C PROGRAMMING LANGUAGE TEACHING BASED ON CDIO

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ABSTRACT

"C Language Programming" course is a professional basic course for most engineering majors, which is set up in the first year of undergraduate programmes. It is an important basic course to cultivate students' computer programming ability. The traditional C Language teaching adopts the training method of programming on PC only, the course content is basically around scientific calculation and algorithm design, which is insufficient for students' programming training based on practical engineering problems. This paper introduces the application of CDIO teaching mode in the teaching of "C Language Programming" in Automation Major of Beijing Institute of Petrochemical Technology(BIPT). The isolated programming course and practice are put into the specific automation system, and the "engineering object teaching method" is adopted to integrate the four links of CDIO " Conceive, Design, Implement and Operate" and the key knowledge points of programming into a series of practice projects, the learning mode of "task practice → skill induction → knowledge summary → project re practice" is adopted to train the programming ability. From the teaching practice effect of the course, this mode can promote students' knowledge acquisition activities to be more active, more practical and more effective, improve students' learning quality, and comprehensively improve students' knowledge, ability and professionalism. While learning C Language, the students have "early engineering experience", which can improve their interest and confidence in future professional courses.

KEYWORDS

C Language Programming Teaching, Engineering Object Teaching Method, Early Engineering Experience, Learning by Doing, Standards: 2, 3, 5, 6, 7, 8, 9, 10, 11

INTRODUCTION

In China, there is a lack of effective transition and connection between the basic education in middle school and the engineering education in University. In middle school, there is a lack of engineering practice ability training, and students enter the university to study engineering with almost no professional perspective. For the C Language course set up in the first year of University, students do not know the application needs of the programming knowledge in the professional problems in the future. The traditional C Language teaching method is based on PC programming to learn C Language grammar. Most of the practical problems are confirmatory, students cannot get real ability, and even breed boredom. This will lead to students in the third grade learning professional courses need to program when unable to start. Knowledge is mastered but not applied.

Contemporary college students are in the information age. They use all kinds of application software with powerful functions and gorgeous interfaces every day. They have high learning expectations for programming courses and are interested in how to compile computer programs. However, they are not interested in traditional teaching contents such as inputting 10 numbers to get the average value. The traditional teaching method of programming course is still based on learning grammar. The confirmatory cases used to study grammar are simple and boring, and the comprehensive algorithm cases used to cultivate comprehensive ability suddenly increase the complexity. It has higher requirements for students' mathematical foundation or abstract thinking ability. It's hard for students to imagine how the program works in the computer. There is a big gap between the content of programming course and the function of computer software commonly used by students. This leads to students' lack of interest and initiative in learning. Lack of interest in learning, the effect is very poor, naturally cannot reach the engineering consciousness and innovative thinking of high-level training objectives.

Therefore, we need to start from the professional training objectives, reverse design C Language curriculum objectives, modify the curriculum content, break through the traditional teaching methods, to solve the problems of abstract, boring, difficult to learn, poor learning effect and poor application ability of "C Language Programming" course.

Returning engineering education to engineering is an important strategy of modern higher engineering education reform, and CDIO is an effective educational means to realize this strategy. CDIO standard 2,3,5,6,7,8,9,10,11 provides a framework for the reform of C Language teaching in grade one. Integrating knowledge learning and engineering vocational training, C Language teaching is carried out around the typical robot production project. From the continuous engineering application practice, the common programming knowledge and key skills are summarized, and the ideas of analyzing and solving problems are established. Then these knowledge and skills are re applied to the new programming practice, to achieve the ultimate goal of C Language learning.

FRAMEWORK OF C LANGUAGE TEACHING BASED ON CDIO

The Orientation of "C Language Programming" in Professional Training Program

Since 2015, BIPT has implemented "C Language Programming" teaching based on CDIO in Automation Major. Automation Major passed the Professional certification of Engineering Education in January 2017. Under the background of professional certification, according to the positioning of "C Language Programming" course in the course system of Automation Major, the reverse course design is carried out with the guidance of students' ability cultivation, and the course objectives are determined.

The training goal of Automation Major is "automation system engineer oriented to production line". To train students to solve complex engineering problems of automation system engineering design, product integration, operation and maintenance, and technical service, the following five professional engineering abilities are mainly cultivated: the Application Ability of Mathematics and Natural Science, Humanities and Social Science Knowledge; the Comprehensive Design Ability of Electronic System and Computer Programming Ability; the Analysis and Design and Digital Simulation Ability of Automatic Control System; and the Automatic Control Department Integrated Design, Product Integration, Installation, Commissioning, Operation and Maintenance Capabilities; Enterprise Practice Capabilities. In

order to cultivate these five engineering abilities, the corresponding curriculum modules need to be designed for the professional education training program, as shown in Figure 1.

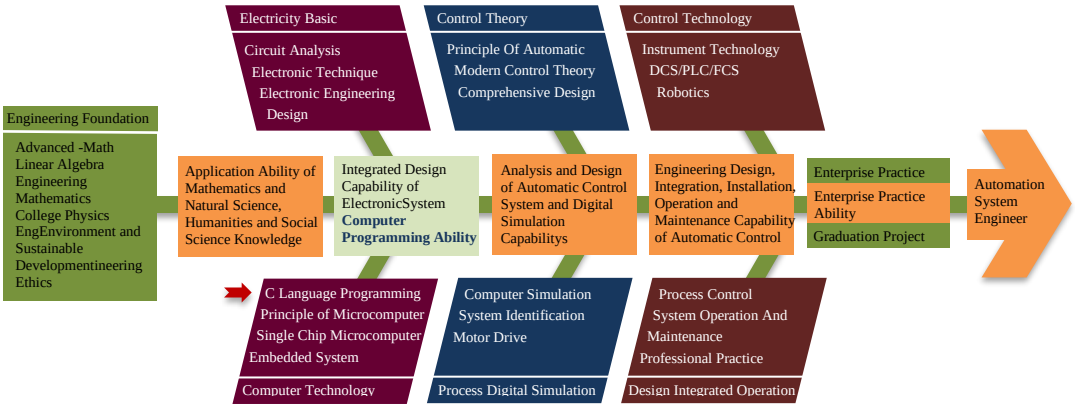

Figure 1. Fishbone Diagram of Training Program Course Module for Automation Major

The course of "C Language Programming" is an important basic course of computer technology module in the training plan of Automation Major for freshmen. It provides strong support for the cultivation of computer programming ability in the five modules of professional ability cultivation. The relationship matrix between the course objectives and 12 Graduation Requirements is shown in Table 1.

Table 1. Supporting Matrix of Course Objectives for Graduation Requirements

Category	Graduation Requirements	Teaching Objectives
Knowledge	Engineering knowledge	**Objective 1:** Master the basic grammar system of C Language, the ideas and methods of structured programming, have the ability of abstract and automatic computing thinking, and be able to use it in programming.
Ability	Design/ development of solutions	**Objective 2:** Have basic programming and algorithm analysis ability, be able to skillfully use C Language to compile basic programs of sequence structure, selection structure and circulation structure, be familiar with common algorithms such as search and sorting, be able to design and implement program modules according to requirements, reflect innovation consciousness, and consider cultural and environmental factors.
	Modern tool usage	**Objective 3:** Familiar with the software development process, with the basic quality of software development, can skillfully use Microsoft Visual C++ 6.0 or at least one other development environment for programming, debugging and testing; have more standardized programming habits and good programming style; establish the spirit of communication and team cooperation in the process of software development, and consider the awareness of engineering practice in the selection of project scheme in addition to technical perspective.
Professionalism	Individual and teamwork	**Objective 4:** Has the ability of team cooperation, understands the individual role division in the team, and is competent for the corresponding role responsibility achievement.
	Communication	**Objective 5:** Be able to communicate effectively on complex engineering problems in the computer field, including writing reports and design manuscripts, making statements, clearly expressing or responding to instructions.

Framework of C Language Teaching Based on CDIO

Based on CDIO standard 2,3,5,6,7,8,9,10,11, the implementation framework of C Language teaching is constructed, as shown in Figure 2. The C Language teaching framework based on CDIO includes the following aspects:

- Construct the engineering experiential practice training environment of C Language learning.
- Redesign the curriculum objectives, teaching methods and teaching evaluation.
- Teacher training to improve teachers' engineering ability.
- Teaching implementation, effect evaluation and feedback.

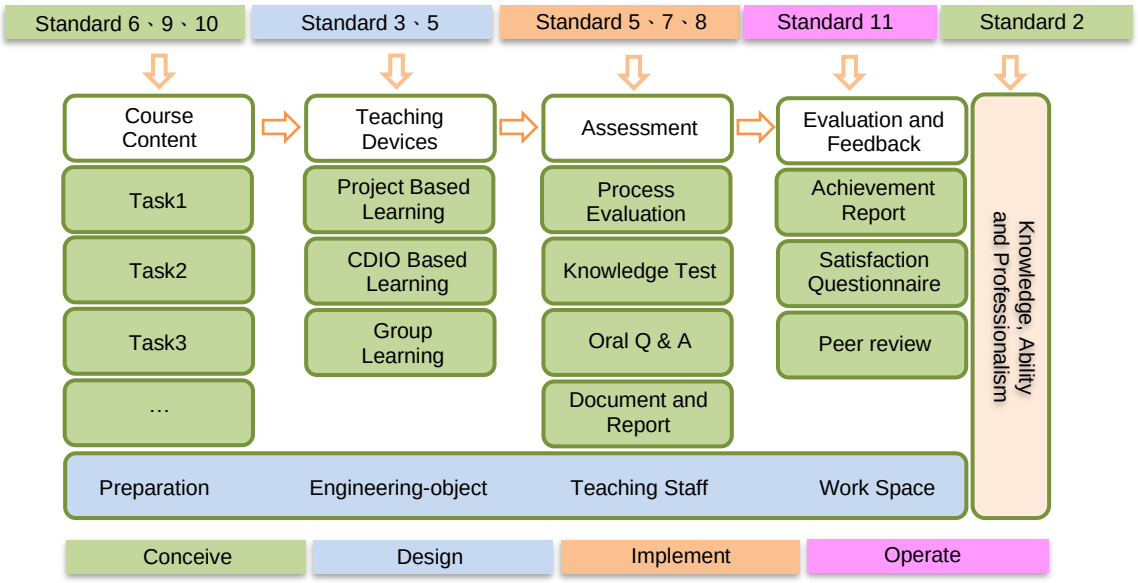

Figure 2. Framework of C Language Teaching Based on CDIO

IMPLEMENTATION OF C LANGUAGE TEACHING BASED ON CDIO

Selection of Engineering Object

In recent years, the rapid development of Educational Robot provides a very suitable engineering object for the engineering education reform of "programming" course. Educational Robot is a kind of robot products, suits or parts specially developed by manufacturers to stimulate students' interest in learning and cultivate students' comprehensive ability. Educational Robot not only provides a variety of programming platforms, but also allows students to disassemble and assemble freely, and allows students to design some parts by themselves.

The following principles should be followed in the selection of Educational Robot in the construction of engineering experience environment of C Language course:

- After simple training, students can understand the hardware structure which have simple perception and mobile functions, and provide I/O expansion interface;
- Support C Language programming and provide suitable software development environment;
- Manufacturers provide appropriate supporting materials and teacher training services.

For example, the C51 series MCU chip as the controller, the main body of wheeled robot, C Language programming development environment, and a variety of supporting sensors are

very suitable for C Language teaching and early engineering experience. Figure 3 is a few pictures of the engineering object for C Language teaching, which is a wheeled robot car, called "Dragon Baby Car".

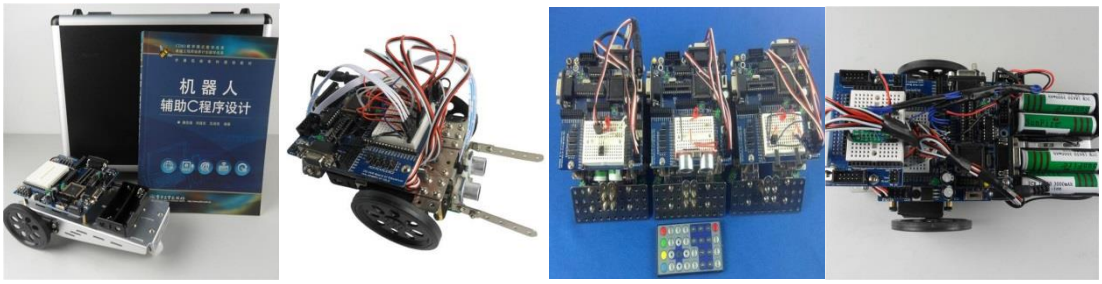

Figure 3. C Language Teaching Robot (Dragon Baby Car)

Course Content

The content of the course is changed from data processing and algorithm research to C Language teaching about a series of production projects of Educational Robot, as shown in Table 2. According to the learning mode of "task practice → skill induction → knowledge summary → project re practice", it breaks through the traditional learning mode of "classroom teaching + programming training on PC", integrates knowledge, ability and quality, and cultivates students' comprehensive ability and advanced thinking to solve complex problems. At the same time, the most basic engineering quality of students is cultivated.

Table 2. Contents of Robot-aided C Language Programming Course

	Task Description	C Language Syntax	Solving Engineering Problems	Professionalism
Task1	Let the robot run the first program	Understand programming, compiling, downloading and running, master the basic framework of C	Can use the integrated development environment to create projects, compile c Language source program, and download to the MCU	Understand the operation of program on MCU
Task2	Robots do arithmetic	Master the basic data type and data operation of C Language	Be able to program sequence structure for data calculation	Understanding computer memory
Task3	Robot walking square	Master the syntax format and operation mechanism of C language cyclic structure	Can program the cycle structure to control the robot to get continuous pulse signals	Understanding the relationship between program output signal and robot motion
Task4	Tactile navigation robot	Master C language choice structure syntax and operation mechanism	Can control the robot to avoid obstacles and cruise automatically by using structure selection program	Understand the control system structure composed of "sensor controller actuator"
Task5	Programming function to realize robot cruise control	Master the definition, call and declaration of user-defined function	Can program functions to realize the basic cruise action of robot	Understand the modular programming idea of top-down divide and rule
Task6	Cruise control of robot with complex path	Master the definition of array and the reference of array elements	Can store path information in array and realize cruise control of complex path robot by programming	Establishing the program design idea of "data structure + algorithm"
Task7	Design and development of integrated project - Intelligent Handling Robot		Simulate the actual working process of the automatic logistics system, use the sensor to control the robot to patrol the line in the given map, and carry the material blocks in the material area to the target area according to the requirements.	

Task8	Design and development of integrated project - Robot Tour in China	In a given site, travel to the attractions in the site map as required. There are 15 scenic spots in the site. The robot starts from the starting point, moves according to the path of the patrol site, travels in the specified scenic spots within the specified time, and returns to the starting point after visiting the scenic spots.

According to CDIO standard 5, the course content is divided into two levels, task 1 to task 6 as the basic level, task 7 and task 8 as the advanced level, so as to achieve the high-level learning objectives.

Early Engineering Experience

The reform of China's engineering education is facing a social problem. The disjunction between examination-oriented education in primary and secondary schools and professional education in universities makes many engineering students lack the most basic understanding of engineering before they enter the University, and their engineering experience is zero. In order to solve this problem, some universities began to learn from international advanced engineering education experience. In order to create an early engineering practice environment for students and provide early engineering experience, universities in many countries have set up engineering experience courses for freshmen. "It aims to provide students with the first year's engineering experience to cultivate professional skills, establish a professional perspective, and understand the social and humanistic environment of the engineering world" (Fei Y. N., 2008).

In the book "Rethinking Engineering Education: CDIO method", Professor Edward Crawley and his co-author of the Department of Aeronautics and Astronautics Engineering of Massachusetts Institute of technology in the United States compare the architecture of engineering knowledge with the structure of a stone arch (Figure 4), and illustrate the role of each level of knowledge with the arch construction process (Crawley E. F., 2007). Among them, the guiding course "early experience course" is like a wooden frame built at the beginning of arch construction, which determines the shape of the arch and the relationship between various stones. Without the construction of this primary frame, no matter how good the stones can form the arch, we can see the important basic position of "early engineering experience" course in engineering education.

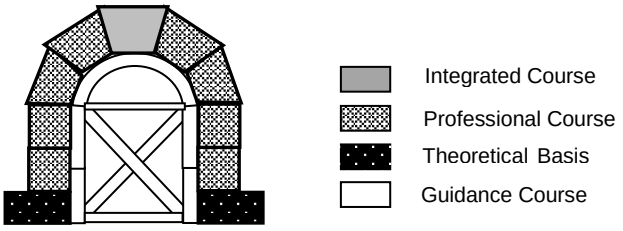

Figure 4. The Structure of Engineering Knowledge System with Arch Analogy

However, there are many practical bottlenecks in the teaching implementation of adding engineering foundation course in the whole university, which leads to the fact that it has not been popularized in China. Therefore, it is a good way to solve the problem to integrate the content of early engineering experience in the C Language course for freshmen. It's a win-win solution.

"Project Oriented" Teaching Organization Mode

Due to the difficulty and challenge of the course content, the teacher decomposes the comprehensive task into several task modules according to the students' cognitive rules, designs the progressive practice content and process, and integrates the basic data representation, logical control structure, function encapsulation and call, combined data of C Language into a series of project task production. Adopt the project teaching organization mode, with 3 ~ 6 students as a team to complete related tasks, each team has a project leader, who is responsible for the organization and coordination of team tasks, and each student in the team undertakes independent program module development. It realizes "learning by doing" and "doing by learning" and realizes the interactive and inquiry learning of teachers and students (Figure 5). To cultivate students' practical ability, innovative ability and engineering quality.

Figure 5. Learning by Doing

Course Assessment

Adopt scientific and diversified assessment methods. The teaching objectives, teaching process, assessment methods and the degree of achievement assessment are related, the process assessment is strengthened. For the process assessment, the evaluation scale (Table 3) is designed to realize the supervision and evaluation of the whole learning process and make a scientific evaluation of the teaching effect.

Table 3. Process Assessment Scale

No.	Item	Ratio	Evaluation Criterion
1	Attitude	0.3	Conscientious attitude, rigorous style; according to the schedule to complete the design task; can well complete the required workload.
2	Ability	0.3	The ability of computational thinking, the ability to solve problems, the knowledge of software and hardware of computer application system, the ability to analyze and solve problems with the thinking mode of C language, and the ability to put forward effective program design scheme; Design simple data structure and algorithm; use programming language to realize algorithm description; program to solve problems.
3	Team	0.2	Have a clear division of labor and distribution ratio, clear their responsibilities; can play their role in the team; team work is effective; in the process of project implementation, can discuss with each other; reflect the work content and its requirements for personal knowledge, ability and quality.
4	Written Expression	0.1	Complete the design report, try professional written expression, use drawing flow chart to express personal design intention; use algorithm to solve problems; be able to realize system design, program design and input and output operation comprehensively.
5	Oral Q & A	0.1	Answer all kinds of questions accurately and fluently, be able to clarify their own point of view, answer the questions concisely and to the point, highlight the key points; understand the questions, according to the known conditions, find out the mathematical method to solve the problem or establish the corresponding mathematical model.

According to the homework, process evaluation and final examination results, the achievement degree of teaching objectives is determined by using the course assessment score analysis method. The final results are filled in Table 4.

Table 4. Calculation Table of Achievement Degree of Teaching Objectives

Course Name		**C Language Programming**						
Teaching Objectives		1	2	3	4	5		
Ratio		0.3	0.3	0.2	0.1	0.1	1.0	
Teaching Link								
Classroom Teaching		√	√	√	√		/	/
Experimental Operation		√	√	√	√	√	/	/
Comprehensive Design		√	√	√	√	√	/	/
Assessment method	Ratio	The Ratio of Assessment Links to Teaching Objectives					∑	Score
Homework	0.2	0.2	0.8	/			1	
Process Evaluation	0.4	0.2	0.2	0.2	0.2	0.2	1	
Final Exam	0.4	0.2	0.7	0.1			1	
∑	1.0	0.6	1.7	0.3	0.2	0.2	3	
Achievement of Teaching Objectives								

Achievement of Teaching Objectives

Figure 6 shows the achievement of teaching objectives of C Language Programming course for Automation Major in recent three years. About 90 students participate in the course every year. It can be seen from the chart that the teaching effect of the course is improving year by year.

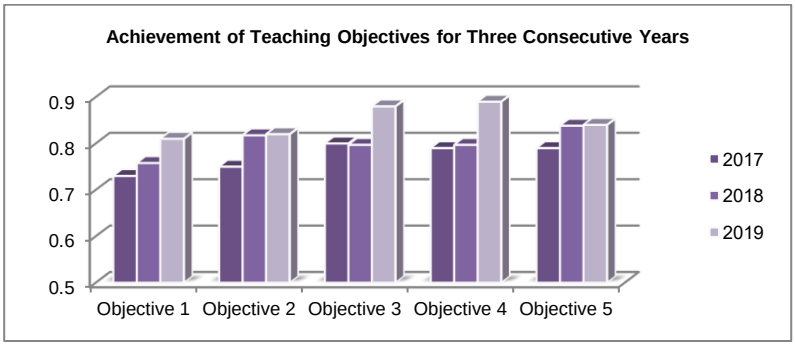

Figure 6. Achievement of Teaching Objectives in recent years

Questionnaire on Students' Learning Outcomes

In order to evaluate students' satisfaction with the course harvest, a questionnaire was designed, including 12 questions, as shown in Table 5.

Table 5. Students' Learning Satisfaction Questionnaire

No.	Questions	Evaluation (3-Agree, 2-Uncertain, 1-Disagree)
1	Be able to deeply understand the importance of programming in this major	
2	Strong interest in programming	
3	Understand the basic concepts of variables, data types, expressions, arrays, functions, pointers, etc	
4	Be able to skillfully use selection structure and cycle structure to write programs to solve problems	
5	Have the ability to analyze problems, be able to program multiple functions	
6	Have the ability to run, test and debug the program	
7	It has good code style and pays attention to the interface design between program and user	
8	Master the basic idea of program design, understand the working principle of computer	
9	Willing to actively participate in class discussion and group learning	
10	Can improve oral and written communication skills	
11	It improves the engineering ability and cultivates the entrepreneurial spirit and innovation skills	
12	Cultivate the quality of persevering to achieve the goal	

According to the students' learning satisfaction questionnaire in Table 5, 88 students from 2019 were investigated, and 82 questionnaires were collected. The statistical results are shown in Figure 7.

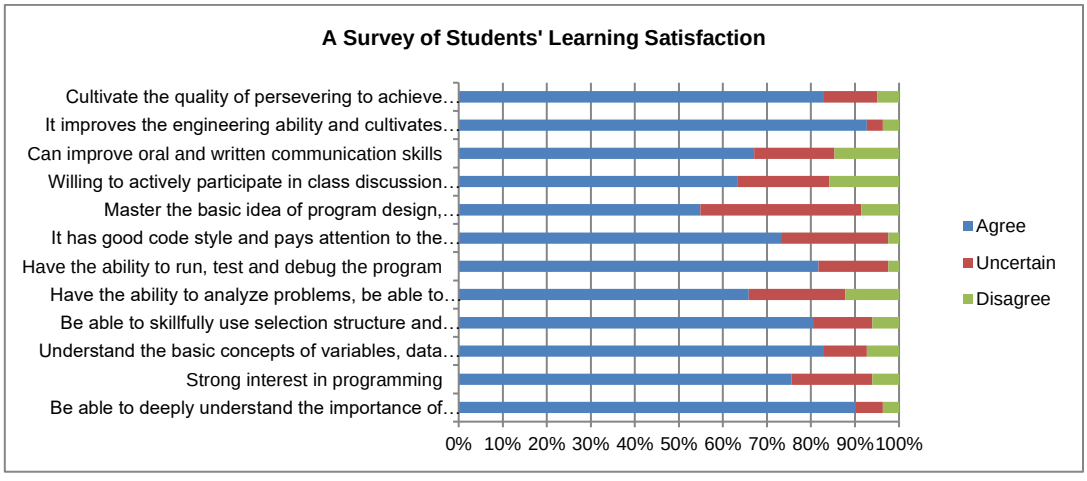

Figure 7. Students' learning satisfaction, taken in July 2019

In 82 questionnaires, more than 90% of the students can deeply understand the importance of programming in their major, and think that they have improved their engineering ability, cultivated their entrepreneurial spirit and innovative skills. More than 80% of the students agree

with the achievement of ability training. On the whole, students are basically satisfied with their learning process and achievements, which confirms the effectiveness of CDIO principle in the course.

CONCLUSIONS

According to CDIO standard, combining programming with practical engineering objects, C Language teaching is carried out in the form of "learning by doing", which stimulates students' interest and enthusiasm in programming, improves learning efficiency and effect, and is well received by students. Students sigh that "robot based programming practice connects the knowledge of C Language with the robots we are interested in, which makes us immerse ourselves and enjoy it all the time". Students summed up that "group training is the first, the training process should be patient, ask for more advice when encountering difficulties, and think more when facing problems".

The effect of the course brings about the improvement of students' programming ability and engineering practice ability. It greatly promotes students' self-confidence, enthusiasm and participation in innovative practice activities. Fruitful results have been achieved.

The first year's C Language course provides students with early engineering experience, helps students establish a professional perspective, and lays a solid foundation for subsequent professional learning. With the smallest incremental investment in teachers, equipment and management, the maximum benefit has been obtained.

REFERENCES

Cha J.Z. (2008). On the CDIO mode under the strategy of "learning by doing". Research on higher engineering education, (3), 1-6, 9.

Crawley, E. F., Malmqvist, J., Östlund, S., & Brodeur, D. R. (2007). Rethinking Engineering Education: The CDIO Approach. New York: Springer.

Fei Y. N., Qiu J., Li W. M., Li M. F., Wang X., & Li S. X. (2008). Design and practice of early engineering experience course. Experimental technology and management, 25(12), 13-16.

Huang H. T. (2014). Evaluation of students' learning outcomes: A Study on the quality assurance of American higher education. Education Science Press.

Li J. P., Liu Y. S. (2013). Research on CDIO training system and curriculum teaching design of electronic information engineering. Beijing, China: Beijing Jiaotong University Press.

Qin Z. Q., Liu J. D., Wang S. H. (2013). Robot aided C programming. Beijing, China: Electronic Industry Press.

Tao Y. F., Shang C. H. (2006). The Enlightenment of CDIO outline on the innovation of higher engineering education. Research on Higher Education in China, (11), 81-83.

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