各种实际问题的过程也是一个操作性强、目标具体的教学过程，减少了共性约束，增加了个性空间，不求所有人都按统一的规格模式发展，但愿每个人的综合素质都能以其适合的方式不断地提高。

这种“设计院模式”的真题真做提高了学生工程思维的能力。过程装备的大型化、现代化、复杂化也要求学生要善于进行工程思维。我们课堂上理论教学往往习惯于科学思维的方法。一般来说，科学思维侧重分析，把各类问题分解、细化，分别加以研究；而工程思维侧重综合，把经过分解、细化的问题按其客观要求重新组合加以研究，从而达到对事物整体的认识。工程实践中的问题是错综复杂的，往往众多因素交织在一起，必须把相关因素联系起来综合考虑，所以工科学生运用工程思维显得非常必要[3][4]。

这种设计模式也培养了学生团队合作精神。这里的合作，涉及到校内同伴间的合作，校外与施工单位的合作，与装置的工艺人员合作，使他们懂得了不同专业间的内在联系和通力合作的重要性。

2.4 毕设全程进展以密切联系产业为方法手段

CDIO 教育模式以产业需求有直接联系，设计过程中也出现了各种实际问题，我们分别采用了与工程范例对照、聘请有丰富工程经验的企业高级工程师讲座和座谈，大家一起讨论和综合分析等方法解决。调用了各类图纸、资料、图片 、录像，多次去压力容器制造厂、波节管制造

厂等企业参观实习，让学生去工程现场的环境中感悟，探索解决这些工程实际问题的办法。如波节管与管板的焊接结构、波节管与折流板的连接结构等具体问题，都是他们多次去现场调研后确定的。这些实践环节，都间接培养了学生的人际交往能力和构思、设计、实施能力，增强了其学习兴趣和动力。工程项目设计是工程实践的精髓所在，其实施过程就应该密切联系实际。这种做法完全改变了以"教"为重的教学模式，学生的知识不是"教"出来的，而是"学"出来的。充分体现了"以学生为中心、以实践性学习为中心、以学习效果为中心"的以"学"为重的教学改革。

2.5 考察及考核以主动性学习和综合性学习效果为依据

这次毕业环节的内容与历届有本质的不同，考核的方式和过程也有很大不同。考核包含了专业知识与技能、工作的主动性、合作性、创新性、责任感、工程意识、实践能力和成果的综合水平等各个方面。这次设计，在学生还没有完全掌握专业设计知识的状况下，就把他们引导到实际问题中去发现问题和解决问题。对应的考核形式、内容也是多样化，在设计进展的过程中就渗透着考核，体现着全程考察、动态考察、全面考核。考察学生发现问题、提出问题、简化问题并最终解决问题的能力，考察其主动性学习、实践性学习、综合性学习的效果，考核其最终设计成品与工程实际应用要求的差异和距离。最后按提交的作品、答辩的状况和实践性学习的效果综合评定成绩。

3. 收获

包括前期的调研准备和近两学期的设计实践，耗时一年多的时间，由教师、研究生和本科生共同完成了这项工作。全套图纸和资料通过了专业设计部门统一审核和企业验收，达到了企业对项目要求。其中的设计计算和强度校核我们分别按国标及行业标准由人工计算和用全国压力容器计算中心 SW6 软件两种途径完成，学生有专业技能和软件应用双方面收获。

这项教改环节的收获是非常大的，也是方方面面的。这是我们首次用 CDIO 模式组织教学实践，自觉、主动、顺其自然地把 CDIO 大纲和标准的要求渗透到工作中的一次尝试，有了几点较深刻的体会。

3.1 项目实施过程中学生工程实践能力有了显著提高

"CDIO 大纲"提出，工科教育是培养工程师的，而工程师的核心能力就是工程能力。回首走过的路，觉得 CDIO 模式实质就是用工程方法培养工科学生，以工程项目设计为导向，让学生在教育过程中接触真正的工程实践，经历真刀真枪的磨练，就会有货真价实的收获。结题后企业验收了项目成果，也录用了我们 3 个学生，让我们直接感受到了 "教育就是创造学生的价值"的含义。工程能力提高还体现在学生真正清楚了国家标准和行业标准，从过去的听说过、看到过到现在能结合工程实际问题熟练应用，这是一个质的飞跃。在设计进行的过程中理解了老工程技术人员"用标准保障设备的安全，用标准保障设备使用人员和设计者自身安全"这句话的深刻含义。设计过程中的诸多行为也都给他们深深地留下了"工程意识"的烙印，这将在他们今后的工作中终生受益。

3.2 项目实施过程中培养了学生协作精神和工程师责任与态度

这次经历让学生在近似社会环境下的 CDIO 系统中扮演了准工程师的角色，企业真实课题让他们在整个项目进展的构思、设计、实施全过程中经受了锻炼，体验到了社会责任。讨论和交图时常听到学生说, 总以为要完成了,细想想又会发现自己的遗漏, 再去现场琢磨，往往要多次重复。这个重复过程, 使认识一点点变得深刻, 知识逐渐变得完善。大家的共识是，不可过早满足于简单的完成。若要做得更好一点, 就要更多的探索，这其间的讨论、相互质疑、相互协作，经常会有很多新发现，大家都有新收获。

3.3 项目实施过程中促进了学生学习动力

CDIO 标准强调主动学习。而这种模式的学习确实对学生有很大的吸引力，有了主动性学习的乐趣和欲望，他们喜欢那种身历其境的感受，觉得更有责任感、成就感。真刀真枪的课题也能让学生更深刻、更全面地了解了专业，用学生自己话说，知道我们专业是怎么回事了，知道今后工作干什么了，从而更喜欢专业、更热爱专业。解决问题的过程也增强了他们的能力和自信

心，在后续毕业求职时都体现出了优势。“知之者不如好之者，好之者不如乐之者”。学生乐于学是我们工作最大的动力。

3.4 项目实施过程中促进了教师能力提升

CDIO 标准重视教师能力的提升。我们很清楚好的研究者才可能是最称职的教师，只有自己从事研究的人,才有东西去教学生。实践教学比理论教学更具有综合性和复杂性，在黑板上讲清楚一些理论问题很容易，在实践中解决好一些具体问题却很难，反反复复审过十几遍的图纸往往还有不如意之处。尽管指导教师都有从事本专业工作二三十年的经验，也有一定的工程经历，有本行业工程设计的审核资历，但在一些问题的深入研究和探讨时，也常有新的收获，真所谓教学相长，不虚此行。此外，教师在今后的教学中，讲授自己亲历其境的创造经验，必然能把知识讲活，讲得生动流畅。从另一方面看，这次难忘的经历也让我们深刻体验到了“CDIO 模式”对教师要求的深度和广度，清晰地明确了自己今后的努力目标和方向。

4. 结语

2010 年 6 月教育部启动“卓越工程师培养计划”，我们理解主要有三个特点：一是行业企业参与培养过程，二是学校按通用标准和行业标准培养工程人才，三是强化培养学生的工程能力和创新能力。现在回想我们所做的工作，似乎每一步都在这个大方向的轨道上。这与 CDIO 工程教育理念的大方向是完全一致的。

这次教改实践我们收到了超预期的效果，但 CDIO 模式不是固定不变的模式，应根据社会发展的需求和我们学校的定位和特色，下一步我们将在专业整体培养计划中全方位渗透 CDIO 元素，不断地改革、探索，不断地提高我们的工作质量。

用 CDIO 模式引领我们的实际工作，参与工程题目、收集工程资料、建立大工程观概念、密切联系产业、突出工程特色、培养有综合能力的工程人才，应是我们工科高等学校永恒的使命。

参考文献 ：

[1] 陶勇芳,商存慧.CDIO 大纲对高等工科教育创新的启示[J].中国高教研究,2006(11):81-83.
[2] 王刚. CDIO 工程教育模式的解读与思考[J].中国高教研究,2009(5):86-87.
[3] 朱高峰. 中国工程教育探源 [J].高等工程教育研究,2005, 06
[4] 涂善东. 全面工程教育引论 [J] 高等工程教育研究,2007 , 02

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