UTILIZING CDIO ENGINEERING WORKSPACES TO FACILITATE DESIGN-IMPLEMENT EXPERIENCES

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ABSTRACT

Design-implement experiences are a key feature of a CDIO program [1]. CDIO engineering workspaces are integrated learning environments promoting creative engineering development and facilitating hands-on project-based learning. In this paper, we present the design and development of our CDIO engineering workspaces under a ubiquitous computing campus infrastructure, discuss how the workspaces are utilized to support our CDIO curriculums and extracurricular student activities, and address the challenging issues of operational management and staffing of the workspaces. We will show that the CDIO workspaces have enhanced the education of engineering students; the design-implement experiences students obtained under our CDIO curriculum are highly rated by students and their parents, faculty, and industry stakeholders.

KEYWORDS

CDIO, Design-implement Experiences, CDIO Engineering Workspace

INTRODUCTION

As one of the Chinese universities pioneering in the *Conceive-Design-Implement-Operate* (CDIO) engineering education reform, *Dalian Neusoft University of Information* (DNUI) has developed a TOPCARES-CDIO educational model, adopted from the CDIO international engineering education initialtives [2,3]. TOPCARES is an acronym for the first level of eight ability-measurements, standing for ***T****echnical knowledge and reasoning,* ***O****pen minded and innovation,* ***P****ersonal and professional skills,* ***C****ommunication and teamwork,* ***A****ttitude and manner,* ***R****esponsibility,* ***E****thical values, and* ***S****ocial value created by application practice*. In the past several years, continuous efforts have been made by DNUI to realize the vision of the CDIO reform [2].

Design-implement experiences are a key feature of a CDIO program [4]. This paper introduces the CDIO engineering workspaces developed by DNUI under a ubiquitous computing campus infrastructure, providing a viable low-cost solution to our CDIO based engineering education. A plan of project-based courses for our 4-year electronic information engineering program is presented to show how active-learning are supported by the engineering workspaces.

The design and development issues of CDIO workspaces can be found in a number of literatures. In [5], the characteristics of the workspaces at each of the primary CDIO collaborating schools are identified. Guidelines for workspace design and operation are suggested. The learning spaces designed and constructed for Integrated Learning initiative developed at Queen's have the potential to be useful models for new construction in schools pursuing CDIO [6]. In [7], CDIO workspaces created by renovation made the borders of engineering programs gradually fade. Interesting contributions in electrical engineering can be found in [8, 9].

Design-implement experience plays a key role in an integrated curriculum. Andersson *et al* have shown that design-implement experiences can be provided in a design-build-test project course developed systematically [10]. In [11], four integrated learning projects in Mechanical Engineering CDIO curriculum permit students to foster multidisciplinary team-based experiences and experienced the complexity of synchronizing design and manufacturing activities based on concurrent engineering practices. The projects show that the LIPS model, an industry-like model for project management, can be used for any type of design-implement project course, independent of the project outcome [8]. Competitions introduced in an embedded system design have enhanced students' design-implement experiences [9].

This paper is organized as followed. We first introduce the integrated CDIO curriculum, present the design and development of our CDIO engineering workspaces, discuss how the workspaces are utilized to support the CDIO curriculums and extracurricular student activities, and address the issues of operational management and staffing of the workspaces. Finally, we show that the CDIO workspaces have significantly enhanced the education of engineering students.

DESIGN-IMPLEMENT EXPERIENCES THROUGHOUT THE CURRICULUMS

A typical academic year in the Chinese school system consists of fall and winter semesters, separated by a roughly 50-day winter recess around Chinese New Year. Summer recess is from July to August. In our CDIO curriculum design, the fall and winter semesters are shortened and a third semester, a one-month summer term, is introduced exclusively for project-based learning. We refer this setting as the "1321" system, i.e. *1* academic year is comprised of *3* semesters, including of *2* regular semesters and *1* project-based learning semester.

The course designs for the fall and winter terms in the CDIO curriculum involve in determining relevant contents and selecting appropriate lab work and projects, and making the course work a part of the integrated 4-year design-implement expertises. Conventional laboratory settings and works have been redesigned not only to support scientific inquiry, but also design-implement experiences.

In the third semester, a project emphasising on building products and implementing processes in a real-world context is given to students. Students, usually divided into groups, should complete a CDIO process, governed by real or near-real world project management rules. Faculty members work as mentors and consultants. At the end, presentations and demonstrations are given by student groups to entire class and open to public.

It is known that a single design-implement experience, no matter how well planned, is insufficient to provide students with a complete understanding of the design-implement process [1]. We provide students with a sequence of design-implement experiences from basic to advanced levels in terms of both scope and complexity. Four cycles of design-implement opportunities are built in a 4-year engineering program. Moreover, ex-curricular activities, such as design contests at course/departmental/school/national/ international levels and student clubs with special interests are strongly encouraged, and financial support and faculty support are provided.

Options are available to honor students to participate in our co-op programs, obtaining additional real-world work experiences. Consequently, active learning and experimental learning take place through the multiple-cycles of development of products, processes, or systems, and teach students design and implementation skills, personal and interpersonal skills, and reinforce the learning of disciplinary knowledge.

THE INTEGRATED PYSICAL LEARNING ENVIROMENT

The campus was built from scratch during 2000-2003. A ubiquitous computing environment, called 3A's, i.e. all students and faculty have compatible hardware and software, and have access to internet and teaching and learning resources *anytime*, *anywhere*, in *any way,* was part of a strategic vision to build a new institution for the 21st century [3]. DNUI is a residential university, accommodating over 13,000 students. On campus, power outlets and the high-speed internet access are connected to all desks in classrooms, labs, libraries and student dormitory. As part of a more recent infrastructure improvement, the campus now is covered by WIFI technology. The Teaching-learning Supporting Centre of the university is equipped with high performance servers and massive storage devices, providing 24-7 support to the campus-wide resource management tools, as well as the teaching and learning resources.

The physical learning environment for our CDIO programs includes traditional and multimedia classrooms, state-of-the-art laboratories, seminar rooms, study rooms in libraries, and engineering workspaces. As part of the CDIO reform, several joint teaching/research labs with the industrial leaders, such as Intel, IBM, Mentor Graphics, HP, and SAP have been built to support the learning of product, process, and system building skills. These resources are managed at both University and departmental levels. An online booking system is used to manage and schedule these resources, permitting a high level of utilization.

DESIGN AND DEVELOPMENT OF THE ENGINEERING WORKSPACES

As part of our CDIO engineering education reform, new types of engineering workspaces have been carefully planned and developed to support the learning of product lifecycles and engineering skills. One of the unique features of our CDIO engineering workspaces is due to the ubiquitous computing campus infrastructure. Ten thousands of notebook computers constitute a huge computational power, and possess great flexibility and mobility. This setting significantly reduces the demands and pressure for CDIO facilities and their operational managements. Our CDIO engineering workspaces are created by retasking conventional laboratories, underutilized class rooms, meeting rooms, and student study areas, as conceive and design workspaces and by converting an office building, previously used for rental, to the university CDIO centre.

The CDIO centre is named of SOVO (Student Office & Venture Office). It measures 6,800 m^2, conveniently located on the top of the Student Center building and across the street to the student dormitories. The primary functions of SOVO have been identified as the centre for our CDIO-based teaching and learning, the fertile ground for students' start-up companies, and a bridge of university-industry-government corporations.

In the centre, four kinds of workspaces are provided to support learning about the C, D, I, O phases of the lifecycle of a product or systems. A program may be assigned to a few to several hundred square meters of space. These facilities are flexible and multifunctional, supporting information-based and hardware-based projects. All the workspaces are accessible by students after normal class hours.

The *conceive workspaces*, equipped with movable furniture, white boards, data projectors and access to online and library resources, include both team and personal work spaces, providing support to the human interactions of talking, listening, and reflection. Figure 1 shows a team of Computer Science students working in a conceive workspace. As described earlier, our ubiquitous computing campus infrastructure supports 24-7 access to teaching and learning resources, such as libraries, CAD/CAM/EDA tools, and the internet. Our *design workspaces* are normally shared with the conceive workspaces or can be anywhere that meet their design requirements on campus.

The *implementation* and *operate* workspaces vary significantly among programs. For example, the electrical engineering workspaces enable students to build small and medium electronic systems, and include tools, instruments, equipment for making *printed circuit boards* (PCB), and computers for integrating software into the product; the setting of the workspaces for Digital Art program consists of several workshops, with 2-d/3-d CAD software and spaces for painting, sculpturing, MTV making, and a standard broadcasting studio. Figures 2 and 3 show students in the implementation and operating phases of a project respectively.

Figure 1. Students in design

Figure 2. Students in implementation

Figure 3. Students in operation.

One of main goals in the design of the SOVO centre is to make the environment inviting, student centred, user friendly, accessible, and interactive. So that it attracts students and faculties, to allow them to work together in stimulating environments strengthen the motivation of students. A lounge, with tables, bright colour sofas and coffee-machines, is placed on the first floor. Group activities, social interactions and community-building are promoted and taking place. Moreover, several exhibit halls and areas that reflect the history of the university and display the engineering research projects and tell the successful stories of former graduates can be found in the building. These exhibits now are one of the campus attractions and a showcase of the university.

OPERATIONAL MANAGEMENT & STAFFING

Operational management of CDIO workspaces is of great importance to the successful implementations of a CDIO curriculum. A centralized two-level management system is used to manage the teaching and learning facilities. Facilities are divided into common and dedicated types, each can be futher separated by regular and temperary usages. Common facilities managed at university level by administrative staffs can be booked through online facility booking systems. Laboraties are accessible for after hour use by appointment and open from 8am-10pm daily, except for pubilic holidays and school recess. At the beginging of each semster, applications for facility support required by predicable events are accepted for scheduling. For example, an annual national design contest may require 3-month preparation using a space of 50 m^2 from March to May. Scheduling during highly congested periods, such as mid-term and end-of-term, presents challenges. Again, our campus-wide ubiquitous computing environment plays an important role in relieving the pressure – students can choose to study at best locations, not limited to fixed areas, fewer computer labs and common areas are needed, more spaces can be used for other activities with high utilization, greater faculty availability and continuous contact among students are supported.

Each academic department has decicaded workspaces. These spaces are self-directed by a team of students under the supervision of a departmental SOVO coordinator, a faculty member with prior management experience in industry. In addition, a faculty with technical expertiese and some practical experiences is assigned to each project. He/She works as a mentor and consultant.

Another challenging issue in the operations of CDIO workspaces is staffing. CDIO settings acquire faculty members to be proficient in wide number of professional areas. In supervisions of advanced design-implement projects, personal industrial experiences in product development, process management become nonoptional for some faculty members. Our experiences show that at least one key person is required for each displine in order to develop and provide adequet support to a CDIO program. This type of person with desirable engineering experieces and competent in teaching and directing CDIO projects are mainly from new hirings. Special recruiting policies to attract, recruit, develop, and retain effective teachers for CDIO programs were in place. We have also developed new faculty development programs by offering training courses, mentoring and exchange programs to help faculties with pure academic backgrounds to change their teaching styles and methods, and obtaining practical experiences. We have graduadly changed the composition of our faculties to meet the CDIO chanllenges. Now, around 20 per cent of staff members and faculties have some industrial experiences, and at least one key person with high competnecy in engineering practices is in place for each displine.

In addition to technical competency, it is also desirable that the CDIO directors and faculty members who teach in CDIO settings are those who are willing to work with students. Few engineers hired from industry are readily prepared to assume responsibility for teaching the young. They were used to work with professionals and lack of necessary interpersonal skills to effectively communicate with students who are a generation younger. Mentoring and new faculty orientation programs must be introduced to help them to meet the chanllenges.

DESIGN-IMPLEMENT EXPERENCES IN THE CDIO CURRICULUM

As part of our engineering education reform, CDIO curriculums for all 14 engineering programs with over five thousands students have been developed closely following the CDIO guidelines [2]. Design-implement experiences and engineering skills are discipline-dependent, varying from one to others. We present below a plan of design-implement experience for the 4-year Electronic Information Engineering program of 1,200 students, providing insights to the teaching and learning in our CDIO programs. It is shown that the disciplinary and interdisciplinary knowledge are taught through four cycles, curricula and extracurricular activities are integral part of our applied engineering education.

A Design-Implement Experience Plan for the E.I.E. Program

First-year project. In the first two semesters of a freshmen year, common fundamental courses, such as mathematics, physics, English, C Programming Language and Computer fundamentals, introductory to engineering profession, are taught. In the third term, the engineering design-implement experiences are divided into two parts, a C-programming design and implementation project and the assembly of two radios receivers: one with discrete components, another in IC chips.

The first part emphasizes the fundamental principles of software system development process. Students typically work in groups of five, go through the process from user needs to building and testing, practicing communication and teamwork skills. A simple project management model is introduced with milestones, nomenclature, and templates for project documentation and presentation.

In the second part, students work individually. Engineering skills, such as identification of electronic components, use of voltage-current meters and other lab tools, making of simple electric circuits on breadboards, employment of wire colour-coding schemes, and soldering are introduced. The tasks are simple, but enable students to go through the process of building and testing. Students complete this semester and go away with two working radio receivers they are very proud of. Figure 5 is a picture of a working FM radio receiver built by a student.

Note that the software development project above complies with the C-D-I-O process of a product lifecycle as suggested in the CDIO initiative [4]. The radio receiver assembly project is otherwise. It is not only because electronic circuit courses have not been offered to students at this stage of the program, but also because we believe that “learning by doing is the best way to go” for the engineering skilled covered by this project. This project has been running for eight years to an average of four hundred students each year. Feedbacks from students and instructors have been very positive.

Two course-based contests are designed in the following term, four hundreds freshmen compete for the title of “The Golden Solderers”. Figure 6 shows The Creative Award winning soldering project – The Light Cube. Figure 7 shows the user interface of a first-prize winning C-programming project. Winners of the contest are qualified to participate provincial, national, or international contests.

Figure 5. An FM radio receiver

Figure 6. The Light Cube

Figure 7. A screen-dump of a software

Second-year project. In the engineering project term of the second year, students are to design, build, and test a proto-type of a remotely controlled car model. The design-implement experience requires application of the knowledge acquired in the courses of digital electronics, analogue electronics, microprocessors and the C-programming language, etc. The engineering skills, such as the use of a CAD tool to design PCBs, soldering, use of a *single-chip microcomputer* (SCM), and programming of EPPROMs, are also incorporated in this project. The objective of the project is to have the car model perform a set of required functions, such as forward/backward, obstacle detection, and parking, and complete a run on a given trail in shortest time possible. Figure 8 and Figure 9 depict two of the student designs.

The project started as an extra-curricular student activity for a national electronic design contest. It was shown that it was such a valuable learning process for students. Then, we decided to have it developed into a credited design-built-test course. It was carefully designed and tailored to the 2nd year students. It is fun and students are highly motivated to make their system work. The basic parts of the car model are provided to students. Students are again in group of four or five. The same project management model, introduced in the C-programming course in the first year, is modified to meet the hardware system development needs. In the second-year experience, communication skills have been explicitly taught and practiced in the first year as well as a number of project-based courses in the 2nd year. At this point, students present their work orally to the class and share their progress and ideas in written reports in a more professionally manner and quality.

Figure 8. An intelligent tracking car model

Figure 9. Racing car models

Third year project. In the third-year, students are asked to redesign the car model project to employ the new knowledge and skill they acquired, to improve the performance, and to introduce additional features. The design-implement experience is designed to integrate the knowledge acquired in a number of courses, including operating systems, computer interfacing, driver programming and application program development.

In fourth year, a 4-month capstone project is followed by a 6-month thesis project. The one-year comprehensive engineering design-implement experiences, designed for the final enforcement of disciplinary/interdisciplinary knowledge and engineering skills, completes the four cycles of design-implement opportunities in the curriculums.

The aim of the capstone project for students is to design and build an embedded system from scratch in groups of four or five. A list of project topics is given. Students may or may not choose from the list. Students come up with project proposals. When approved by their advisors, students need to make design decisions, shop for parts and electronic components, build the hardware, develop the software, operate and test their systems. The project deliverables include an operable prototype that demonstrates real performance, a formal presentation in a multi-media classroom, and a written report using a template complying with industry standard, and a set of continuous documents throughout the entire project.

The thesis project must be conducted under supervision of a faculty advisor. Topics of thesis project are open. Industrial projects are also available. Figures 10-12 show a prototype of an electrostatic precipitation control system for pneumatic steelmaking developed by our faculty members. A team of students completed their thesis work in the project. CO-OP students, however, must conduct their thesis work in companies they work for in their final year under co-supervision of qualified industrial supervisors and faculty members.

Figure 10. The cabinet

Figure 11. The control panel

Figure 12. The system under control

Development of Business Skills and Entrepreneurship

In addition to the learning designed in the curriculum, SOVO is the home of tens of student enterprises, open to students of all the programs. Students with entrepreneurial spirits get together, come up with their business plans, and compete for supports from the university student-venture fund. As a plan is approved by the SOVO Steering Committee, composed of professors/SOVO management staff/industrial representatives, the company is officially registered with SOVO and becomes a SOVO student enterprise. Each September, every company shall submit its annual business plan and register their proposed projects with SOVO. Semi-annual and annual assessments are conducted by SOVO officers. A workspace may be assigned to a company according to needs and availability of spaces.

Student enterprises are self-directed and must comply with SOVO's rules and regulations. Students from all programs compete for available positions of an enterprise from CEO, CFO, to employees. Applying the knowledge and skills learned in our applied-education programs, student enterprises provide services to the university community and external customers. During the process, students work with real problems with support from faculties and industrial mentors, learn professional skills, and understand business operations, and improve on communication skills, team work, responsibility, social values and attitudes. Currently, the student enterprises in SOVO have approximately 1,200 student employees and 1,500 interns.

STAKEHOLDERS FEEDBACK

In our CDIO programs, students are given a sequence of opportunities to gain practical skills that are in demand and the chance to use the latest technology. Opportunities are available to honor students to make industry contacts and gain relevant work experience in the optional CO-OP programs. The teaching and learning in our engineering education can be in part reflected by the enormous awards students have received in provincial/national/international contests, the above-average high employment rates maintained by our graduates, and the success of student start-up companies cultivated by SOVO and the TOPCARES-CDIO programs. The data from a recent survey to the graduates in the past several years indicates that those who had been with SOVO when they were students at DNUI are twice more likely to become entrepreneurs than those who did not have such experiences. The former members of SOVO student enterprises have founded and currently are running over two hundred companies nation-wide.

In our study of the impact of design-implement experiences, all the stakeholders, students and their parents, faculty, and industry representatives, gave these experiences high marks. Here are some of their comments.

"I enjoy the process of design and building working systems. Our professors really know their stuffs." – WANG Yu, a student of Electronic Information Engineering major.

“I appreciate the CDIO based learning experiences. It makes all the differences. I got the job I want. – LIU Xiao, a student of Computer Science major.

“My son has changed completely in the past two years. Now, he is so enthusiastic about his projects and school work. I can hardly recognize him.” – CAO Xu, a parent, about her son’s progress in design-implement based learning.

“The students become more self-motivate and creative.” – CHEN Gong, EIE SOVO Coordinator.

“Students’ self-learning ability and team sprits are unbelievable.” – LIU Long, a project advisor.

“Combining hardware and software techniques to develop systems of pragmatic functions are highly creative work. The students here under direction of very experienced teachers have grasped embedded system techniques.” -- Alpine Electronics (China), comments on an exhibit of students projects.

“The overall quality of you students has exceeded our expectations. We hope to have long term collaborations with your university.” -- Intel (China), feedback on employees graduated from DNUI.

SUMMARY

In this paper, we presented the design and development of the CDIO workspaces at *Dalian Neusoft University of Information* under a ubiquitous computing campus infrastructure. A CDIO centre was created and the physical learning environment and engineering workspaces are utilized to support the CDIO curriculums and the development of students’ business skills and entrepreneurship. The issues of operational management and staffing challenges of the workspaces were discussed. A four-year design-implement experience plan for Electronic Information Engineering program was given, providing insights to the integrated CDIO curriculum. Finally, our study of the impact of design-implement experiences showed that positive feedbacks were given by all the stakeholders.

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