An Exploration of Practical Teaching of "Computer Organization and Structure" for the Software Engineering Major

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Abstract. In response to the common practice in software engineering education of focusing on software and neglecting hardware, and the deficiency of computer hardware foundation experiments in the practical teaching system, this paper analyzes the industry needs, student abilities, the advantages of the discipline, and the situation of the faculty team, and proposes a practical teaching plan to enhance the hardware foundation skills of software engineering majors. This paper analyzes the practical teaching plan based on the theoretical course "Computer Organization and Architecture" from the perspectives of teaching content, teaching methods, and teaching platforms, with the aim of enhancing students' in-depth understanding of the underlying logic of computers through practical teaching and achieving the goal of "dual-wheel driving" in the process of cultivating software engineering majors.

Keywords: Computer Organization and Structure; Hardwired Controllers; Virtual and Physical Combination

1 Introduction

The traditional software engineering major places emphasis on the training of students' software engineering capabilities, programming skills, and software innovation abilities. In the course setting, it emphasizes continuous mathematics learning, continuous programming practice, and continuous software engineering thought, but the teaching of the underlying logic of computers, the principles of computer organization, and the working principles of computer hardware modules is not deeply explored. The course setting lacks a series of courses related to computer hardware, such as "Digital Logic and Digital Circuits," "Principles of Computer Organization," and "Computer Architecture." There is not enough clarity on the execution process of machine instructions. With the development of information technology, the artificial intelligence technology of hardware and software integration has become an industry trend, and the requirements for software engineering talents are becoming increasingly comprehensive. A good hardware foundation should be the basic skills of software engineering undergraduates. In the revision of the training program, relevant practical teaching content is

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added, aiming to strengthen students' in-depth understanding of the underlying logic of computers through hardware experiments, and achieve the goal of "dual-wheel driving" in the training process of software engineering.

The curriculum construction adheres to the concept of solid foundation, method teaching, and ideological guidance, and attaches great importance to the case-based teaching mode of breaking through key problems and exploring frontier research through the design and implementation of computer hardwired controllers. It cultivates students' interest and passion for engineering and guides them to further grasp the relevant technologies and methods of computer hardware design, as well as the patriotic sentiment of becoming a warrior who will no longer be "throttled" by others in the future of the motherland. Through learning, students can gain a deep understanding of the underlying logic of computers, computer organization, and the working principles of each module, understand the concept of hardware and software layering, master the process of instruction execution and its interrelationships, and understand the support provided by the lower layer to the upper layer. They can also master FPGA technology and its applications, and master EDA programming tools [7]. They can have a good understanding of the technological development trajectory of CPUs and acquire the ability to design controllers to some extent [4]. They can fully understand the concept of computer systems as a whole and improve their ability to apply computer systems, and train During the course, the teaching method is selected according to the students' mastery of the preceding knowledge [1].

The course is designed and implemented based on the national-level excellent course "Principles of Computer Composition". The in-class experiments of "Computer Organization and Structure" and the practical course of "Course Design of Computer Organization and Structure" offered on the basis of this high-quality course system will establish a more comprehensive hardware practical system for undergraduate students majoring in software engineering [12]. Emphasizing the combination of theoretical teaching and practical teaching, and fully considering the existing theoretical foundation of undergraduate students majoring in software engineering, in the content design of the experimental teaching, on the one hand, it closely adheres to the theoretical teaching, and on the other hand, it realizes the deepening and supplementation of the theoretical teaching content. We strive to achieve "Equal emphasis on engineering practice and theoretical teaching, and drive theoretical teaching with practical teaching", to address the issue of coordinating hereditary learning with engineering practice and the cultivation of innovative capabilities.

A hierarchical and all-round practical teaching content has been designed, from basic experiments of digital systems → cognitive experiments of computer organization and structure → experiments of hardware description language → experiments of hardwired controller design → experiments based on FPGA, forming a progressive and deepening practical system layer by layer. Build self-confidence, stimulate interest, thereby achieving the goal of exercising practical ability and innovation ability, and laying a solid foundation for subsequent studies. Cultivate advanced software engineering talents with comprehensive development driven by both software and hardware.

2 Course Content

The course content employs a teaching mode that progresses hierarchically from verification-type to design-type and then to innovation-type.

2.1 Confirmation Experiment

Six verification experiments have been designed, encompassing combinational logic circuit experiments in digital systems, sequential logic circuit experiments, data path experiments in computer organization and structure, microprogram controller experiments, CPU composition and instruction experiments, and basic syntax and application experiments of hardware description language [10]. During the instructional process, targeted selections were made in accordance with students' grasp of the preceding knowledge.

The aim of verification experiments is for students to review and sort out the theoretical foundation courses they have previously studied, deepen their understanding, and lay a solid foundation for subsequent design and innovative experiments.

2.2 Design Experiment

It is required to design and implement a hardwired controller capable of fulfilling console operations. Combine the design schemes from different levels and perspectives with the specific implementation processes, conduct repeated deliberation, iterative refinement, and gradual distillation to ultimately form the design and implementation plan. Utilize simulation software tools for simulation implementation, debugging, and testing, and subsequently download the program to the hardware chip for actual debugging, running, and testing.

(1) Analyze the functional requirements of the hardwired controller, complete the overall block diagram design, logic module diagram design, console instruction flow chart design, machine instruction flow chart design, the number of clock cycles for instructions design, combinational and sequential logic function design. This controller is capable of performing console operations, including initiating program execution, reading memory, writing to memory, reading registers, and writing to registers; it can achieve the given instruction functions, and the instruction execution is correct, and the functions operate normally.

(2) Complete the coding using the hardware description language and apply simulation software for simulation implementation, debugging, and testing.

(3) Download the program to the FPGA hardware chip for debugging, running, and testing. Combine this hardwired controller with the data path of the TEC-PLUS model computer to realize a complete controller functional system.

Cultivate students' hands-on abilities, stress resistance, enhance the rigor of their thinking, and strengthen their striving spirit; based on various phenomena and problems that arise during the experimentation, encourage students to integrate the theoretical knowledge they have learned, contemplate the underlying causes and mechanisms, and provide reasonable and unique explanations, thereby fostering their thinking capabilities.

2.3 Innovative Experiment

For students with surplus academic capacity, they are required to improve the program flow and internal logical functions on the basis of the aforementioned design-oriented experiments, complete the pipeline design, address the hazard phenomena in the pipeline design, and propose solutions for the hardware design. Utilize open-source code analysis and modification modules to conduct research on the CPU and complete the entire analysis scheme; or design the CPU independently and execute multiple instruction formats.

Besides, students are encouraged to present their own thoughts and opinions, design logical functions independently based on the Tec-Plus system, and implement and verify them. Inspire students to optimize their designs, broaden their horizons, cultivate their innovative spirit, and enhance their innovative thinking and ability.

3 Teaching Methods

3.1 Heuristic Teaching

The combination of traditional teaching methods and advanced technologies is employed, with the intention of fully stimulating students' enthusiasm and facilitating their autonomous learning, collaborative learning, and research-oriented learning. This integrated teaching mode not only enhances students' practical capabilities but also elevates their innovative consciousness. During the specific implementation, the flipped classroom model and blended teaching approach are adopted. Teachers no longer consume a significant amount of class time for one-way lecturing; instead, they organize knowledge points, direct the learning orientation, and offer guidance on autonomous learning strategies, thereby granting more initiative to students. In this novel classroom setting, the precious class time is utilized more effectively, enabling students to concentrate more on active learning based on practical projects and engage in in-depth discussions and exchanges with teachers. Regarding students as the main body in teaching activities contributes to stimulating their intrinsic motivation and also enables teachers to establish clear and achievable teaching objectives for different modules [6].

To achieve this objective, with the support of diverse teaching methods, teachers will flexibly apply the most appropriate methods in consecutive teaching activities to fulfill the guidance, direction, and counseling during students' learning processes. Additionally, after the experiment, through the summary and discussion session, it can assist students in reviewing what they have learned, deepening their understanding, and consolidating their knowledge. Such summaries not only permit students to reflect on their experimental procedures but also prompt them to grasp the professional knowledge of the course in a holistic manner. This ensures that students can progressively recognize, understand, and master the relevant professional knowledge of the experimental course from simple to complex and from easy to difficult, laying a foundation for cultivating talents with a solid theoretical foundation and practical abilities.

3.2 Integration of Theory and Practice

The experimental content is fully integrated with the theory course, achieving a learning process from simple to complex, from cognitive verification to design innovation. In the specific implementation process, the self-top-down method is used for overall planning, and the complex system is decomposed into multiple manageable small units through module division. After each module is independently completed, it is implemented through circuits, and the functions of each subcircuit are correctly integrated together. This process emphasizes the strict testing and verification of each subcircuit function to ensure its normal operation. On this basis, further circuit cascading and system optimization are carried out. Cascading refers to connecting the verified subcircuits according to the predetermined logic to make the entire system have higher-level functions [2]. Optimization involves repeated evaluation and improvement of the existing design scheme to achieve goals such as improving performance, reducing energy consumption, or simplifying structure. This methodology not only helps students understand the electronic system design process, but also cultivates their rigorous thinking ability to solve real-world problems.

During the experiment, special emphasis was placed on stimulating and encouraging students to think deeply about the underlying causes of phenomena. For example, when a part of the circuit did not function as expected, the students were guided to analyze various factors that could have led to the phenomenon, including design flaws, chip characteristics, and external environment influences, and were required to provide plausible explanations. This inquiry-based learning approach not only enhanced students' problem-solving abilities but also promoted the development of their critical thinking, helping to form a comprehensive and in-depth knowledge system. Through such practical activities, students could solidify their grasp of relevant theoretical knowledge and apply it flexibly in actual engineering projects, laying a solid foundation for their future careers.

3.3 Integration of Production, Research, and Teaching

The transformation of production and research achievements into experimental teaching content constitutes an essential means to integrate theory with practice. This process encompasses not only practical operations but also incorporates virtual simulation technologies, enabling students to conduct exploration and experimentation within a safe and controllable environment [9]. Through this modality, students can acquire a more intuitive comprehension of complex scientific principles and repeatedly practice in a simulated setting, thereby enhancing their hands-on skills and problem-solving capabilities. Additionally, the combination of scientific research and practical teaching is conducive to enhancing students' awareness of the application of disciplinary knowledge. In the classroom, teachers can introduce the latest research projects or cases, enabling students to participate in the process of solving real problems. This sense of participation extends learning beyond textbooks to practical application domains, stimulating students' recognition of the application value of the knowledge they have acquired. Instructing students on scientific research concepts, scientific research culture, and the value of scientific research not only assists them in establishing a correct scientific perspective but also enables them to recognize the significance of scientific and technological innovation for social progress. It stimulates students' new interest in scientific research and guides them to contemplate how to apply their specialized knowledge to practical issues. Further, this educational model emphasizes the cultivation of good scientific ethics to ensure that future researchers possess a high degree of responsibility and ethical consciousness. On this basis, through continuous training, the comprehensive ability of students in scientific and technological innovation can be enhanced, enabling them to better confront future challenges and contribute to the advancement of national science and technology [11].

3.4 Hierarchical Teaching and Individualized Instruction

Progressive teaching content requirements are imposed on students of varying learning levels to satisfy the learning demands and development potential of all types of students. For those with a weak foundation, a series of sequential course contents are designed to assist them in consolidating the basic knowledge. In this process, through group discussions, practical operations, and individual tutoring, etc., their basic concepts and skills are strengthened, enabling them to master the core knowledge points while gradually being exposed to more complex problems, thereby achieving the improvement of their abilities [8]. For students with surplus learning capacity, after completing the basic design tasks, they are encouraged to conduct in-depth thinking and exploration. By introducing open-ended questions, innovative challenges, and other means, these students are not confined to superficial understanding but are able to analyze problems from multiple perspectives and propose unique opinions. This hierarchical and targeted teaching strategy can not only effectively enhance the comprehensive quality of all students but also promote each student to formulate a suitable learning path based on their own characteristics, thereby achieving the goal of individualized teaching and all-round development.

3.5 Individual and Team Combination

Basic verification experiments are required to be completed by individuals to guarantee that each student can think and operate independently. Design and innovation experiments are demanded to be carried out in a group development mode. While training students' engineering practical abilities and innovation capabilities, it enables students to establish teamwork communication and collaboration, and cultivate the awareness of jointly analyzing and solving problems.

3.6 Diversified Teaching Combining Online and Offline Modes

In-class hours are conducted offline, where teachers provide on-site theoretical knowledge guidance, design analysis, and solve problems encountered by students in the experimental process in real time. Out of class, teachers offer electronic teaching resources related to theoretical knowledge and conduct counseling and Q&A through instant communication tools.

4 Teaching Platform

The practical teaching relies on the TEC-PLUS model computer experimental platform, which is a Chinese patented product custom-designed by Beijing University of Posts and Telecommunications and manufactured by the Scientific and Educational Instrument Factory of Tsinghua University. The chip employed in the TEC-PLUS core board is the FPGA chip from the Spartan-6 series of XILINX, featuring high performance and flexibility and providing students with an ideal experimental setting. This platform not only offers robust technical support for this experiment but also establishes an excellent practical stage for enhancing students' engineering capabilities and innovative abilities.

The model computer adopts an 8-bit word length, presenting a simple yet practical structure that facilitates students in deeply comprehending the working principles of the entire model computer. During the experiment, binary test programs are manually inputted through 8-bit data switches, allowing students to grasp the fundamental mechanisms of computer operation from the bottom up. This bottom-up learning approach not only strengthens their mastery of basic knowledge but also nurtures their capacity for independent thinking and problem-solving. Additionally, the instruction system employs a 4-bit opcode, capable of accommodating 16 instructions, among which 14 typical instructions such as addition, subtraction, AND, storing, loading, etc., have been implemented. These functionalities enable students to directly perceive various basic operations and control flows during practical operations. To embody modern CPU design concepts, this platform utilizes dual-port memory as the main memory and realizes the instruction pipelining function, thereby enhancing the overall operational efficiency. Simultaneously, the controller section combines two types: the microprogrammed controller and the hardwired controller, to showcase the current state of computer control technology. The transition between the microprogrammed controller and the hardwired controller is carried out through a one-time full-switch mode, and the microcode stored in the PC can be downloaded into the system for debugging. This process enables students to better understand the differences between different types of controllers and their application scenarios. In the arithmetic unit, the ALU is implemented using two 74181 chips, while the four 8-bit register groups are accomplished with one EPM7064 chip. Such a design not only conforms to modern computer design principles but also enables the machine instruction timing to adopt variable-length machine cycles, enhancing system flexibility. Within the general area, multiple dual-inline package component sockets are provided, allowing the same system to employ programmable devices such as the Spartan-6 series FPGA either as a hardwired controller or for large-scale design experiments in the "Digital Logic and Digital Systems" course.

Through the utilization of the model computer experimental system, students can have a direct and intuitive experience of the working principles and processes of real computer systems. They can download the controllers they have designed and implemented onto the FPGA hardware board, verify their functions through experimentation, and further optimize and improve. This process concretizes abstract theories, thereby enhancing their sense of achievement in learning. Nevertheless, traditional hardware experiments also present certain limitations [3]. For instance, only the circuit results can be observed, while the internal processing process cannot be examined in detail, which may pose certain difficulties in debugging. Additionally, due to the requirement of a specific equipment room for experiments, the participation threshold is inadvertently raised. Furthermore, the human and financial costs associated with the maintenance of hardware equipment are relatively high. Therefore, the introduction of digital circuit simulation software (such as Multisim) emerges as an effective supplement, capable of overcoming the aforementioned shortcomings.

This practical teaching adopts the pattern of "giving priority to practice and integrating the virtual with the real", establishing an effective bridge between theory and practice. At the verification experiment stage, learning activities are carried out through simulation software, enabling students to debug more conveniently without being constrained by time and location [5]. This flexibility not only boosts students' participation but also allows them to practice repeatedly in diverse environments, thereby deepening their comprehension of key knowledge points. Meanwhile, the simulation software offers an intuitive feedback mechanism, facilitating students in rapidly identifying errors and making timely adjustments. This process significantly enhances learning efficiency and stimulates their enthusiasm for exploring unknown fields. In the design and innovation experiment stage, students are encouraged to develop a hardwired controller using hardware description language initially. Through this procedure, students can apply the theoretical knowledge they have acquired to practical issues, deepening their understanding of the synergy between hardware and software. On this basis, they can utilize simulation software for debugging. This stage enables them to observe the system behavior in real-time, analyze the running results, and promptly identify potential problems. Through this method, not only is their problem-solving ability enhanced, but also a meticulous and rigorous work attitude is cultivated. Eventually, when all the achievements have undergone thorough testing, students download them to the model computer system for verification. This step not only constitutes a test of their previous efforts but also enables them to experience the significance of the entire engineering process from conception to implementation. Such experiences assist them in understanding the importance of "hardware and software coordination" more profoundly and promote the expansion of their comprehensive perspective, enabling them to realize how various components interact and collaborate to accomplish complex tasks. Additionally, throughout this process, students will also come into contact with multiple skills such as project management and teamwork.

In conclusion, this current practical teaching model has not only effectively enhanced the learning effect in the classroom by integrating the virtual and the real but also laid a certain foundation for cultivating talents with comprehensive qualities, playing a crucial role in shaping students' ability to address complex engineering problems.

5 Conclusion

The course "Computer Organization and Structure" poses a more significant challenge to students majoring in software engineering who have insufficient prerequisite courses, due to its high difficulty level and the abstract nature of its concepts and principles. This course encompasses the fundamental components of computer systems, their working principles, and the interrelationships among various components. These contents typically demand that students possess a certain amount of foundational knowledge for in-depth comprehension. Hence, it is of paramount importance to establish an excellent practical teaching system that can support theoretical teaching to the fullest extent and materialize abstract principles and concepts through experiments. Such practical activities not only assist students in deepening their understanding of theoretical knowledge during practical operations but also enhance their interest in the learning content and stimulate their learning impetus.

In the subsequent teaching process, the principle of centering on students will be adhered to. The practical teaching system will be continuously adjusted, improved, and optimized based on the actual circumstances of different student groups to render it more rational and effective. Simultaneously, the practical teaching links will be constantly evaluated and reflected upon. Existing problems will be identified and resolved promptly, thereby continuously elevating the teaching quality. The aim is to cultivate engineering-oriented and innovative software engineering talents and provide high-quality human resource support for the development of the industry. During this process, attention should not only be paid to the development of technical skills but also to the cultivation of students' comprehensive qualities such as active thinking, teamwork, and communication abilities, in order to adapt to the talent standards required in the rapidly evolving field of information technology.

References

1. Wang Yingfeng, Yang Chengbo et al. Research and Discussion on the Experimental Teaching of "Computer Organization Principles". Theoretical Research, 2023 (07): 119-121.
2. Qiao Daoshi, Liang Zhijian. Exploration of "Computer Organization Principles" Teaching Reform with "Practice-Oriented and Integration of Real and Virtual" Approach. Win the Future, 2023 (1): 110-112.
3. Li Zhenxiang, Wang Jialiang. Practice and Implementation of CPU Simulation Based on Dream Logic. Computer Education, 2023 (9): 192-200.
4. Wang Hairui, Pan Shengmin et al. Teaching Reform of "Computer Organization Principles" under the Background of Domestication. Software Journal, 2023 (6): 70-74.
5. Xiao Juan, Zhang Wenwu, Wang Song et al. Application of Virtual Experiment System in the Reform of Computer Organization Principles Experimental Teaching. Computer Education, 2014 (14): 33-36.
6. Tian Huifeng. Research on the Experimental Teaching System of "Computer Organization Principles" with the Combination of Virtual and Real and the Coordination of Hardware and Software. Software & Applications, 2023 (08): 57-59.

7. Li Li, Yang Shuang, Su Yuting. Construction of Experimental Teaching System with Integration of Virtual and Real for "Computer Organization Principles". Computer Education, 2023 (6): 184-188.
8. Zhang Qian, Ji Shaochi, Xu Shiyu. Design of Blended Teaching Model for "Computer Organization Principles" Course. Education and Teaching Forum, 2023 (11): 161-164.
9. Chen Zhi'min. Exploration of Computer Organization Principles Experimental Teaching Based on Multi-Si Network Virtual Experiment System. Science and Education Journal, 2023 (13): 104-106.
10. Qi Wenqing, Li Xiaoqin, Yan BoWu. Teaching Reconstruction of "Computer Organization Principles" Course Based on OBE Concept. Journal of Hubei University of Science and Technology 2023(2):59-63
11. Chen Zhigang, Liu Haoxha, Lu Yutong. Reform and Practice of RISC-V Computer Organization Principles Experimental Teaching. 2023(2):128-132
12. Fan Yanen, Zhang Junxia. Exploration of Computer Organization Principles Experimental Teaching with Integration of Discipline Competition and Course Design. Software Guide 2023(6):1182-186