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Network Transport Layer Experiment Design Based on Online Platform

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***Abstract*—Through three years' teaching practice, our teaching group found that the current computer network experimental teaching cannot well complete the training objectives of curriculum. Based on the CS144 course experiment of Stanford University, our teaching group has carried out an improved design. The improvements include the online experiment platform, the addition of a comprehensive experiment component, and the enrichment of the testcase framework. We have deployed the improved network transport layer experiments in the spring semester of 2022. The teaching results show that the improved network transport layer experiments takes the lead and improves the innovative and challenging degree of network practice. The improved experiment solves the problems of lack of pratice for students and lack of difficulty in practice. The improved experiment allows students to master the principles of the TCP protocol and apply what they have learned in their future work, and some students have stimulated their interest in scientific research and achieved good results.**

***Index Terms*—computer network, online experiment platform, comprehensive experiment, TCP**

I. Introduction

Since the 1990s, the computer network technology represented by the Internet has developed rapidly, and has gradually developed from an initial educational and scientific research network to a huge commercial network [1]. Computer networks are changing all aspects of work and life, and accelerating the process of the global information revolution, which is the greatest change in communication since the invention of printing.

Computer network is the core basic course of computer major. The goal of the course "Computer network" is not only to give students a deep understanding of the design and implementation technology of many protocols, but also let students initially accumulate development experience and the ability to apply the concepts and techniques discussed in the course to hardware/software design and development and scientific research. Computer network is a course focusing on the network protocol and related technologies of both Internet and Intranet. The course mainly covers network architecture, reference model and its applicative functions, both transport and network layer protocols. Of all transport and network layers protocols, the most important part is TCP/IP protocol. The TCP/IP protocol suite realized the Internet architecture and allowed communications between computers, smart phones and embedded devices. As the most popular open protocol suite, TCP/IP protocol is open, so as many of its implementations. It is said that TCP/IP protocol suite constitute the foundation of the Internet.

The computer network course not only emphasizes the study of theory, but also emphasizes the practice of experiment. Practical teaching is the testbed for classroom theoretical teaching. Appropriate practical teaching can significantly enhance students' innovative ability. Practical teaching is the core of modern teaching technolgies [2], [3]. Therefore, the practical teaching plays a key role in the computer network course. There are two types of computer network experiments: real scene experiment and virtual experiment. In the real scene experiment, a large amount of capital is required for equipment purchase and its supporting. To build a fully functional experiment environment requires a variety of equipment of different types (switches, routers, firewalls, servers, etc.). In order to meet different experiment needs, the number of equipment required is quite large, and the cost of equipment update and maintenance is high. Real scene experiments, despite their many shortcomings, are irreplaceable in practice. Real scene experiment is the effective way to improve students' intuitive perceptual cognition, promote knowledge understanding, and cultivate students' comprehensive application and innovation ability. [4] using actual Huawei hardware equipment, let students practice VLAN, DHCP and other network settings experiments, which produced good results. Using virtual simulation software such as Wireshark, Packet Tracer, and ns2 can well avoid the problems of real scene experiments [5], [6]. Wireshark software is often used as the main auxiliary tool for experiments on TCP/IP principles and applications [7]. Using wireshark software, Students grab the specified protocol data packets of the network, analyze the header information, data information and time information carried by the data packets to learn the relevant theory of the TCP/IP protocol. In the teaching process, different tools will also be used for different teaching objectives, for example, use command line tools Ping and Nslookup to realize the application practice of DNS [8]. By analyzing the relevant literatures, our teaching group believes that there are some problems in the current conventional computer network experiments.

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- The traditional experimental difficulty is not hard enough. Most network experiments use existing software such as Wireshark, NS-2, and follow fixed steps to complete the experiment, which is difficult to exercise students' innovation ability.
- The experiment process lacks source code design and implementation, and the training of students' system ability is insufficient.
  For example, in the TCP protocol experiment, the TCP protocol is only verified by analyzing the network packet capture without examining the source code. This type experiment is not enough to cultivate the students' system design ability.

In contrast, the CS144 course experiment of Stanford University starts from the source code and guides students to supplement the source code according to the course knowledge [9]. The CS144 experiment design is both difficult and flexible, and it can exercises students' computer programming ability. The experiment scheme contains a number of interrelated sub-problems, guiding students to look at the problem from a systematic perspective and realize the systematic solution of the problem. The teaching group made adaptive modifications based on the experiment framework of Stanford University's CS144 course and conducted teaching practice in the spring semester of 2022, obtained relevant teaching data, and achieved good results.

II. Introduction of Stanford University CS144 Course Experiment

Stanford University CS144 course experiment takes the experiment of TCP protocol as the main topic. The goal of the experiment system is to require students to use C++ programming to realize a real and usable TCP protocol. In the experiment design, according to the principle of modular decomposition, the TCP protocol is decomposed into 8 sub-experiments, which are: networking warmup, stitching substrings into a byte stream, the TCP receiver, the TCP sender, TCP in full, the network interface, building an IP router, putting it all together. After finalizing the content integration, the student's TCP source code can run directly and communicate with the real network. The experiment scheme can solidly improving the students' systematic ability.

III. Improved experiment design

A. Improved experiment organization and time arrangement

In terms of specific experiment implementation, 8 experiments are designed in this course experiment, of which the first 7 experiments are basically consistent with the CS144 course experiments. The time arrangement of each experiment is generally 2 weeks, and the most complex lab4 experiment time is 3 weeks. In addition, a comprehensive experiment is added at the end, allowing students to choose topics freely and conduct research on topics. This course has 3 class hours per week on the curriculum, a total of 40 class hours. The relationship of each experiment is compared, and the time arrangement of the experiment is shown in TABLE. I.

TABLE I
THE RELATIONSHIP TABLE OF CS144 AND IMPROVED EXPERIMENT.

CS144	Improved experiment	Time Arrangement
Lab checkpoint 0 networking warmup	Lab0	Teaching week no. 1-2
Lab checkpoint 1 stitching substrings into a byte stream	Lab1	Teaching week no. 2-3
Lab checkpoint 2 the TCP receiver	Lab2	Teaching week no. 3-4
Lab checkpoint 3 the TCP sender	Lab3	Teaching week no. 4-5
Lab checkpoint 4 the summit (TCP in full)	Lab4	Teaching week no. 5-7
Lab checkpoint 5 down the stack (the network interface)	Lab5	Teaching week no. 7-8
Lab checkpoint 6 building an IP router	Lab6	Teaching week no. 8-9
Final checkpoint putting it all together		
-	Comprehensive Experiment	Teaching week no. 10-14

B. Additional Experiment Components

The additional experiment components are optional, and do not provide detailed requirements. Ask students to complete their own research, define problems, and give their own solutions. Additional experiment components are as follows.

- Based on the experimental framework, design and implement a new protocol.
  The topics include adding congestion control, fast retransmission, implementing RIP or OSPF protocols, etc. They requires students to implement the above algorithms and design the corresponding testcase framework.
- Dedicated research analysis for parts of interest in the experimental framework.
  The topics include the analysis of the EventLoop class, the interactive analysis of bidirectional_stream_copy() and _initialize_TCP() on network socket read and write, etc.
- Share experience in the realization of this experiment.
  This topics include the analysis report of the error-prone parts found during the experiment, the addition and reorganization of the PPT content of the experiment explanation, etc.

C. Online platform for experimental deployment

Students use their account to conduct experiments through the CourseGrading platform. The CourseGrading platform is designed by Zhengzhou Yunhai Technology Co., Ltd. The CourseGrading platform platform is in a leading position in the construction of domestic online experimental platforms, and the platform has very broad application prospects and promotion value. Based on this platform, the arrangement of experimental tasks, the statistics and evaluation of experimental scores, etc. can be completed. The student online experiment interface is shown in Fig. 1. In Fig. 1, the left

side is the experimental description, and the right side is the virtual machine experimental environment.

The main steps for students to use the platform are as follows.

- Students complete login first.
- On the online experiment platform, students choose the experiment assigned by teachers to conduct experiment.
- Students edit source code online on the platform and save to the gitlab.
- The source code can be compiled and run online, and students can view the results of the experiment through the platform online judge system.
- If students encounter bugs, they can contact the teaching assistant to debug in the online experiment platform.
- After the experiment is completed, students log out the platform.

The main work of teachers and teaching assistants on the platform are as follows.

- Complete the registration of each student account according to the class roster.
- Arrange the experiment according to the time schedule.
- Query the students' experimental status(experiment time, experimental evaluation results), and analyze the teaching situation based on the queried data.
- Debug the source code in the students' virtual machine online at the student's request.

Fig. 1. Online experiment interface.

D. Improvements to the experimental framework

The original CS144 experimental test framework has 161 test cases, which can be tested comprehensively. However, since the experimental frame of this course has been shared on the Internet for several years and has not been updated, students can easily find many solutions for this experiment on open source code platforms such as github and gitee. This situation challenges the validity of the experiment. The teaching group has also conducted special research on these shared codes, and found that some codes can indeed pass the CS144 experiment with the original test framework, but it is not perfect, and there are still some hidden bugs. In order to improve the effectiveness of the experiment and prevent students from plagiarizing, it is necessary to design new test cases and conduct more comprehensive tests. The design of new test cases mainly involves two aspects.

- Add functional testcase.
  For example, in the lab5 the network interface experiment, some network codes (https://gitee.com/kangyupl/sponge.git) can perfectly pass the original make check of the experimental framework. Through analysis, it is found that the implementation has the problem of exit exception. Therefore, the detection testcase of program exit status is specially added.
- Add performance testcase.
  In Lab checkpoint 6 building an IP router, students are required to complete the establishment and query of the routing table in the network router. The teaching group has specially increased the requirements for the performance of the routing query algorithm, and guided students to use the dynamic hash table or radix tree for routing query. By evaluating the routing performance achieved by students, students are encouraged to conduct scientific research and increase their interest in scientific research and innovation.

IV. Teaching Practice and Improvement

A. The situation of teaching practice

In the spring semester of 2022, this course has carried out teaching practice. Since it is the first time to open, there are fewer students taking this course. In this experimental course, 12 students initially chose courses, and finally 4 students completed all experiments (the remaining 8 students dropped out of the class due to other reasons), and the completion rate of the experiment was 33.3%. The low completion rate also shows that this experiment course of a certain degree of difficulty. The small number of students in this course has the advantage that teachers and teaching assistants have ample time to understand the specifics of each student.

The average experimental time of Lab0-lab6 is shown in Fig 2. The experiment time can reflect the difficulty of the experiment, the more difficult the experiment will take longer time. From Fig 2, it can be found that the first four experiments of lab0-lab3 are less difficult. The general experiment time of lab0-lab3 is about 500 minutes. Lab4 is very difficult, the average time is 1221 minutes, with the longest being 3000 minutes. Lab5 and lab6 are less difficult to implement. Comprehensive experiment is not conducted on the online platform, so the statistics of the time of comprehensive experiment are not carried out.

The total time of each experiment for a single student is shown in Fig 3. It can be found that the data is quite different, and it is distributed from 2274 to 7143 minutes. Through other teaching data, it is found that the capability of student No.

4 is very prominent, so his time spent on this experiment is relatively short. This also shows that the stronger the student's personal ability, the shorter the time it takes to complete the same work.

The average score for each experiment is shown in Fig 4. Due to the difficulty of lab4, some students cannot pass all test cases such as big data transmission (transmitting 1M data in a packet loss environment). Lab5 adds a lot of functional tests, which are very comprehensive, resulting in relatively low student scores.

The average scores of students in lab0-lab6 are shown in Fig 5. In general, students are better at completing the experimental requirements.

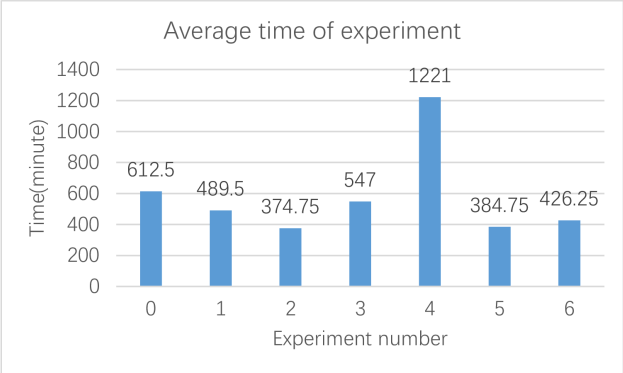

Fig. 2. Average time of experiment.

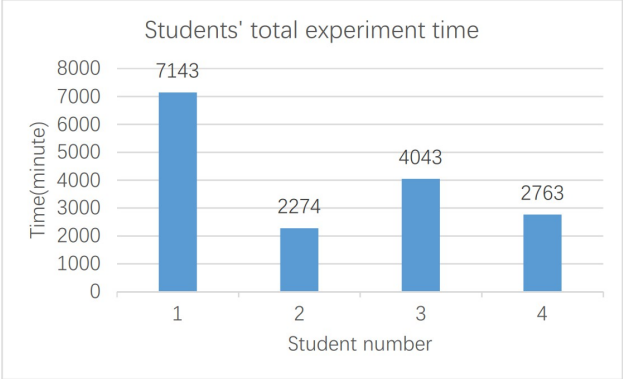

Fig. 3. Students'total experiment time.

B. Improvement direction

According to the feedback of students, the reasons for giving a positive evaluation to this experiment mainly include the following.

- After completing this experiment, students can gain a lot of knowledge about and TCP.
- The design of the experimental framework of CS144 is quite delicate. There are many bright designs, and students have learned a lot of relatively novel technologies of C++17 language.

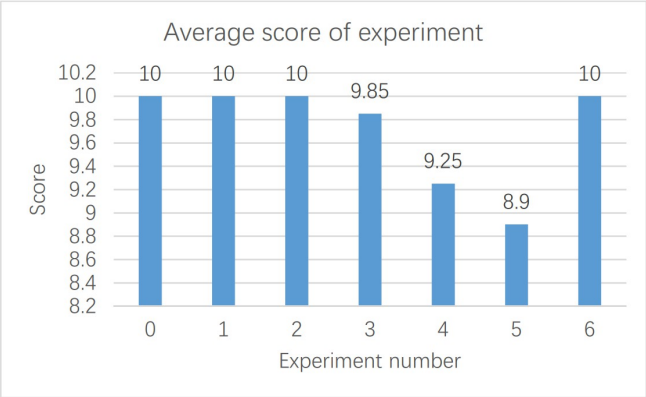

Fig. 4. Average score of experiment.

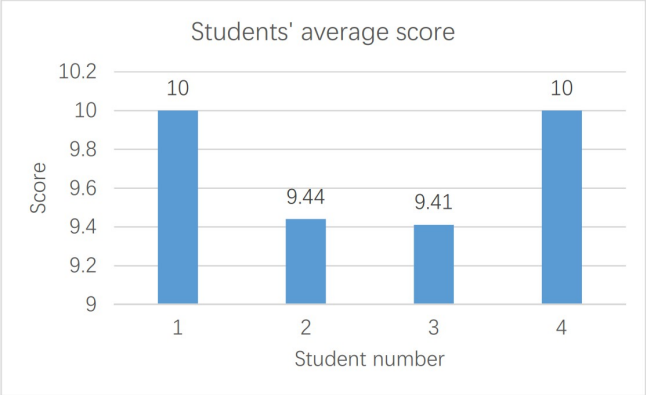

Fig. 5. Students' average score.

At the same time, students also reported the following problems in the course.

- The experiment is difficult and requires a lot of time to conduct the experiment (as shown in Fig 3, the student number 1 nearly takes 50 hours for lab4).
- This experimental course has 40 class hours, but only 1 credit, the credit is too low.

In response to the above teaching feedback, the teaching group believes that the following improvements can be made in the future experimental organization.

- Reduce the difficulty of the experiment and complete the experimental guide in detail. Explain the key points and difficulties of the experiment clearly in the experiment guide.
- For the experimental framework, design more functional implementations (such as congestion control, sack) and performance requirements in comprehensive experiments. Allow students to have more free space for exploration and stimulate students' interest in scientific research.

V. Conclusion

Based on the CS144 experiment of Stanford University, we have reorganized and designed a new experiment course. By allowing students to implement a real and available TCP protocol software and IP routing by themselves, strengthen students' understanding of the core protocol of TCP/IP, and cultivate students' ability to combine theory with practice. Through the implementation of this experiment, students are trained to learn and master related software tools. During the experiment, students need to master software engineering methods and tools (such as gdb, bash script, cmake, tshark, tun, tap, etc.) as well as new features of C++17 language. Through the use of the online platform, conducting experiments in a fixed laboratory is no longer required, thus expands the time and space constraints of experiments, and adapts to the current development needs of online experiments. By adding new TCP test framework and IP routing performance analysis, we improved students' understanding of network related protocols and algorithms. Students experiment on the online platform, and the relevant experimental data is convenient for statistics and analysis of learning situation. In the future work, according to the teaching feedback information, the teaching group will further optimize the teaching plan and improve the teaching effect.

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