Research on 3D Virtual Simulation Experiment Teaching of *Principles of Computer Organization*

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Abstract. In the study of the course of *principles of computer organization*, experiment plays a crucial role in understanding and mastering theoretical knowledge. Offline experimental teaching by operating the experimental box is often limited by time and venue, and it is difficult to correct errors after students make mistakes. Aiming at this problem, the online experimental teaching of the *principles of computer organization* is explored. Based on 3D virtual simulation experimental platform, from the perspective of case design, students not only can master the course knowledge more intuitively and thoroughly by personalized experimental projects, but also can achieve the goal from understanding and analysis to independent designing. This model could solve the problems caused by the limitations of traditional experimental teaching effectively. 3D virtual simulation technology makes the experimental scene realistic, which is conducive to the demonstration of abstract teaching content. The experimental scenes constructed through animation are rich and varied, which can improve students' interest in learning.

Keywords: principles of computer organization · experimental teaching · 3D virtual simulation · case design

1 Introduction

The Principles of Computer Organization is the basic core course for computer majors which are also the unified examination course for the national postgraduate admissions examination. It plays a key role in connecting the previous and the next in the computer professional knowledge system. By studying the composition and internal operating principles of the various hardware components of the computer, students will establish the concept of the complete computer and have the ability to analyze and design computer systems [1]. The course is very theoretical and the concept is relatively abstract. It is difficult for students to understand and master the knowledge only by the teachers in the theory course, so the experimental course in the teaching is particularly important [8]. In the teaching of computer majors, the cultivation of students' practical ability is very important. The experimental course plays a pivotal role in improving the comprehensive quality of students. For the course of Principles of Computer Organization, through different experimental contents, students can fully understand the internal operating mechanism of various computer components under actual hands-on operation. This can

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deepen their understanding of theoretical knowledge. The combination of theoretical knowledge and practice can further improves students' practical ability and innovative design ability, laying a solid foundation for further studies. As an important link and key component of the whole course, the experimental course of Principles of Computer Organization has been paid more and more attention by teachers and students.

2 The Current Situation and Existing Problems of Experimental Teaching of Computer Courses

For the students majoring in computer science, both software and hardware courses will be offered, but the focus will be different. For software language courses, such as Java programming, Python programming, etc., offline experimental teaching can easily achieve a seamless connection with online experimental teaching. For hardware courses such as the Principle of Computer Composition, traditional experimental teaching often uses the way that students go to a special laboratory to use special experimental equipment to conduct experiments. Therefore, after transferring to online teaching, the experimental link becomes difficult to carry out. In addition, the current teaching methods of experimental courses on the Principle of Computer Composition in most colleges and universities mainly use hardware description languages such as Verilog on the simulation platform Quartus II to complete the simulation design of various experimental modules and model machines [2]. Then the students connect wires on the experiment box, burn the program to the FPGA chip, and complete the design and verification of the project by flipping the control switch finally. This experiment mode has certain drawbacks. For example, some experiment content requires a lot of hardware connections. Students are prone to errors and difficult to troubleshoot during operation. Students are not willing to spend time on studying hardware description language. Coupled with the shortage of experimental equipment and the limitation of laboratory opening hours, the actual hands-on design and operation time of students is greatly shortened, which cannot meet the needs of students' learning. Therefore, it is urgent to explore the online experiment platform of the Principle of Computer Composition course.

Virtual simulation experiment [6] is the use of virtual reality, multimedia, human-computer interaction and other technical means to build a highly simulated virtual reality environment and experimental objects on a computer. Students can simulate the real environment and conduct experiments in this environment according to their own needs. Compared with traditional experiments, virtual simulation experiments are not restricted by time and space, and have low cost. Through the simulation and virtualization of the teaching environment, operation process and verification process involved in experimental teaching, students can conduct experimental learning in the virtual experimental teaching environment. The virtual simulation experiment builds a bridge of communication between theory and practice, software and hardware [5, 7]. Relying on the virtual simulation experiment platform to carry out the experimental teaching of the Principle of Computer Composition can effectively improve the effect of experimental teaching, and cultivate students' interest in learning and independent innovation ability.

At present, the literature on the application of virtual simulation experiment platform to the construction of the Principle of Computer Composition experiment course is endless [4], but most of them are discussed around the architecture design and implementation of the experimental platform. This technology is very mature now. The focus of the construction of experimental courses lies in how to design personalized experimental cases with students as the center, so as to make students willing to learn, take the initiative to learn, so as to deeply understand and master knowledge, and improve their own comprehensive quality and innovation ability [3, 6]. In response to this problem, this article starts from the perspective of a case and designs a specific virtual simulation experiment project of the Principles of Computer Organization to make it easier for students to master the course and form a certain degree of computer professionalism, independent learning ability and the ability to solve practical problems.

3 The 3D Virtual Simulation Experiment Teaching Project Planning of Principles of Computer Organization

Based on the von Neumann computer, we take the representation and storage of data in the computer as a starting point; study the working principle of each component. Through communicating with each component by instructions and buses, we break the traditional experimental teaching mode and use virtual technology to simulate the working principles of the various components of the computer for experimental teaching which provides an effective way to improve students' interest and learning motivation. The effective combination of virtual experiment teaching and theoretical knowledge teaching can not only stimulate students' experimental interest, cultivate students' open thinking, exercise students' active ability, but also cultivate teachers' open teaching ability and continuous learning consciousness in order to adapt the randomness, innovation, and openness of the teaching platform.

Focusing on the theoretical teaching of the Principle of Computer Composition course, the virtual simulation experiment consists of five experimental projects: data representation and operation, memory system, input and output system, CPU design, and instruction system, as shown in Fig. 1. Experimental projects witch from principle verification, design to comprehensive application, enable students to carry out independent design and comprehensive application on the basis of understanding the working principles of computers, so as to master the working principles of computers and cultivate students' innovative experimental ability.

The theoretical part of principles of computer organization course is explained from general overview to the specific components. Therefore, the experimental setting also follows this principle. For more complex and comprehensive experimental projects, the students' understanding and mastery level can be improved by increasing the number of class hours. Table 1 shows the class schedule of the virtual simulation experiments.

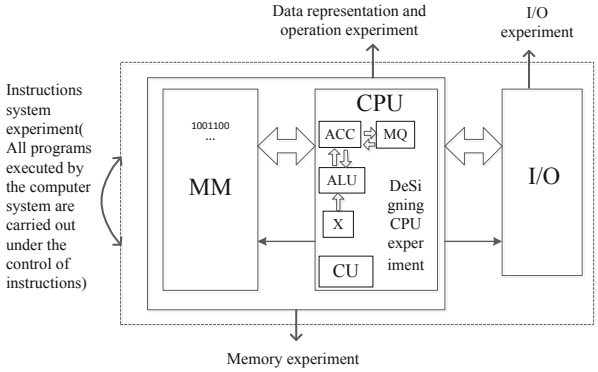

Fig. 1. Five virtual simulation experiments of principles of computer organization

Table 1. Class schedule of virtual simulation experiment of principles of computer organization

No.	Knowledge point	Virtual simulation experiment	Class schedule
1	Original code, inverse code, complement code representation and corresponding operations	Data representation and operation experiment	2 class hours
2	Storage capacity expansion, data exchange with CPU	Memory experiment	4 class hours
3	Interrupt controller	I/O experiment	2 class hours
4	The structure and working principle of CPU	DeSigning CPU experiment	6 class hours
5	Interpretation instructions system	Instructions system experiment	4 class hours

4 Teaching Case of Virtual Simulation Experiment of Principles of Computer Organization

Taking the memory experiments as an example, the design and analysis are carried out one by one from four parts: experimental purpose, experimental principle, experimental design, and experimental result verification and evaluation. The main page of the virtual simulation experiment platform is shown in Fig. 2.

4.1 The Purpose of the Experiment

Through this experiment, students should master the following three aspects:

a) Understand the basic structure of semiconductor memory.

b) Master the principle of reading and writing RAM and ROM.

c) Design the memory that meets the requirements and realize the correct connection with the CPU.

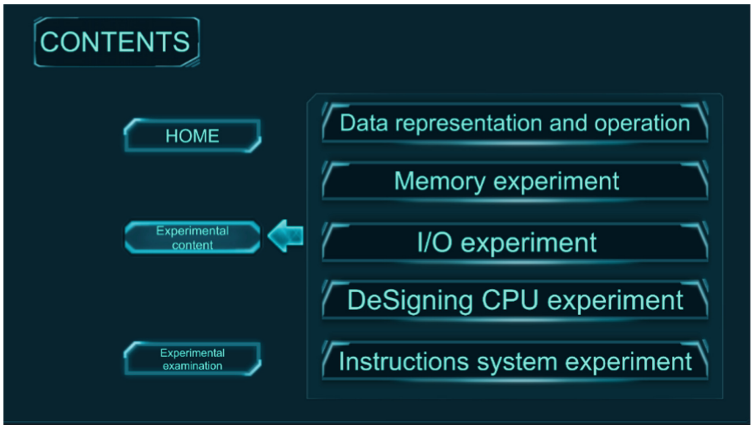

Fig. 2. The virtual simulation experiment platform

4.2 Experimental Principle

The classification of semiconductor memory, the working principle of RAM and ROM, and the structure of memory chips are explained one by one.

Students open virtual computer case and see various components that make up the computer intuitively, and then locate the memory part. The memory part is a kind of semiconductor memory which used to store programs and data, and plays a very important role in the working process of the computer. Then the classification of semiconductor memory is introduced. It is divided into two categories according to the function which is read-only memory (ROM) and random access memory (RAM). RAM is readable and writable and is often used to store data and intermediate results. Information in RAM will be lost when power is turned off. The content in ROM can only be read. Information in ROM can be permanently stored and will not be lost due to power failure. ROM is often used to store system programs or data that cannot be easily changed. Figure 3 shows the basic structure of the memory chip.

Through dynamic circuit diagrams, the working principles of static RAM and dynamic RAM are shown intuitively. So that students can understand that static RAM stores information through the working principle of flip-flops, while dynamic RAM stores information by storing electric charge on capacitors.

The memory chip is connected to the CPU through the bus, and the CPU sends the address of the memory unit to be accessed through the address bus. After decoding by the decoding drive circuit, a memory unit in the memory matrix is selected. CPU sends out a control signal through the write or read bus. Under the control of the read or write control circuit, the data in the selected memory cell is read and written.

The scene shows that there is a chip selection bus between CPU and memory. What is the purpose of the chip selection bus? This will guide students to think how to expand when the capacity of a single memory chip cannot meet the storage needs. This is called the expansion of storage capacity. The function of the chip selection bus is to determine on which memory chip the memory unit corresponding to the address sent by the CPU is located.

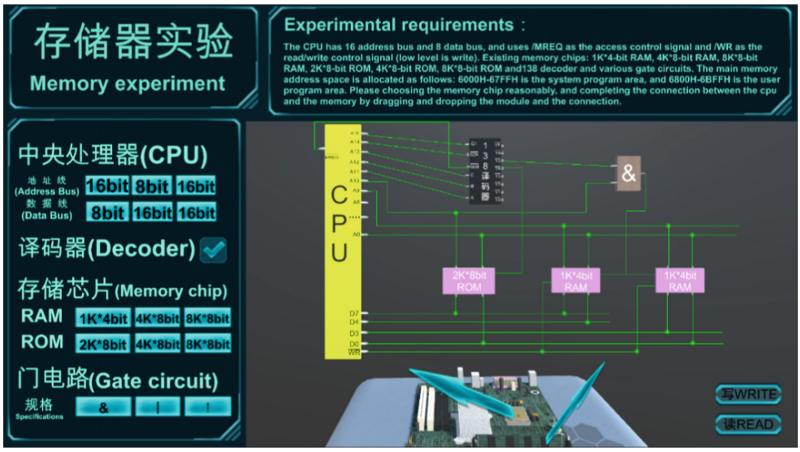

Fig. 3. Memory experiment

The expansion of storage capacity is divided into word expansion, bit expansion, and simultaneous expansion of words and bits. The principle of each expansion method is shown through animation examples (bit expansion is to increase the word length, such as two 1K*4-bit memory chips to form a 1K *8-bit memory. Word expansion is to increase the number of words, such as two 1K*8-bit memory chips to form a 2K*8-bit memory).

4.3 Experimental Design

After mastering the working principles of RAM and ROM, students enter the design module and given a number of memory chips, CPU, etc. Students build the host in the form of building blocks by pulling the modules. They will understand the classification of memory, the storage principle and the method of storage capacity expansion. Then it's time to enter the students' independent design link.

According to the specific subject requirements, the memory composed of multiple memory chips can be correctly connected to the CPU by dragging and dropping. First, the known elements and optional drag and drop modules are given as follows: memory access control signal/MREQ, read/write control signal/WR, address bus, data bus, memory chips of different capacities, including RAM and ROM, some related circuits, 138 decoder, grounding and connecting signals. Students should pay attention following points when designing: ROM chips are usually used in the system working area, and RAM chips are usually used in the user working area. Students make connections (green lines) according to specific experimental requirements. The final result is shown in Fig. 3.

4.4 Validation and Evaluation of Experimental Results

Students write data to the corresponding storage address of the host design, and then read the data for verification.

Fig. 4. Verification module for memory experiments

After the student has connected the memory to the CPU, how can they verify that the design works correctly? This is the examination stage. The general idea is to write a piece of data into the specified memory unit, and then read out the contents of the memory unit. If the written and read contents are consistent, the experiment is passed. In addition, there is a summary module at the end, through which students can give feedback on the experience of this experiment. Teachers can keep abreast of students' mastery. The final verification result is shown in Fig. 4.

5 Conclusion

The traditional experimental teaching of principles of computer organization has drawbacks such as site and equipment limitations, and students' operation errors. In addition, due to the impact of the COVID-19, offline experimental teaching has become difficult to carry out. In view of the above two problems, the virtual simulation experiment platform applied to the online experiment teaching is very necessary. From the perspective of case design, taking one of the most important experiments in the principles of computer organization course——memory experiment as an example, the whole experiment is analyzed and designed. Relying on the virtual simulation experimental platform to carry out the experimental teaching of principle of computing organization can effectively improve the effect of experimental teaching. In the intuitive and visual guidance, students can combine theoretical knowledge with practice closely through immersive learning and understand the concept of the whole computer system in-depth. This not only provides a good teaching mode for the online experimental teaching of the principle of computing organization, but also cultivates students' learning interest and independent innovation ability, which is worth spending time and energy for further exploration and research.

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