Teaching Reform of Digital Logic Circuit Course: An Innovative Exploration from Theory to Practice

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Abstract: This paper explores the teaching reform of the Digital Logic Circuit course in the context of emerging engineering education. The reform optimizes teaching content by integrating new technologies like FPGA and HDL while streamlining traditional parts. Diverse teaching methods, including heuristic, project - driven, and blended teaching, are adopted to boost students' enthusiasm and comprehensive abilities. Practical teaching is enhanced through well - designed experiments and simulation software. Looking forward, the reform will further update teaching content with the latest digital trends, integrate modern educational technologies, strengthen enterprise cooperation, and engage in international exchanges. Overall, this reform aims to cultivate high - quality engineering talents with innovation and practical skills.

Keywords: Digital Logic Circuit; Teaching Reform; Teaching Method Innovation; Practical Teaching

1. Introduction

In the era of rapid technological development, digital technology has been deeply integrated into various fields of society. From the smartphones and computers used in daily life, to the automated control systems in industrial production, and then to the 5G technology in the communication field, digital logic circuits, as the foundation of digital systems, are of self - evident importance. For students majoring in computer science and technology, the Digital Logic Circuit course is a crucial professional basic course, occupying a pivotal position in the entire curriculum system.

However, with the advancement of the emerging engineering education, higher requirements are put forward for engineering education [1]. The emerging engineering education emphasizes being guided by industrial needs and cultivating diversified and outstanding engineering talents with innovative ability, practical ability, and interdisciplinary thinking. To some extent, the traditional teaching mode of digital logic circuits is difficult to meet the needs of the emerging engineering education, and there are many problems. In terms of teaching content, some of the teaching content is outdated, failing to reflect the latest development achievements of digital technology in a timely manner and being divorced from practical engineering applications. In terms of teaching methods, the traditional indoctrination - based teaching method, with teachers as the main lecturers, puts students in a passive learning state [2]. Students lack initiative and enthusiasm for learning, and it is difficult to stimulate their innovative thinking and practical ability. In the experimental teaching link, the experimental content is often too simple, with a large number of verification - based experiments and few comprehensive and design - based experiments, which cannot effectively cultivate students' ability to solve practical problems.

Therefore, it is of great practical significance to carry out teaching reform on the Digital Logic Circuit course.

2. Analysis of Problems in the Digital Logic Circuit Course

2.1 Disconnection between Theory and Practice

In traditional digital logic circuit teaching, the disconnection between theory and practice is quite prominent, seriously affecting students' understanding of knowledge and the cultivation of their application ability [3,4]. Take the teaching of the Digital Logic Circuit course for computer science and technology majors as an example. In the experimental course, when students conduct experiments on combinational logic circuits, they often just connect various gate - circuit chips according to the steps in the experimental instruction manual to achieve a specific logical function, such as designing a simple three - person voting machine circuit. Most students can complete the circuit connection smoothly and obtain correct experimental results [5]. However, when asked about the function of each gate circuit in the circuit and the working principle of the entire circuit, many students are unable to explain clearly. This indicates that students are only mechanically operating during the practice process and do not truly understand the theoretical knowledge behind it. They only know what to do but not why.

2.2 Disconnect between Teaching Content and Technological Development

At present, there is a certain degree of disconnection between the teaching content of the digital logic circuit course and the development of modern advanced technologies, which affects students' learning outcomes and future career development to some extent. With the rapid development of information technology, new devices, technologies, and design methods are constantly emerging in the field of digital logic. However, the teaching content of the digital logic circuit course in some universities still focuses on traditional small - and medium - scale integrated circuits, with relatively little introduction to new devices and design methods[6]. In terms of textbook selection, some textbooks are not updated in a timely manner and fail to reflect the latest development achievements of digital technologies. During the teaching process, teachers do not explain new devices and technologies in - depth either. They only mention them briefly without guiding students to conduct in - depth study and practice. As a result, students have insufficient understanding of the development trends of modern digital logic technologies and have difficulty quickly adapting to the requirements of job positions after graduation [7].

2.3 Monotonous Teaching Methods

The traditional teaching method of digital logic circuits mainly features "cram - down" teaching. Although this method can impart a large amount of knowledge within a certain period, it has many drawbacks and exerts an adverse impact on cultivating students' enthusiasm for learning and innovative ability. In the "cram - down" teaching mode, teachers are the dominant figures in the classroom, and students passively receive knowledge [8]. Teachers explain according to the textbook content on the platform, while students listen and take notes below, lacking interaction and communication. This teaching approach makes the classroom atmosphere dull, and students are prone to feeling bored, thus reducing their enthusiasm and initiative in learning.

When teaching sequential logic circuits, teachers explain the working principles, characteristic equations, and analysis and design methods of flip - flops through PPT demonstrations and blackboard writing. Due to the abstract nature of the content, students only mechanically record what the teacher explains in class, lacking in - depth understanding and thinking of the knowledge [9]. Many students said after class that they had difficulty understanding this part of the content and had little interest in learning it.

In addition, the "cram - down" teaching method is not conducive to cultivating students' innovative ability. Under this teaching mode, students are accustomed to passively accepting knowledge and lack opportunities for independent exploration and thinking. Teachers teach according to the established teaching content and methods, restricting students' thinking, and making it difficult for them to put forward their own opinions and ideas. The cultivation of innovative ability requires students to have the spirit of independent thinking, the courage to question, and the eagerness to explore, which the "cram - down" teaching method obviously cannot meet. In the curriculum design section, some students, due to a lack of innovative thinking, simply imitate the cases in the textbook for design and are unable to design digital circuits with innovation and practicality.

2.4 Low Student Interest in Learning

Students' lack of interest in the Digital Logic Circuit course is a significant issue in current teaching, which affects the teaching effectiveness and students' learning quality to some extent. The Digital Logic Circuit course is highly abstract and theoretical, with its content involving numerous concepts and principles such as logical algebra, gate circuits, and sequential logic [10]. These contents are rather dull and difficult for students to understand, easily causing them to develop a fear of difficulties.

The lack of interesting elements in the teaching process is also one of the reasons for students' low interest in learning. Teachers mainly rely on PPT presentations and blackboard writing in class, rarely using other teaching methods to stimulate students' interest in learning. When explaining the working principles of digital circuits, teachers merely use static pictures and text, failing to enable students to visually perceive the working process of digital circuits.

3. Strategies and Methods for the Teaching Reform of the Digital Logic Circuit Course

3.1 Optimization of Teaching Content

3.1.1 Integration and streamlining

Based on the needs of various majors for digital logic circuit knowledge in the context of emerging engineering education and the actual learning situation of students, the teaching content is comprehensively integrated and streamlined. After in - depth analysis of the training programs and curriculum systems of majors such as computer science and technology, the positioning and role of the Digital Logic Circuit course in different majors are clarified, so as to adjust the teaching content in a targeted manner. For the computer science and technology major, attention is paid to the connection between digital logic circuits and knowledge such as computer organization principles and microprocessors.

In terms of content integration, the traditional chapter boundaries are broken, and related knowledge points are organically integrated. The basic knowledge of logical algebra, gate circuits, and parts of combinational logic circuits are integrated, with the simplification and implementation of logical functions as the main line running through the teaching of these three parts. When explaining the basic laws and rules of logical algebra, actual gate - circuit cases are introduced, allowing students to realize logical functions through the connection of gate circuits, so as to better understand the application of logical algebra in digital circuits. At the same time, the contents of flip - flops, counters, and registers in sequential logic circuits are integrated, with the analysis and design methods of sequential logic circuits as the core, guiding students to master the working principles and application scenarios of different sequential logic devices.

In terms of content streamlining, some complex and less practical contents are cut. When explaining small - and medium - scale integrated circuits, in - depth analysis of their internal structures and detailed working processes is reduced, because these contents are not very helpful for students to understand the basic principles and applications of digital logic circuits and are likely to make students feel intimidated. For example, for some traditional discrete - component gate circuits, such as diode AND gates and transistor OR gates, only their working principles and logical functions need to be briefly introduced, and the focus should be on the external characteristics, electrical parameters, and typical applications of currently widely used integrated gate circuits, such as TTL gate circuits and CMOS gate circuits. For some complex logical function simplification methods, such as the complex formula derivations in the formula simplification method, which are rarely used in practical applications, the explanation can be appropriately simplified, and practical methods such as the Karnaugh map simplification method should be emphasized. Through such integration and streamlining, the teaching content becomes more compact and practical, in line with students' cognitive laws and professional needs.

3.1.2 Incorporation of new technologies

With the rapid development of digital technology, it is of great significance to timely integrate new devices and technologies into the teaching content of the Digital Logic Circuit course to enhance the course's timeliness and practicality. In teaching, the content related to new programmable logic devices such as Field - Programmable Gate Arrays (FPGA) and Complex Programmable Logic Devices (CPLD) is added. By elaborately introducing the basic structures, working principles, and development processes of FPGAs and CPLDs, students can understand the advantages and application scenarios of these devices in digital system design. When explaining digital system design, FPGA - based design examples are introduced, such as the design of a digital clock and a digital quiz buzzer. Taking the digital clock design as an example, students are guided to use Hardware Description Languages (HDL) like Verilog or VHDL for circuit design. Through programming and downloading on the FPGA development board, the function of the digital clock is realized. In this process, students not only master the development technology of FPGAs but also learn how to apply the theoretical knowledge of digital logic circuits to the actual digital system design.

Meanwhile, HDL is regarded as one of the key teaching contents. HDL has become the mainstream tool for modern digital system design, and proficiently mastering HDL is crucial for students' future work in digital circuit design and development. In teaching, special chapters are arranged to explain the syntax structure, programming specifications, and design methods of HDL. Through numerous examples and exercises, students are enabled to master the skills of using HDL for digital circuit modeling, simulation, and synthesis. For instance, when teaching combinational logic circuits, in addition to using traditional logic diagrams and truth tables for design, students are also guided to use HDL for description and implementation. Taking a simple three - person voting machine as an example, codes are written in both Verilog and VHDL and verified through simulation, allowing students to compare the advantages and disadvantages of different description methods and deepen their understanding and application ability of HDL.

Moreover, attention is paid to the latest research results and application cases in the field of digital logic, which are promptly integrated into the teaching content. Digital logic circuits play an important role in emerging fields such as artificial intelligence and the Internet of Things. In teaching, cases such as the digital logic circuit design in artificial intelligence chips and the digital signal processing in Internet of Things sensor nodes are introduced to broaden students' horizons and stimulate their learning interest. Through the incorporation of these new technologies and cases, the teaching content of the Digital Logic Circuit course can keep up with the pace of the times, cultivate students' innovative awareness and practical ability, and improve their comprehensive qualities and employment competitiveness.

3.2 Innovation in Teaching Methods

3.2.1 Heuristic teaching

In the teaching of the Digital Logic Circuit course, the heuristic teaching method can effectively stimulate students' thinking and guide them to actively think and explore knowledge. Take the teaching of counters as an example. At the beginning of the course, the teacher first shows a physical digital clock or demonstrates its time - keeping function to arouse students' interest. As a common time - keeping tool in daily life, students are quite familiar with the functions of a digital clock, but they know little about its internal time - keeping principle. The teacher uses this as an entry point to pose the question: "How does a digital clock achieve accurate time - keeping?" This question is like a stone thrown into the lake of students' thinking, creating ripples and guiding students to think about the time - keeping mechanism behind the digital clock.

After students actively start thinking, the teacher further guides them to analyze the time - keeping process of the digital clock, thus introducing the concept of counting. The teacher gradually explains how a counter counts the input pulses and the working principles of counters in different number systems. During the explanation, the teacher continuously poses questions, such as "How should we design a counter with a modulus of 60?" and "How can we ensure the accuracy and stability of the counter during its design?" These questions guide students to deeply think about the design methods and key points of counters, stimulating their thirst for knowledge. Through such heuristic teaching, students are no longer passive recipients of knowledge. Instead, under the guidance of the teacher, they actively think and explore the principles and applications of counters. This teaching method not only enables students to better understand the relevant knowledge of counters but also cultivates their logical thinking ability and problem - solving ability. In the subsequent course design, students can use the learned counter knowledge to design digital systems with different functions, such as digital frequency meters and digital timers, fully demonstrating the important role of heuristic teaching in cultivating students' innovative thinking and practical ability.

3.2.2 Project - driven teaching

The project - driven teaching method is a teaching approach that is project - oriented and student - centered. It enables students to master the knowledge and skills of digital logic circuits in practice and cultivate their comprehensive abilities. Take the project of designing a digital system as an example. Students are given an actual project requirement, such as designing a digital combination lock for a smart home control system. This project requires students to comprehensively apply the knowledge of digital logic circuits, including combinational logic circuits, sequential logic circuits, encoding and decoding.

During the project implementation process, students first need to analyze the project requirements and clarify the functional requirements of the digital combination lock, such as password input, password verification, unlocking control, and error prompt. Then, students design the system according to the functional requirements, determining the overall architecture of the system and the design schemes of each functional module. When designing the password verification module, students need to apply the knowledge of combinational logic circuits to design a logic circuit for password comparison and verification; when designing the unlocking control module, they need to use the knowledge of sequential logic circuits to achieve correct control of the unlocking signal and state conversion.

After completing the circuit design, students need to select appropriate hardware platforms and tools for circuit construction and debugging. Students can choose to use digital circuit experiment boxes, programmable logic devices (such as FPGA, CPLD) for hardware implementation. During the debugging process, students may encounter various problems, such as circuit connection errors and logical function errors. At this time, students need to apply the knowledge they have learned, gradually troubleshoot and solve problems by observing experimental phenomena and analyzing circuit principles.

By completing this digital combination lock project, students not only master the relevant knowledge and skills of digital logic circuits but also cultivate their abilities to analyze and solve problems, as well as teamwork and innovation abilities. During the project implementation process, students need to closely cooperate with team members to jointly complete project tasks, which helps to improve their teamwork ability. At the same time, students may put forward some innovative ideas and solutions during the design process, which helps to cultivate their innovation ability. This project - driven teaching method allows students to learn in practice, closely integrating theoretical knowledge with practical applications, and improving students' learning effectiveness and comprehensive qualities.

3.2.3 Blended teaching

The online - offline blended teaching model combines the advantages of traditional classroom teaching and online teaching, providing students with a more flexible and diverse learning approach. In the Digital Logic Circuit course, teachers utilize online teaching platforms such as Chinese University MOOC and XuetangX to offer students a wealth of teaching resources, including teaching videos, e - textbooks, online tests, and discussion forums.

Before class, students watch teaching videos on the online platform to preview the course content and identify the key points and difficulties of the course. Teachers set some questions in the teaching videos to guide students' thinking, enabling them to learn with questions in mind. When learning the analysis methods of combinational logic circuits, teachers explain the basic analysis steps and methods in the teaching videos and present some simple combinational logic circuits, asking students to try to analyze their logical functions during the preview. If students encounter problems during the preview, they can communicate with their classmates in the discussion forum or ask questions to the teacher, and the teacher will provide timely answers and guidance.

In the classroom, teachers conduct in - depth explanations and discussions on the problems students encountered during the preview and the key and difficult points of the course. Through classroom questioning, group discussions, and case analyses, teachers guide students to deeply understand the course content and cultivate their thinking ability and problem - solving ability. When teaching the design of sequential logic circuits, teachers can present some actual design cases, let students discuss the design schemes in groups, and then each group sends a representative to report and present. Teachers comment on and guide students' design schemes to help them improve. After class, students complete the homework and online tests assigned by the teacher on the online platform to consolidate the knowledge they have learned. Teachers can timely understand students' learning situations through the online platform, analyze and provide feedback on students' homework and test results, and offer targeted tutoring for the problems students have. Meanwhile, students can also conduct extended learning on the online platform, consult relevant literature, and learn about the latest development trends in the field of digital logic circuits.

Through this online - offline blended teaching model, students can flexibly arrange their learning time and methods according to their learning progress and needs, enhancing their learning autonomy and enthusiasm. The richness and diversity of online teaching resources provide students with more learning channels and materials, which helps to broaden their knowledge. The interactivity and practicality of offline classrooms enable students to better understand and master knowledge and cultivate their practical and teamwork abilities.

3.3 Reform of Practical Teaching

3.3.1 Design of experimental projects

To cultivate students' practical ability and innovative thinking, a series of comprehensive and innovative experimental projects have been carefully designed in the practical teaching of digital logic circuits. Take the multi - functional digital circuit experiment as an example. This experiment requires students to design a digital circuit system with multiple functions, such as integrating the functions of a digital clock, a digital frequency meter, and a digital quiz buzzer. In the design of the digital clock function, students need to use digital logic devices such as counters, decoders, and displays to construct a circuit that can accurately keep time and display hours, minutes, and seconds. Students should deeply understand the working principle of the counter and achieve the counting and frequency division of the clock pulse through reasonable circuit connection and parameter setting to obtain an accurate time signal. In the design of the digital frequency meter function, students need to design a circuit capable of measuring the frequency of the input signal. This requires students to master knowledge and skills such as signal conditioning, counting, and data processing. They need to shape and divide the frequency of the input signal, then use the counter to count the pulses, and finally convert the count value into a frequency value and display it.

During the experiment, students need to comprehensively apply the knowledge of digital logic circuits they have learned for circuit design, simulation, debugging, and optimization. In the circuit design stage, students need to select appropriate digital logic devices and design schemes according to the experimental requirements and draw the circuit schematic diagram. When selecting a counter chip, they should consider whether its counting range and counting speed meet the experimental requirements. When designing the decoder, they should ensure that it can correctly convert the output of the counter into a signal that the display can recognize. In the simulation stage, students use simulation software to conduct simulated tests on the designed circuit to check whether the circuit functions correctly and whether there are logical errors or timing problems. Through simulation, students can discover and solve some potential problems in advance, improving the experimental efficiency. In the debugging stage, students build the designed circuit on the experimental platform for actual testing. In this process, students may encounter various problems, such as circuit connection errors, device damage, and signal interference. Students need to apply the knowledge and skills they have learned and gradually troubleshoot and solve problems by observing experimental phenomena and measuring circuit parameters.

Through such comprehensive and innovative experimental projects, students can not only consolidate and deepen the knowledge of digital logic circuits they have learned but also cultivate their practical ability, innovative thinking, and problem - solving ability. During the experiment, students need to constantly think and explore and try new design ideas and methods, which helps to stimulate students' innovation awareness and ability. At the same time, the complexity and challenge of the experimental project also require students to have good teamwork and communication abilities. Students need to closely cooperate with team members to jointly complete the experimental task.

3.3.2 Introduction of simulation software

In the teaching of digital logic circuits, introducing simulation software such as Multisim and Vivado can effectively help students understand abstract concepts and circuit principles, thereby enhancing the teaching effect. Take Multisim software as an example. It is a powerful electronic circuit simulation software with an intuitive user interface and a rich component library. When teaching combinational logic circuits, teachers can use Multisim software to conduct circuit simulation demonstrations. For instance, in the case of a simple three - person voting machine circuit, the teacher builds the circuit in Multisim. By setting different combinations of input signals, students can observe the changes in output signals and compare them with the theoretical truth table. In this process, students can visually see the signal states at each node in the circuit and the transmission and change processes of signals in the circuit, thus better understanding the working principle and logical function of combinational logic circuits. Vivado is a professional software for FPGA development. It not only provides powerful design and synthesis functions but also has a wealth of simulation tools. When teaching FPGA - based digital system design, teachers can guide students to use Vivado software for practice. When designing a digital clock system, students first write code in Vivado using a hardware description language (such as Verilog) to describe the functions and logic of the digital clock. Then, they use Vivado's simulation function to verify the written code through simulation. Students can set different clock signals and control signals to observe whether the time - keeping and display functions of the digital clock are correct. Through simulation, students can promptly identify errors and problems in the code and make modifications and optimizations. Before actual hardware implementation, simulation can greatly reduce design risks and improve the success rate of the design.

The introduction of simulation software can also expand students' learning space and time. Students can independently use simulation software for circuit design and experiments after class without being restricted by laboratory equipment and time. According to their own interests and learning progress, students can design various digital logic circuits, conduct simulations and tests, and deepen their understanding and mastery of knowledge. Meanwhile, simulation software can serve as a platform for students' innovative practice. Students can try new design ideas and methods in the simulation environment to cultivate their innovation ability.

4. Conclusions and Outlook

4.1 Conclusions

This research conducts an in - depth exploration of the teaching reform of the Digital Logic Circuit course in the context of emerging engineering education. Through the optimization of teaching content, not only is the traditional teaching content streamlined and integrated, with complex and less practical parts cut, but also cutting - edge technologies such as new programmable logic devices like FPGA and CPLD, and hardware description languages like Verilog and VHDL are incorporated. This makes the teaching content keep pace with the development trend of digital technology, being more timely and practical.

In terms of teaching method innovation, diversified teaching methods such as heuristic teaching, project - driven teaching, and blended teaching are comprehensively applied to stimulate students' learning interest and initiative. Taking the teaching of counters as an example, heuristic teaching guides students to think by setting questions, enabling them to better understand the principles and applications of counters. In the digital combination lock design project, project - driven teaching allows students to comprehensively apply knowledge in practice, cultivating their teamwork and innovation abilities. Blended teaching provides students with a more flexible and diverse learning approach through the combination of online and offline teaching, improving students' autonomous learning ability and classroom participation.

The reform of practical teaching is one of the key points of this research. By designing comprehensive and innovative experimental projects and introducing simulation software such as Multisim and Vivado, students' practical ability and innovative thinking are comprehensively enhanced. In the multi - functional digital circuit experiment, students comprehensively apply the knowledge they have learned to design and implement a digital circuit system with multiple functions, solve practical problems, and cultivate innovative thinking. The introduction of simulation software enables students to intuitively understand circuit principles, improving the efficiency and effectiveness of experiments.

In general, this teaching reform of the Digital Logic Circuit course plays an important role in student cultivation and professional development. Through the reform, students not only master solid professional knowledge and skills but also cultivate innovation ability, practical ability, and comprehensive qualities, laying a solid foundation for the subsequent study of professional courses and future career development.

4.2 Outlook

Looking ahead, the teaching reform of the Digital Logic Circuit course will develop in a more in - depth and comprehensive direction. In terms of teaching content, continuous attention will be paid to the cutting - edge development of digital technology, such as digital logic optimization in artificial intelligence chips and the digital logic foundation in quantum computing. The latest research results and application cases will be continuously integrated into teaching to ensure that the teaching content remains advanced and practical. Regarding artificial intelligence chips, in - depth explanations will be provided on the architectural design of internal digital logic circuits, algorithm implementation, and the differences from traditional digital logic circuits, enabling students to understand the innovative applications of digital logic in emerging technology fields.

In terms of teaching methods, modern educational technologies such as virtual reality (VR) and augmented reality (AR) will be further integrated to create a more immersive learning environment for students. With the help of VR technology, students can build and test digital logic circuits in a virtual laboratory, immersively experience the working process of the circuits, and enhance the fun and interactivity of learning. With the development of artificial intelligence technology, intelligent teaching systems will gradually be applied to the teaching of digital logic circuits. These systems can provide personalized learning paths and guidance for students based on their learning situations and characteristics, achieving precise teaching.

In practical teaching, in - depth cooperation with enterprises will be strengthened to establish long - term and stable industry - university - research cooperation relationships. Practical projects will be jointly developed with enterprises, allowing students to participate in the actual digital circuit design and development projects of enterprises. This way, students can better understand industry needs and development trends in practice, improving their engineering practice ability and employment competitiveness. At the same time, active participation in international exchanges and cooperation will be carried out to introduce advanced teaching concepts, methods, and resources from abroad and align with the international advanced teaching of digital logic circuits.

Through these continuous reforms and developments, the Digital Logic Circuit course will play a greater role in cultivating high - quality engineering talents with innovation ability, practical ability, and social responsibility.

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