Make experimental device to be a toy - the experimental teaching in Digital Logic Circuit course

Shanshan Li, Ninghan Zheng, Yuchao Gao, Chengbin Quan, Weidong Liu
Department of Computer Science & Technology
Tsinghua University
Beijing, China
lishanshan,zhengnh,gaoyuchao,quancb,liuwd@tsinghua.edu.cn

***Abstract*—This Research-to-Practice Work in Progress paper presents a type of Digital Logic Circuit experiment device like toys to attract the students' interest for the experiments. Digital Logic Circuit course is a course that emphasizes the actual hand-on experiment. Because it is fundamental course, its experiment maybe monotonous and boring for the students. The traditional experiment is hard to attract students. In this paper, we tried to turn the experimental device to the digital toys. We divided the whole experimental device into several kinds of modular blocks, which can perfectly cover the contents of the traditional experiments and greatly improve the fun of students' experiment. The experiment integrated the traditional chip connection type experiments and the programmable device experiments. The experiment blocks were colored, like the toy blocks, and it is easy to connect, so the experimental process is very interesting. The students can do the experiment like play toys, to build a simple and interesting digital circuit. We had used this device in the Digital Logic Lab course in a small scale, the students were more willing to do the experiment than others not using this device. The results proved that this kind of experiment is beneficial to train students in improving their hardware application ability, not only in mastering the knowledge effectively, but also in strengthening the ability of practice.**

Keywords—Experimental Teaching; Hardware Course; Practice Training

I. INTRODUCTION

Digital Logic Circuit is a basic compulsory course for Computer Engineering major, and it is the prerequisite course for the following hardware courses such as Computer Organization and Embedded System [1]. The course is also the first hardware course in the curriculum for CE students. Digital Logic Circuit course is designed to introduce Boolean algebra, basic logic gate, combinational logic circuit and sequential logic circuit, etc.

It is a challenge to teach the principles of basic logic circuits for students with no circuit fundamental knowledge to intuitively understand the correlation between input and output signals in electronic digital circuits. Experiment-based learning is a powerful tool in teaching these technical subjects. It allows the students to experience logic circuit behavior. Through the experiment practice, the student can get the intuitive image of the circuit, learn the principle of the circuit with hands-on work. The experiment will deepen the understanding of the relevant theoretical knowledge, and also train the hands-on ability.

However, the students majoring in computer are accustomed to the software thinking, and are willing to take the software courses. They have no idea for how to learn hardware courses well, and even have conflicts to do so. They feel that the hardware courses are boring and complex. They are generally reluctant to take hardware courses, and even perfunctory to the experiments.

How to solve this problem? We think the most important thing is to arouse students' interest [2]. With interest, even K12 children can do digital circuit design [3]. Therefore, we try to improve our experimental equipment to have better interoperability and scalability, let the students feel that it is simple, convenient and interesting just like using toys to do experiment on our equipment. We think it will stimulate students' learning interest, arouse students' enthusiasm, tap students' potential, and then promote students to learn Digital Logic Circuit course. We also reorganize the experiment, to design a set of experiments that emphasizes foundation and close to engineering, so that the students cultivation will turn from the of basic practical ability to the engineering innovation ability step by step.

This paper described some exploration in Digital Logic Circuit experimental teaching using our newly developed modular experiment device, including (1) the device composition, characteristics and some technical implementation details, (2) the design of the corresponding experiments, (3) the experience in actual using in experiment teaching, (4) the feedback of students and some the expectation work in the future.

II. EXPERIMENT METHOD

In the experiments of Digital Logic Circuit course, there are primarily two methods for conducting experiments, physical experiments with electronic circuits and software simulations. Both approaches often require an infrastructure to be conducted, for example in a laboratory or on a computer to execute simulation-software.

Software simulation is using software to simulate the working state of the real circuit, which is very convenient to carry out experiments. At present, there are many software tools [4] [5]. But using simulation-software, students do not have an intuitive understanding of the hardware. In the process of experiment, they only operate through the mouse or keyboard, do not actually connect wire or assemble the circuit, so they may lack of hands-on training. And generally the function provided

by software simulation is limited and can not completely simulate the whole working state of real hardware. Especially for the circuit with fault, the simulation software sometimes can not accurately reflect the fault phenomenon, so the students will lack of training in circuit debugging.

With the emergence of programmable devices, hardware experiments are carried out in hardware design language (HDL). All circuit behaviors can be described in the form of software language, and then finally configured to programmable chip through compilation and synthesis by the EDA software. The advantages of using this method are obvious, which can greatly simplify the circuit design process [6]. For circuit high-level design, the efficiency is very high, but there are not many operations that can be carried out on the actual experimental equipment in this way.

Presently there are many kinds of experimental equipment, including breadboard experiment [7], ready-made industrial products [8], and circuit making by students themselves [9], even online courses still need a portable experimental kit [10]. Programmable device is the trend of experiment in the course experiment teaching. Because of the consideration of cost or expansibility, many experiment equipment only supports the experiments of programmable device, giving up the experiment of chip connection circuit using wires. There are still some experiment devices that retain the chip wiring experiments, but these experiment devices are too large, inconvenient to carry, and have poor scalability, so they can only support some fixed experiment content.

III. Experiment Equipment

A. Requirement

Over two hundreds students majoring in Computer Engineering will take the Digital Logic Circuit lab course every year in our university. They will be divided into 8 classes to do the experiments. Through this lab course, we hope we can cultivate their practical ability, guide their interest in hardware course, and arouse some innovation consciousness [11] [12].

Therefore, for the Digital Logic Circuit experiment, we hope that our experimental device can have the following functions or features:

1) The experiment equipment should be compatible with the traditional circuit connection experiment, using the chip and the connecting wire to design and assemble the circuit, so as to train the students' practical ability.

2) Programmable device experiment can be carried out to let students contact advanced experiment technology and understand popular and latest design methods.

3) The experiment equipment should not be too big or bulky, and it can support experiment out of laboratory, so it needs to have some debugging functions on it.

4) The experimental equipment can be easily expanded, to support the students attempt to do some exploratory or innovative experiment.

5) The experimental equipment should look interesting, to attract students to operate, and the experiment results can be shown well on it.

6) The experiment equipment should be easy to learn and handle, especially when wiring the circuit.

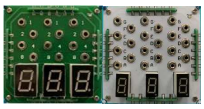
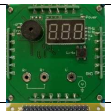
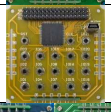
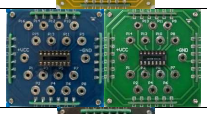
B. Modular experiment blocks

In view of the above requirements, our first solution is to use the bread board and connecting wire. The bread board can be easily connected, easy to expand and carry. However, in the actual use, we encountered some problems that are difficult to solve, such as the connecting wires is often broken in the jack of the bread board, which can not directly support non DIP chips, especially the programmable chip in current. And it's not very convenient to connect and debug on it. The other problem is that the circuit connected looks a little untidy.

Therefore, we refer to LEGO's design [13], dividing the equipment into several different building blocks according to the function. The programmable device is also made into a block. The building blocks can be freely connected, and form into a circuit through the customized connecting wires.

We have designed nine kinds of modular blocks, as shown in the Table 1. For the students who first learn the hardware course, the circuit they designed is generally not very complex, just need some input and output, using some simple logic chips. And we also refer to the previous student experiments, basically these modular blocks can support these experiments in the Digital Logic Circuit course.

TABLE I. Experiments

Block	***Picture***	***Function***
Seven-segment LED Block		Two type blocks, each have three Seven-segment LED. Left one has decoder, need four inputs, right one has no decoder, need seven inputs.
Meter Block		It can measure the voltage, frequency and on-off of the circuit.
Programmable Block		It has a programmable device and the configuration circuit.
Chip Carrier Block		It can insert 74 series DIP chips into the chip base. There are two types, one is 16pin, the other is 14pin.
LED/Switch Block		It has four switches and four LED.
Clock Block		It has 1M/2M/4M/8M/16M clock signas, and has two microswitches that has de-twitter circuit.
Power Block		It provides 5V power.

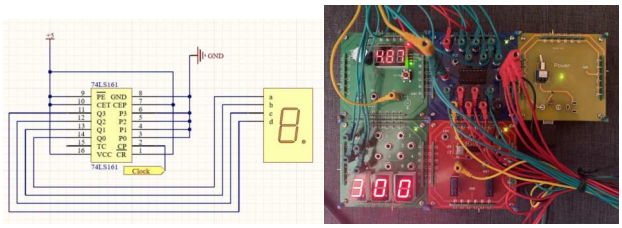


Fig. 1. Counter Circuit

All the blocks are in the same size, and can be easily built together. The power and ground will be connected automatically when the blocks are spliced. With these modular blocks, the students can build their circuit according to their design, only need to splice the blocks together, and then connect the signal wire. For example, the circuit of a counter is shown in Fig. 1., left is schematic, right is the real circuit built.

The device is divided into various blocks, so the supported experiments can be much more than before. In theory, the number of blocks can be infinite, so that the restrictions on students are less. They can use the programmable devices and common logic chips on one circuit design in the experiment. Using these blocks, the students can play their own initiative to design and try some new content in experiment.

With this modular blocks, the experiment can be expanded easily and we can design different levels of experiment. For example, if we want to add the minute display part in the original stopwatch circuit, we only need to add some new blocks and connect the wires. So we can implement the hierarchical experiment teaching in class, and the content of the experiment is progressive for different level students.

Using the mode similar to LEGO can also improve the operability and entertainment of the experiment. The blocks identify different functions by colors, and the connecting wires also use different colors. The same type of signal uses one color, such as the ground uses black wire, and the power supply uses red wire, which not only looks beautiful, but also in the process of circuit checking and debugging it is convenient for the students to debug the circuit. They can track the signal transmission path or identify the signal type according to the color, so that when designing a complex circuit, it is easy to clarify whether the circuit connecting is correct or not. It is very helpful for the students who are learning the circuit design and can improve the efficiency in their experiments. Like LEGO toys, the experiment uses blocks to build a functional circuit, and it also looks interesting. When the circuit completed, it will give students a certain sense of achievement, so as to attract students to carry out hardware experiment and enhance their interest in the course.

The experiments of Digital Logic Circuit are very fundamental. How to guide the students to do more exploration in experiment? We add some comparative experiment content. For the experiment of using wire connecting chips, we added the experiment using programmable devices with the same requirements. Such as the four-bit full adder experiment, we not only arrange the experiment using chips of gate, but also the experiment using HDL on programmable devices, so that the students can compare the similarities and differences in circuit design using these two methods. In the circuit design, we also set different levels of requirements, such as ripple carry adder and carry-lookahead adder, etc.

C. Technical Issues

In the process of the experiment, in order to supply power to each block conveniently, we specially designed the power supply around the module. Four sides of each block are equipped with pogopin. When the modules are spliced together, the power and ground are automatically connected through the pogopins. Each pogopin can carry 1A current, which can ensure the normal experiment. The students do not need to make each block connected to power supply separately in the experiment, only need to splice power block, each block will have power supply.

When the modules are spliced, the pogopin requires the modules be connected tightly without dislocation. Here, we use two strong magnets on each contact side, to ensure the good connection of pogopin by using the suction of magnet. And two magnets can ensure the connection will not be misplaced.

In the experiments using wire to connect signals, the most common problem for students is the poor contact of the connecting wire. For example, the jack on the bread board is not firmly connected, which makes it difficult for students to debug. Here we use the self-locking socket and connecting wire. The connecting wire can be locked by turning clockwise, and the contact is very firm. Turning anticlockwise can easily disconnect the connection.

In order to be portable, the blocks need to be able to be stored easily. We have adopted the position limiter design on the block shell to facilitate the blocks to be stacked and put into the box, the block design is shown in Fig. 2.

In addition to the normal block, we also made the programmable device as a modular block. Because the programmable device resources needed in the students' experiments are not very large, we chose epm240 as the experimental chip, and led the pin out to the socket for wire connecting. We also put the configure circuit on the block. Thus the students only need a USB cable to configure the programmable device.

And we also made the circuit debugging tool into a modular block, which can measure the voltage, clock frequency and circuit on-off. These functions basically satisfy the needs of students in debugging.

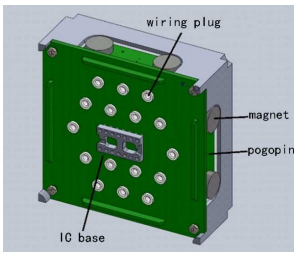


Fig. 2. Block design.

IV. EXPERIMENT ARRANGEMENT

The new modular equipment has been applied in the Digital Logic Circuit Lab course. At present, students have used it in two semesters, and the corresponding experiment content has been optimized. The purpose is that by using these modular blocks, the students can understand the knowledge more deeply, learn to use the knowledge to solve the engineer problems, and improve their hardware ability to design and debug.

A. Experiment Arrangement

The theory and lab course are arranged in the same week to ensure that the students can practice the theoretical knowledge soon. The theory course is on Tuesday, in large class of about 200 students, while the lab course is arranged on Friday, in small class of 30 students each, and staffed with lab teacher and TA. At the beginning of the lab class, the relevant content and precautions of the experiment will be introduced. The lab teacher and TA need to answer the experiment questions and check the experiment results.

At the beginning of the semester, the device was distributed to the students, and the experiment requirement was put on the course website in advance. Students can design the experiment circuit in advance, especially for those complex experiment. Generally, students need to design the circuit in advance, simulate on software, build the circuit and do the test. When they encounter the problem, they can ask the teacher for help in the lab class. Do the experiment with the problem, the students will get more knowledge. And the portable experiment equipment also let the students have the possibility and willingness to do more experiment expansion.

The experiment content refers to the knowledge points involved in the theory course. The experiment starts from the basic logic gate, and then gradually builds a complex circuit system with certain functions including the sequential logic and combinational logic circuit. In the lab course, there are 8 experiments the students need to be complete, begin with the instrument operation lab, and end with hands-on experiment exam. The detail experiment arrange is shown in Table II.

TABLE II. EXPERIMENTS

Experiment	***Description***	***Type***	***Blocks***
Instrument Operation	Learn how to the use of experimental instruments, including the oscilloscope, logic analyzer, etc.	Basic	0
Chip Measurement	Measurement of the delay and transmission characteristics for 74 series chip.	Basic	2
Lighting the LED	Using programable device to light the LED	program	2
Full Adder	Assemble the adder circuit using 74 series chips.	Combinatio nal	5
Four-bit Adder	design and implement an four-bit adder 1. Using 74 series chips 2. Use HDL	Combinatio nal Program	7
Counter	design and implement a counter 1. Using 74 series chips 2. Use HDL.	Sequential Program	5
Electronic Cipher Lock	Use HDL to design and implement an electronic cipher lock.	Program	4
LED Show	Use the LED or LED array to complete a creative idea experiment.	Innovation optional	U
Examination	Use chips to design a couter Use HDL to design circuit	exam	>8

In the lab course, many students are the first time to contact with hardware experiment, so we have set up a special instrument using experiment, so that the students can master how to use these instruments to help themselves debug hardware, especially using oscilloscope, logic analyzer, etc. Following we arrange 74 series of chip experiment and programmable experiment contents, including combinational logic circuit and sequential logic circuit, which can not only make students intuitively understand the most basic internal structure unit of the circuit, but also let students learn the current technology for hardware design.

Because the experiment is divided into different functional blocks, the students only need to bring a few blocks for the experiment to laboratory. The connection between blocks adopts standardized connectors, which improves the efficiency of students' circuit building, and reduces the probability of circuit error caused by wiring or connecting in experiment process. And if any block goes wrong, we can easily replace the block quickly without replacing the whole set of experiment device, which saves the experiment time and cost.

In the experiment, we especially emphasize the cultivation of practical knowledge and hands-on ability. As the integration of digital circuits is becoming higher, students have no real understanding of the internal components of circuits, and can only have abstract understanding from theoretical knowledge. The wiring experiment makes up for this gap. The Wiring experiment can let students understand the composition and working principle of the gate level in the digital circuit directly and concretely, which is helpful for students to understand the theory of digital circuit and smoothly transition to the later stage of complex circuit design.

B. Assssment

The score of the lab course include 60% for each experiment and 40% for the experiment examination. Each experiment needs to be checked and evaluated by the teacher or TA to check whether the circuit function is correct, whether the experiment operation is in line with the experiment specifications, etc. After the lab class, the students should submit the experiment report, which will be reflected in the experiment score.

In the experiment exam, we set two experiments for assessments. The first is to use 74 series chips to build circuits. Students are required to design and complete a counting circuit, counting from zero and stop at their student ID number. This content is sent to students before the exam. Students can design

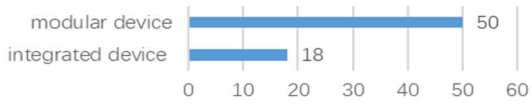


Fig. 3. Students survey result

and debug the circuit before the exam, but they can't take the ready-wired circuit directly to the laboratory for checking. They are required to connect and build the circuit on site and run correctly. The second exam is to complete a programmable device experiment in laboratory. The experiment's requirement will be given on exam. In 2019, the exam include Morse code, countdown timer, four-way responder, etc. The students need to write the HDL code on site and work correctly on the programmable device. These two exam contents can fully test the practical operation and hardware debugging ability of the students.

C. Feedback

In the lab course in 2018, we selected three classes to try to use this modular experiment device, and made some survey to the students who used the new device when they returned the experiment device at the end of the semester. We'd like to use this survey to investigate the students' feelings about this new device. The questionnaire is anonymous and the students voluntarily to answer it. The question is:

Which experiment device do you prefer, the traditional integrated device or the modular blocks device? Why?

We have received 68 valid surveys. The result is shown in the Fig. 3. From the results, we found that the students were more willing to choose the modular blocks device, about 73% of students prefer to choose it. As for why to choose modular device, students mainly mentioned the following three aspects: (1) The operation of the modular block device is convenient, easy to assemble and carry; (2) The block device is flexible and can be easily expanded; (3) The blocks look interesting.

From the student's feedback, the students were quite approved of the new experiment device, but some students also brought out some questions, such as the pogopin is sometimes easy to break, the wires provided is not enough, etc.

For the follow-up Computer Organization course, through the training in Digital Logic Circuit course, students can better adapt the higher-level course experiment. Especially the training of hands-on ability and the programmable experiment is very helpful for the experiment of the following courses.

V. Conclusion and Next Work

After two semesters of practical use in the course, the modular experiment device has received positive feedback from students. Students' interest is a guarantee of the teaching effect of the course. Through the experiment like playing with toys and reasonable arrangement of experimental content, students' acceptance for the courses is higher. For fundamental courses such as digital logic, students' interest is more important. The experiment can enhance students' interest in hardware courses, improve their hands-on ability, and further stimulate their creativity.

In the lab use of the experiment device, we also found that the device need further improvement. Firstly, we need to add some new blocks, such as functional modules, like MCU block, serial port block, sensor block, etc. Current blocks can only complete some relatively simple experiment. With these new blocks, students can do some complex experiments, especially the addition of MCU and sensors blocks can be used for some high-level experiments. Secondly, the experiment also needs to be further arranged, and the experiment content needs to be hierarchical to meet the needs of students at different levels. It will gradually improve their ability through the progressive experiment setting. Finally, we are designing an online simulation system to fit for the modular blocks. Students can build circuits and simulate it on web pages. The combination of online and offline experiment will give more convenient experience for the students.

Acknowledgment

Thanks are due to Zhao Youjian for assistance in the corresponding theory courses and for valuable discussion. We gratefully acknowledge the valuable cooperation of Tian Shuzhen in experiment teaching with us. This work is supported by Natural Science Foundation of China(61877035).

References

[1] Carroll Bill D., Gieser Shawn N. and Levine David, "A hierarchical project-based introduction to digital logic design course", ASEE Annual Conference and Exposition, Conference Proceedings, 2014.

[2] Dugan Joanne Bechta,"Learning about Digital Logic by Discovery", ASEE Annual Conference & Exposition, Conference Proceedings, 2015.

[3] Dua Rohit, "Interactive Digital Logic Laboratory for K-12 Students", ASEE Annual Conference & Exposition, Conference Proceedings, 2017.

[4] Gunes M., Thornton M.A., Kocan F. and Szygenda S.A., "A survey and comparison of digital logic simulators", Midwest Symposium on Circuits and Systems, v 2005, pp 744-749.

[5] Alsadoon Abeer, Prasad P.W.C. and Beg AzamJ, "Using software simulators to enhance the learning of digital logic design for the information technology students", European Journal of Engineering Education 2017, v 42, n 5, p 533-546.

[6] Wang Heng, Chen Xinrui, "Development and Optimization Design of Digital Logic device based on FPGA", 2nd International Conference on Computer Information Science & Application Technology, CISAT 2019.

[7] Hoffbeck Joseph P., "Using Practical Examples in Teaching Digital Logic Design", ASEE Annual Conference and Exposition, Conference Proceedings, 2014.

[8] Bonniwell Jennifer L. and Schneider Susan C., "Using the Basys-3 Trainer to Support VHDL in Digital Logic Fundamentals Course", Proceedings - Frontiers in Education Conference, FIE, 2016.

[9] Jan DÜRRE, Guillermo PAYÁ VAYÁ and Holger BLUME, "Teaching Digital Logic Circuit Design via Experiment-Based Learning - Print your own Logic Circuit", WMSCI 2016 - 20th World Multi-Conference on Systemics, Cybernetics and Informatics, Proceedings, v1, pp 242-247.

[10] LaMeres Brock J. and Plumb Carolyn, "Design & Evaluation of a multi-purpose course structure for teaching digital logic", ASEE Annual Conference and Exposition, Conference Proceedings, 2019.

[11] Yelamarthi Kumar and Drake Eron E., "Increasing Student Learning and Interest in a Flipped First-Year Electrical & Computer Engineering Course", ASEE Annual Conference and Exposition, Conference Proceedings, 2015.

[12] De La Rosa-Pohl Diana G., Long Stuart A. and Goodwin Casey, "Introduction of a Digital Logic Project in a First-Year Honors Engineering Course", ASEE Annual Conference and Exposition, Conference Proceedings, 2013.

[13] Estrada Francisco J., "Practical Robotics in Computer Science Using the LEGO NXT", Annual Conference on Innovation and Technology in Computer Science Education, ITiCSE 2017, v Part F128680, pp 329-334.