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Exploration of Reforming Experimental Modes in Computer Hardware Courses for Engineering Accreditation

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Abstract—*With the aim of achieving engineering education specialization certification, efforts were made towards integrating experiments in key hardware-focused computer courses. Course experiment mode reform was implemented for digital electronics technology and computer architecture principles. This included the completion of integrated designs for experiment objectives, content, and platforms. The outcomes of experimental work from prerequisite courses were extended and applied to subsequent ones, aiding students in constructing a comprehensive knowledge system and structure of computer systems. Experiment reform expanded both the scale and difficulty of experiments, enhancing students' abilities in innovative design and solving complex engineering problems, thereby elevating their proficiency in computer systems.*

Keywords— *Computer hardware courses; Virtual simulation; Engineering accreditation; Integration of experimental systems*.

I. INTRODUCTION

"The Washington Accord" is currently the most internationally recognized and authoritative agreement for the mutual recognition of undergraduate engineering education. China officially became its member in June 2015 [1]. Engineering education promotes a shift from a "knowledge-oriented" to a "competency-oriented" approach by examining the rationality of professional training objectives and the effectiveness of their implementation. Since 2006, China has launched pilot projects for engineering education program accreditation. The main features of engineering education program accreditation include international equivalence, goal orientation, competency focus, and continuous improvement. Unlike undergraduate education assessment, engineering program accreditation emphasizes outcomes and pays more attention to what students have learned and can do. It particularly emphasizes students' ability to solve complex engineering problems, strengthens the linkage mechanism between talent cultivation and the industry, and enhances adaptability to industrial development [2].

This guiding principle places practical components in a more important and prominent position, serving as a crucial means of assessing the effectiveness of theoretical teaching [3][4]. Courses related to computer hardware are integral parts of computer science programs, characterized by strong practicality and engineering applicability [5][6][7][8]. Thoughtful planning of laboratory projects is essential for improving the quality of hardware courses and fostering students' innovative design skills and understanding of computer systems. Currently, most of the computer hardware course experiments at our university are validation-oriented and involve simple design tasks. While small-scale experiments may help students achieve a basic understanding and mastery of fundamental principles and develop preliminary system development skills, the lack of sufficient engineering scale and complexity often conceals deeper issues present in complex systems.

II. REFORMING COMPUTER HARDWARE COURSE EXPERIMENTS FOR ENGINEERING ACCREDITATION

Our university has traditionally adopted separate experiment box models for digital electronic technology experiments and computer architecture experiments. This component-separation approach leads to low reliability, difficult debugging, challenging acceptance, high costs, and requires extensive space. Moreover, these experiments tend to focus more on verification than on design, thus failing to cultivate students' abilities to solve complex engineering problems and understand computer systems. Each experiment is designed as an independent unit without integration, neglecting the potential for effectively integrating these experimental outcomes into a complete computer system. There is a lack of systematic planning at the system level, hindering students from developing a holistic understanding of computer systems. Therefore, we aim to decompose the experimental content with whole-machine design as the ultimate goal, determining specific experimental content and projects for digital electronic technology and computer architecture courses. This will form a comprehensive experimental system, achieving the integrated goal of the two core hardware courses' experimental teaching system.

A. *Integrated Design of Computer Hardware Course Experiments*

Following the system design philosophy of 'progressive levels, synthesized systems,' we unify the planning and design of experimental projects for digital electronic technology and computer architecture courses. The digital electronics technology experiments mainly revolve around constructing various functional components needed inside the CPU (Central Processing Unit). Specifically, this includes the combinational logic circuit section (such as decoders, data selectors, adders, encoders, etc.) and the sequential logic circuit section (such as flip-flops, registers, counters, memories, etc.). These functional components serve as a foundation for subsequent experimental work in computer architecture principles courses.

Furthermore, to further enhance students' ability to solve complex engineering problems, we include at the end of the course experiments some moderately scaled and complex digital system designs and implementations, such as traffic light systems, intelligent vending machine systems, electronic clock systems, holiday decorative light systems, and so on. The comprehensive design section not only increases the academic challenge but also stimulates students' motivation to learn and their professional interest, allowing them to gain a sense of accomplishment. Additionally, considering that second-year students are just beginning to engage with hardware, the difficulty level should not be too high to avoid dampening their enthusiasm for learning hardware-related courses. By reasonably increasing the scale and difficulty of the design, we aim to enhance students' comprehensive application of knowledge, improve their innovative design skills, and enhance their ability to solve complex problems, thereby further developing students' computer system capabilities.

The results of digital electronics technology experiments are extended and applied to computer architecture principles laboratory projects, achieving seamless continuity from logic gates to CPU. The computer architecture principles experiments are based on the functional components developed in digital electronics technology experiments, focusing on constructing a MIPS CPU capable of supporting operating system operation. This includes designing the ALU (Arithmetic Logic Unit), memory, controller, single-cycle CPU, multi-cycle CPU, and five-stage pipelined CPU.

B. Unified Experiments Platform for Core Hardware Courses

In digital electronics technology experiments, we employ a strategy of combining physical and virtual elements. The first approach involves using physical experiment kits, allowing students to directly interact with chips and integrated circuits, providing them with a sensory understanding. The second approach utilizes virtual simulation software like Logisim, breaking free from the spatial and temporal constraints imposed by physical experiment kits. This approach enables a blended teaching mode that combines in-class and out-of-class learning as well as online and offline activities.

Logisim adopts a schematic design approach, which is simple to learn, easy to debug, and incurs zero experimental costs. It effectively extends the time available for experiments and supports sub-circuit encapsulation. This approach sidesteps the issues of overly abstract hardware description languages and overly procedural hardware design, thereby facilitating the development of students' hardware design thinking. Logisim's experimental results are visually intuitive, as shown in Figure 1, which greatly stimulates students' interest and motivation in experiments, thereby enhancing the effectiveness of course experiments.

In computer architecture principles experiments, we also make use of the Logisim virtual simulation environment. By utilizing a unified experimental platform, students can avoid the need to familiarize themselves with the experimental environment again, allowing them to devote more time and energy to CPU design. Computer systems are highly complex, with computer architecture principles experiments playing a pivotal role as a bridge between different components. On the one hand, computer architecture principles experiments utilize the results of digital electronics technology experiments. On the other hand, the CPUs designed in computer architecture principles experiments can serve as a foundation and preparation for experiments in operating systems and compiler principles courses.

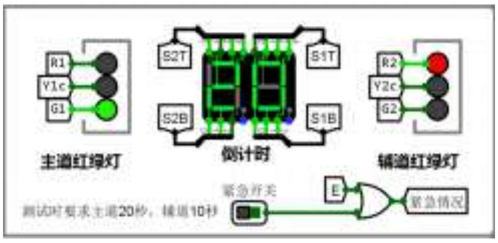

Fig. 1. Demonstration of Logisim experiment results

Our university has introduced a comprehensive digital system design training course between the courses of digital electronics technology and computer architecture principles. This course primarily utilizes the hardware description language Verilog to complete various digital circuit designs and employs Xilinx's Vivado integrated simulation environment. Therefore, in computer architecture principles experiments, we require students to implement using Verilog language. The experimental results can be verified using Xilinx's FPGA experimental board Nexys 4 DDR (as shown in Figure 2), as well as using Vivado's simulation functionality (as shown in Figure 3). This experimental mode is not limited by space and time constraints. The Nexys4DDR development board is compact and easy to carry, allowing students to conduct experiments anytime and anywhere. Additionally, on the Learning Platform, we provide students with many specific case explanation videos for learning and reference. In the future, we also plan to further apply this experimental platform to experiments in operating systems and compiler principles courses, thereby truly achieving the integration of the entire system core course experimental platform.

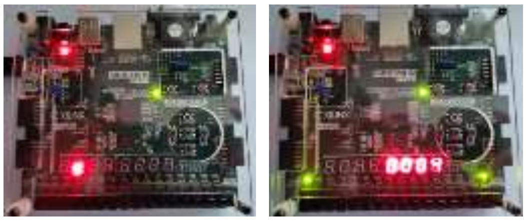
Fig. 2. Demonstration of experiment results using Nexys 4 DDR Board


Fig. 3. Demonstration of simulation results using Vivado

C. Enhanceing Experiment Scale and Difficulty Using Virtual Simulation Environments

In our university, the digital electronics technology experiment course only consists of 18 class hours, resulting in insufficient hardware experiments and inadequate cultivation of students' hardware design and innovation abilities. To address this issue, we make full use of spare time and utilize the Logisim virtual simulation environment to enhance the scale and difficulty of experiments. During class time, basic verification experiments and simple design experiments are mainly conducted using physical experiment kits. After class, students are required to utilize the Logisim virtual simulation environment to design complex digital circuits of specific scales. They then upload their design results to the Educoder online virtual training platform for automated evaluation. Within the Educoder platform, we decompose complex problems into several smaller ones, much like advancing levels in a game. Upon completing one level, students proceed to the next, providing them with timely feedback akin to the experience of clearing game stages. This experimental mode greatly stimulates students' interest in experimentation and encourages a spirit of continuous exploration.

Problem-Based Learning (PBL) is a comprehensive method centered around students and guided by problems to design learning scenarios. Following the principles of PBL, we meticulously design each experiment project guided by problems, employing a strategy of breaking down complex digital systems into manageable parts. This approach allows for gradual and progressive development, fostering students' computer system capabilities step by step. We allocate scores reasonably for each experiment point and place the experiment tasks on the Educoder platform for students to complete. Simultaneously, to assist students in successfully completing the tasks, detailed experiment manuals and essential explanatory videos are provided on the Educoder platform.

In computer architecture principles experiments, we extend the results of digital electronics technology experiments to computer architecture principles experiment projects, achieving continuity from logic gates to CPUs. We also utilize a unified experimental platform, leveraging the Logisim virtual simulation environment and the Educoder platform. In order to provide students with a more practical experimental experience closer to the actual industry demands and better prepare them for entry into the industrial field, we require students in computer architecture principles experiments to simultaneously use the hardware description language Verilog and Xilinx's Vivado integrated simulation environment to complete relevant experiment projects. Verilog supports parallel description, enabling students to better understand and implement concurrent systems, which is crucial for learning computer architecture principles. Xilinx is one of the leading manufacturers in the FPGA field, and using Xilinx tools and the Verilog hardware description language is a practice that aligns with industry standards. Through this practice, students can more easily adapt to and integrate into related industries. This practical component not only helps students deepen their understanding of computer architecture principles but also provides skills training consistent with industry standards and practical applications.

III. METHODS OF EXPERIMENT ASSESSMENT

The digital electronics technology experiment adopts a strategy of dual-line intersection and integration of virtual and physical components. Consequently, the final experiment score includes offline experiments using physical experiment kits, experiment reports, online experiments on the Educoder platform, and the final exam. Offline experiments are conducted in groups of two students each, and based on the completion of experiments and responses to questions from the experiment teacher, each group receives a score for offline experiments (which accounts for 20% of the total score). The experiment report, in addition to detailing the experiment principles, steps, and results, requires each student to provide personal insights and reflections on the experiment. The score for the experiment report is based on its content and format (also accounting for 20% of the total score). Online experiments on the Educoder platform are completed using Logisim. Experiment teachers can directly export students' online experiment scores from the Educoder platform (which also accounts for 20% of the total score). The final exam score (40% of the total score) includes in-class quizzes using the physical experiment kits and a comprehensive test on the Educoder platform, each comprising half of the final exam score. The in-class quizzes using the physical experiment kits take place during the 18th week of class, where the experiment teacher provides 5-6 different-level quiz questions, and students choose one to complete based on their own circumstances. Their scores are determined based on their completion of the experiments and their responses to the experiment teacher's questions. The comprehensive test on the Educoder platform consists of 3-4 more challenging and comprehensive questions related to complex digital system designs, and students have one week to choose one question to complete. Efficiency points and scores for each level can be set, and based on the time spent and the progress made by the students, the platform automatically generates a comprehensive test score.

The computer architecture experiment utilizes both the Logisim virtual simulation environment and Xilinx's Vivado integrated simulation environment. Consequently, the final experiment score includes online experiments, experiment reports, and comprehensive design. Online experiments are conducted on the Educoder platform using the Logisim virtual simulation environment, and the experiment teacher can directly export students' online experiment scores from the platform (accounting for 30% of the total score). Experiment reports document the principles, steps, and data processing of each experiment. Additionally, each student needs to provide personal insights and reflections on the experiment. The score for the experiment report is based on its content and format (accounting for 20% of the total score). Comprehensive design tasks are assigned in the 17th week, giving students one week to use the Vivado integrated simulation environment to complete the design of a five-stage pipeline MIPS CPU, considering relevant controls. Students are required to work in pairs, develop a design plan, and present their results in the form of a PPT during the 18th week class. Based on the completion of the design and presentation, students receive a score for comprehensive design (accounting for 50% of the total score). The comprehensive design helps foster students' teamwork and problem-solving skills.

Using the Educoder platform, the experiment teacher can also track the completion time, completion rate, pass rate, and timeliness of each assessment point for each experiment project. This allows for further analysis of whether the skill development meets standards, if the experiment design is appropriate, and if the course learning is effective.

IV. EFFECT OF REFORM IMPLEMENTATION

In our digital electronics experiments, we retained the traditional experiment box mode to expose students to real hardware devices; and expanded the use of the virtual simulation platform Logisim on this basis. Comparing the two experiment modes, students generally find that the Logisim platform is more efficient than the experiment box method, enabling more complex digital system designs and providing a sense of accomplishment. The computer architecture experiments based on the Logisim virtual simulation platform further allow students to experience the separation of hardware design and implementation. Students can run the design principles on the simulation platform before implementing them on Xilinx's FPGA experiment board Nexys4 DDR, greatly enhancing design efficiency, and also providing a differentiated choice for students who are unwilling to learn FPGA development.

The reform of digital electronics technology and computer architecture experiments has achieved good results. Students generally feedback that this is one of the experiments in the university stage that closely aligns with the teaching content, effectively improving the efficiency and scale of experimental design, helping students establish a good hardware design mindset, and deepening their understanding of theoretical knowledge in the course. The reformed experimental projects are progressive and incrementally challenging, with high completion rates and a strong sense of achievement, meeting the requirements of engineering education certification and contributing to the cultivation of computer system capabilities. The reform of the experimental mode has greatly stimulated students' enthusiasm for experimentation, learning, and innovation. Through the automated evaluation of the EduCoder platform, it has significantly reduced the workload and pressure on experimental teachers.

V. CONCLUSIONS

Following the systematic design principle of "progressive hierarchy, synthetic system," the integrated design of digital electronics technology experiments and computer architecture experiments has been achieved, including the integration of experimental objectives, content, and platforms. The reform of the experimental mode adopts a strategy of dual-line crossover and virtual-real integration, allowing students to interact with hardware devices while increasing the scale and difficulty of the design. By utilizing the game-style challenge mode of the EduCoder platform, students' interest and enthusiasm for experimentation are greatly stimulated, helping them overcome the fear of "soft but not hard" mentality. The decomposition of complex digital systems and the strategy of tackling them one by one, progressively deepening layer by layer, gradually cultivate students' ability to solve complex engineering problems and computer system capabilities, meeting the requirements of engineering education professional certification.

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REFERENCES

[1] Jiang, Zongli. "Characteristics and Comparison of Engineering Education Accreditation Indicators and Evaluation." Chinese Universities Education, no. 1, pp. 36-38, 2009.

[2] Dai, Hongling, Hu, Fengping, Peng, Xiaoming. "Construction and Practice of Professional Practice Teaching System from the Perspective of Engineering Education Accreditation." Experimental Technology and Management, no. 11, pp. 225-228, 2017.

[3] Zhang, Fujia, Sun, Danfeng, Zhao, Jianyong, Lin, Fei, Li, Ertao. "A Teaching Method for Computer Hardware Courses." Laboratory Research and Exploration, vol. 38, no. 5, pp. 151-154, 2019.

[4] Li, Runzhou, Kang, Lei, Song, Caili. "Exploration of Computer Hardware Course Experiment Reform Oriented to OBE." University Education, no. 3, pp. 98-100, 2020.

[5] Chen, Jiazhen, Wu, Weimin, Zheng, Zihua, Ye, Feng, Lian, Guiren. "Integration Design of Computer Hardware Course Experiments Based on EDA Technology." Laboratory Science, vol. 24, no. 1, pp. 120-122,126, 2021.

[6] Mao, Yanyan, Feng, Yanli, Xie, Qingsong, Cheng, Dapeng, He, Kai. "Systematic Ability Cultivation of Computer Majors under the Background of New Engineering." Computer Education, no. 7, pp. 50-53, 2019.

[7] Han, Jiandong, Gao, Jiawei, Zhang, Xia, Li, Ru. "Research on Digital Logic Design Teaching from the Perspective of Systematic Ability Cultivation in New Engineering." Computer Education, no. 3, pp. 135-138, 2021.

[8] Li, Lili. "Research on the Reform of Digital Logic Course Teaching Mode Oriented to Computer Orientation." Journal of Jining Normal University, no. 3, pp. 49-51, 2022.