Research on Teaching Reform of the Course of Computer Organization and Architecture Guided by Experimental Operation Cases

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Abstract: "Computer Organization and Architecture" is one of the most important core basic courses of computer science, aiming at the current situation and existing problems in the teaching process of this course in China, and through analyzing and drawing lessons from the teaching experience of the related courses of foreign first-class universities, combining with China's actual situation, this paper puts forward the teaching reform program of the course, finally forms a new teaching mode and teaching method which is characterized by "Experimental operation runs through theoretical teaching", "Teach hardware courses starting with software" and "Diversity+ Personalized Assessment". The practical results show that the new teaching reform program works well and can provide reference for other courses.

Keywords: Computer Organization and Architecture, teaching reform, computer system architecture, undergraduate higher education.

1. Introduction

The course of "Computer Organization and Architecture" is one of the most important core basic courses of the electronic information majors in China's general higher education institutions, the course content is located at the junction of software and hardware[1], which is not only closely related to the digital logic circuit design of the lower-middle layer of computer system hierarchy architecture, but also closely related to software technology such as upper operating system and compiler. Therefore, this course plays an important role that forms a connecting link between the preceding and the following in the whole teaching of electronic information specialty. Because the course involves a wide range of knowledge, massive content, complex
and abstract concepts, according to reflecting by most of the teaching peers in domestic colleges and universities, it showed in the relevant teaching process of the course that students generally feel that the course content is boring, their learning interest is low, and always feel not fully understand for some classroom teaching, just memorize mechanically for coping with test, and completely forgot all content after the test. Therefore, this course is also regarded by most students as one of the most difficult computer courses to learn. With the update of training programs and the constant emergence of emerging computer technologies, most higher colleges and universities in China still regard this course as a single computer hardware course unilaterally, and still organize teaching following the traditional hardware course idea of "functional principle analysis - phenomenon experiment verification", fail to consciously establish the connection between software and hardware, which has led to the current course be in straitened circumstances for the current teaching ideas, methods and means of the course. The "dilemma" phenomenon of "students are difficult to learn and teachers are difficult to teach" has become a bottleneck restricting the development of the course teaching[2].

China is currently undergoing major development changes in the structural transformation of the economy, the guiding principles of higher education development and talent cultivation are to "focus on cultivating students' innovative spirit and practical ability." In the transformation process of traditional manufacturing industry to economic structure characterized by the information technology development, the traditional general-purpose computing platform has penetrated rapidly in the direction of the embedded system, cloud computing, re-configurable computing and Internet of Things, and a large number of talents who masters the core chip and hardware system design technology will be needed in all walks of life. At the same time, in terms of social development needs and the information of employment market feedback, the current computer software talents are basically oversupplied, but the talents who are familiar with computer hardware design and own the theoretical basis and design ability of computer system architecture are in serious shortage. Even for those software system designers and developers, without a solid foundation of computer organization and system architecture, it is difficult to be well qualified for the important underlying and system software development tasks. This makes the teaching work of the course of "Computer Organization and Architecture " become more important and prominent in the training of computer professionals in colleges and universities.

Under the background of the new environment of the industry development and the new requirements of national higher education for personnel training, it is of great significance for cultivating innovative talents and promoting the realization of the
strategic goal of higher education and personnel training in China to do a good job in the teaching of the course of "Computer Organization and Architecture" and carry out reform in terms of teaching idea, teaching content and teaching means.

2. **Course status and characteristics**
Professor David Patterson of UC Berkeley University in the United States has used diagrams to clearly describe the hierarchy architecture of computer system and highlighted where this course is located, as shown in Figure 1.

![Hierarchy architecture of computer system](image)

As can be seen from Figure 1, the computer system can be divided into two parts: hardware and software. On the interface between software and hardware is the ISA (Instruction Set Architecture), the shadow part around ISA is the content of Computer Organization and Architecture. This part of the content is extremely important in the entire computer system, the hardware involved in the course includes: processor, memory and input/output system (i/o System), of which the processor is mainly composed of data path and control logic. These hardware are resources directly managed by the operating system (Operating System) and are the platforms that the compiler (Compiler) runs directly on the target program code translated by the high-level language source program. Therefore, in addition to the various components computer hardware involved in and their interconnections, code repertory, etc, the content of this course is also closely related to some technologies and courses such as Digital Design & Circuit Design, operating system and compiler. In addition, the representation of data, the locality of Cache, the implementation of virtual memory,
the hardware implementation of procedure calls, and the conventions for register usage are also closely related to the design and development of applications, therefore, "Computer Organization and Architecture" naturally become the core basic course of computer majors.

From the status of the course, it is a leading course of many follow-up professional core courses (such as embedded technology, parallel processing technology and programming), which plays an important role that forms a connecting link between the preceding and the following in the whole professional teaching, and has a significant influence on training students’ analysis, application, design and development capabilities of computer hardware systems. Therefore, how to grasp the main line and key points of the course, reform the teaching content and teaching mode, lay a solid foundation for students' future professional study, enable students to have certain hardware design and development capabilities, and enhance students' hands-on ability and self-confidence is the problem that teaching reform of the course must solve.

3. Problems existing in the course teaching

In order to further clarify the direction of efforts in the teaching reform of the course, we refer to the results of the study on the teaching setup and measures of four international first-class universities (Massachusetts Institute of Technology, UC Berkeley, Stanford University, Carnegie Mellon University) [3-5] by the Yuan Chunfeng teaching research team of Nanjing University, and analyze the corresponding situation in the light of China's national conditions.

The requirements of the four schools surveyed for the prior preparatory knowledge of the course of "Computer Organization and Architecture" are only to understand the basis of a certain programming language, and in term of this point, the curriculum setup of Chinese colleges and universities is consistent with these first-class universities. The course of "Computer Organization and Architecture" in Chinese colleges and universities is generally held in the second year of undergraduate courses, students have already studied C programming previously, so that we can have the same basic starting point with them in the follow-up process of referring to the advanced teaching initiatives of these top universities. However, comparing with the teaching ideas and contents of these first-class universities, it can be found that these have become a commonality in the teaching process of these first-class universities that the defining the course as a transition course of software and hardware, emphasizing the connection between software and hardware, and guiding students to understand the basic concepts of the underlying hardware architecture and system software of the computer system from the perspective of programmers and inter-
relatedness. For example, the hardware design courses similar to "Digital system
design" that MIT set up for Electrical Engineering and Computer Science majors enable
students to truly understand how to design modern computer hardware systems using
hardware description language through FPGA, Computer Science major of UC.
Berkeley sets up the course of "Machine Structure" as a course between software and
hardware, which gives students a deep understanding of how to convert programs to
machine code and execute on hardware[6]. But for the teaching of this course in China,
most colleges and universities still basically follow the traditional teaching ideal, so
that the teaching content is still in the introduction of the principle of basic composition
and design of the computer hardware system, less to establish the connection with
the software course. Combining with the actual situation of higher education in China,
the problems existing in the teaching of this course are embodied in the following
aspects:
(1) Problems existing in the theoretical teaching mode
The teaching mode of "The Inculcation Education" is still the main theoretical teaching
mode of Chinese classroom. The course of "Computer Organization and Architecture"
involves a wide range of knowledge, massive content, complex and abstract concepts,
if students lack of positive interaction and active thinking in the classroom, they will
easily lead to distractions and inconsistencies, so that they cannot follow the progress
of the course. Through the situation reflected by the teaching peers in most colleges
and universities in China, it showed in the relevant teaching process of the course that
students generally feel that the course content is boring, their interest in learning is
low, and always feel not fully understand for some classroom teaching, just memorize
mechanically for coping with test, and completely forgot all content the after test.
(2) Problems existing in teaching methods and contents
Most of the traditional teaching in China still regards this course as a single hardware
course for computer majors, the content of the lectures still introduces the principle
of the basic composition of the computer hardware system. But it is less connected
for the instruction system design related to computer hardware and some software
design techniques such as operating system and compiler. At present, most of the
undergraduate students trained by the Chinese computer major are generally engaged
in program development after graduation, so facing with the traditional teaching
content of the course, the students feel that the knowledge they studied is out of
touch with practice seriously, the course they learned is useless, and thus lost the
purpose orientation of learning.
(3) Problems existing in practical teaching
The traditional experimental teaching of "Computer Organization and Architecture" is
mainly based on verification experiments, getting more scores is the main purpose for
students taking the experiments, such cases lead to students often follow the experimental instructions to conduct experiments automatically, and have less thoughts on the experimental process and principles, which is not conducive to arousing the student's thinking and the creation ability, so that students can not deeply understand and master the knowledge of computer systems thus fail to achieve the teaching objectives of the experimental curriculum. However, in term of the comprehensive system design experiment, it is difficult for students to complete, which is impossible to establish the confidence of students to learn and fails to stimulate their interest in exploration. The function of the experiment course should be to change abstraction into image, change complexity into simplicity, and improve students' enthusiasm for learning. Most of the domestic practice content settings are the functional component experiment firstly, and then the whole machine experiment followed, this bottom-up approach is not conducive to students to establish the overall concept of computer hardware, causing students understand the knowledge points unilaterally and be disjointed with other content, so that they cannot systematically understand the working principle of computers.

(4) Problems existing in the assessment process

The examination of the course gives first place to the test papers, combines the completion situation of the assignments and experiments at the same time, such the traditional assessment criteria cannot truly reflect the individual differences. Because the current mode of experiment and assignments leads to the performance evaluation only according to the completion result of the experiment and the submission of the assignments, while the verification experiment results are the same, almost all students can complete, the most of homework is largely identical with only minor differences, it can not reflect the differences of students, which leads to teachers difficult to have a targeted basis in the scoring, and thus can not reflect the results of differentiation, and so that attacks the enthusiasm of some serious students.

4. Measures for teaching reform

Based on the analysis of the above problems and the reference to the teaching experience of the relevant courses of the international first-class universities, under the current development strategy of structural transformation of China’s economy, the guiding principles of higher education development and talent cultivation are proposed to “Focus on cultivating students' innovative spirit and practical ability”, "Enhance the scientific and technological innovation and social service capabilities of high-quality talents", which has also become an urgent requirement for the cultivation of talents in national economic construction, science and technology and social development at the same time. The teaching content organization and reform of the course will be
carried out from the following aspects.

1) A new theoretical teaching mode guided by experimental operation
This new way of teaching, which breaks down the comprehensive theory explanation in classroom, is no longer over-pursuing the meticulous and comprehensive teaching of each content while setting up experimental operations (software simulation or hardware verification) for the main functions of the main functional components, completing the relevant key links of theoretical teaching in the laboratory, leading students to do experiment while teaching, teaching anything when using anything, doing anything when teaching anything. Adding programming operation, EDA software application and some functional parts verification into the course of theoretical teaching, students can deeply understand the abstract concepts and knowledge in the teaching content, so as to always keep up with the teaching schedule. The setting of the corresponding experimental operation should follow the principle of short content, strong maneuverability, typical chapter content and difficulty in understanding, such as the correspondence between high-level language source programs and machine code, access anomaly (storage protection), big-endian/little-endian, the composition of virtual address space, system performance evaluation method, operator operation, interrupt control operation and so on. Through the method of "Teaching anything when using anything, doing anything when teaching anything" to change abstraction into concrete so as to attract students' attention and enhance their hands-on ability.

2) Emphasize the teaching method of jointing software and hardware from the perspective of programming
Aiming at the problem that students feel that the knowledge and practice are seriously disconnected and the content they learned is useless, the research uses the teaching method of associating the software and hardware to solve the problem. That is, to change the one-sided understanding of regarding this course as the single hardware course and the traditional teaching method of just teaching hardware in the course, separating software and hardware, to start from the programming that students are familiar with and interested in, through the setup of practical operating cases to let the students further grasp the relationship between hardware and program design by programming, and guide students to establish an idea of software and hardware relating closely then further understand the architecture and hardware configuration of the computer system from the perspective of a programmer, and understand the execution of a program from the perspective of a system architecture and the hardware designer, finally establishing relevant knowledge systems in a systematic way. This course is at the junction of software and hardware, so it is proposed to organize the teaching content with "High-level language program - Assembly language
program - Machine instruction-CPU design" as the main line. By this, students can deeply understand a program from programming design, translation conversion, an entire process of link loading and the system structure of an underlying machine (including instruction format, data representation, register organization, Cache architecture, virtual memory space mapping, etc.), which is closely related to CPU performance finally then further improving their abilities to design and debug programs efficiently. By explaining the problems of affecting the execution efficiency such as various data correlation, control adventure and resource conflict that encountered in the instruction flow processing, it would expound how to use various optimization techniques to avoid or reduce the occurrence of the corresponding problems in the compilation process, and then optimizes the operation efficiency of the program.

(3) Practical methods of taking software simulation as the basic starting point, hardware verification as transition, and the whole machine design as targets
In view of the problem that the content of the simple verification practice in this course is scattered that can not stimulate students' interest in exploration and learning while students would have more difficulties in completing the comprehensive system design experiment, the research uses the three-stage progressive practice method of “programming experiment”, “hardware verification experiment” and “comprehensive innovation experiment” to solve it. The software practice operation is carried out in the software environment of the FPGA developing tool of Quartus II 8.0. By the programming operation throughout the theoretical lecture, the related content is no longer an abstract and boring concept, but can be turned into the easy-to-understand and visible specific data by the executing and debugging a program. After that, the students' understanding of the complex theoretical concepts would be verified and sublimated through actual hardware operations and finally transforming students’ theory knowledge into the ability of apply knowledge by the comprehensive innovation experiment, which is such as asking students to achieve an actual multi-line CPU using hardware description language on the FPGA board. From this the students could experience the entire process from design, implementation to testing personally.

(4) “Diversification + Personalized” assessment method
For the problems such as students taking the credit as the purpose, just memorizing mechanically for coping with test and completely forgetting all content the after test, this research puts forward to use the "Diversification + Personalized" assessment method to reduce the difficulty of students passing the examination. But at the same time, it can also achieve the training objective of improving the students' connotation quality, and thus objectively and accurately assess the learning situation of students. The specific operation is to adopt the method of combining the student's classroom
training, experimental acceptance, experimental report, experimental test and so on to form the final score examination, it is no longer takes the single course examination as the main appraisal index. At the same time, it should focus on the weight of the personalized experimental acceptance link in the composition of the scores, give each student different experimental questions or propose different technical parameters for the approximate topics. Students need to complete the circuit modification, test program writing, downloading and experimental system debugging according to the given topic or requirements. The traditional assessment mode of “the same examination questions for all students” should be changed thoroughly.

5. Conclusion
The course of "Computer Organization and Architecture" is one of the most important core courses in the computer major. In recent years, our teaching group has carried out corresponding teaching research and reform practices around the course itself and related course group. From this project, a new teaching scheme was gotten which is characterized by the traits of "Experimental operation running through theoretical teaching", "Teach hardware courses starting with software" and "Diversity + Personalized Assessment". The results we studied will directly and effectively solve the "dilemma" bottleneck that restrict the development of the course of Computer Organization and Architecture. At the same time, the teaching idea of integrating software and hardware closely which is focused on understanding the architecture and hardware design of the computer system from the perspective of a programmer and optimizing the program execution from the perspective of a hardware designer could guide students to fully construct the relevant knowledge system and help them to catch up with the setting of relevant courses of world-class universities[7,8]. The “three-stage progressive practice method” formed by the research will promote the cultivation of students' innovative spirit and practical ability. The reform program has been applied in undergraduate teaching of our college and has achieved good results. The research results of this project are not limited to the this course rarely, but also can provide positive reference for other similar courses.

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References


