Virtual Experiments for Introduction of Computing: Using Virtual Reality Technology

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***Abstract*—Introduction to Computing is a public course for the first-year non-major undergraduate students, aiming at training students for the abilities in computer science and technology with computational thinking. However, as new computer technologies emerge continuously and rapidly, it is required for this course to accommodate more and more knowledge. Therefore the teaching contents are growing enormously, which makes it very difficult to cover all of them in limited hours, and therefore sets an obstacle in understanding computing principles and building up a clear and general picture of computing, especially for non-major students. As computer science and technology are becoming more and more essential for various disciplines and majors, it is urgent for the education community to find out an effective and propagable way to solve this problem. In this regard, we employ virtual reality technology to the experiment teaching of this course, and have developed 18 virtual experiments to support the whole teaching process. For example, Turing machine is a basic model for computer science and technology. However, since it is not a real machine, it is not easy for the students to imagine the working process of Turing machine and understand the related concepts. Another example, the execution of an instruction is very important to understand the principles of computer organization. However, as the information flow is invisible, it is difficult and time-consuming for the teachers to explain how an instruction is executed inside a computer. Therefore, 3D modeling and animation techniques are used to demonstrate the invisible micro-structure of computers, and human-machine interaction and visualization techniques are used to present the internal process of information evolution, thus constructing a complete virtual experiment system of this course, including demonstration experiments, verification experiments and interaction experiments. Our virtual experiments have applied software copyrights and served more than 12,000 students from five universities of China since 2013. The evaluation demonstrates that the virtual experiments have produced excellent results in both teaching effectiveness and learning efficiency, relieved the conflicts between limited hours and vast knowledge, and helped students understand and build up the knowledge of computing.**

***Keywords*—virtual experiments, Introduction to Computing, virtual reality.**

I. INTRODUCTION

Introduction to Computing is a public course for the first-year non-major undergraduate students, which has been offered in Chinese universities for more than twenty years. Computing technology has become one of the fastest growing domains since the new century. Though computer science is a discipline itself, it can promote the development of other disciplines, and many challenging and frontier research can be conducted using advanced computing technology [1]. Therefore, the development of various disciplines urgently requires computer science and technology to provide deeper and wider support functionalities.

In 1990s when the idea of information era had just swept across China, the goal of this course is to make students familiar with digital media and information tools, which is essentially culture popularization of computer. However, as the role of computer science and technology has become more and more important in various disciplines, the course of Introduction to Computing is now aiming at training students for the abilities of computational thinking [2], which also brings about the reformation and innovation in the goals, contents and means of teaching.

In the rebuilding of this course, some issues have drawn much attention and lead to comprehensive discussion.

On one hand, the concept of computational thinking proposed by Jeannette M. Wing [2] has been accepted in research and education communities in China, and Guoliang Chen further analyzed the connotation and denotation of computational thinking considering the actual situation of Chinese colleges and universities, and proposed the overall goals of the innovation in computing education [3]. However, it is still ambiguous with respect to how to effectively promote the computational thinking oriented reformation of computing education. For example, large amounts of knowledge are not only the reflection of computing discipline, but also a contradiction with the limited course hours. Therefore, it is very difficult to accommodate all these knowledge by using conventional means of teaching, especially when it comes to the invisible, abstract and complex concepts and principles.

On the other hand, experiments are essential for computing education. However, with respect to this course, the experiments have been keeping the same since 1990s, which are mainly the usage of system software and application software. Therefore, the experiments of this course are not in the line with its teaching contents, and the lack of effective experiments has hindered the goal of computational thinking. Though it is very urgent and important to establish new experiments that match the goal and contents of this course, it is not easy to keep pace with the rapid changing technologies, which brings about obstacles to the new experiment system.

Aiming at the above problems, we design and implement virtual experiments for the course of Introduction to Computing using visualization and simulation technologies. Virtual experiments [4] and virtual laboratories [5] have drawn increasing attention from education and research communities all over the world.

An important advantage of virtual experiments is that students can conduct experiments on unobservable phenomena [4], [6-9]. In this course, the teaching contents severely involve the evolving process of information such as the data transmission on computer networks and the micro-structure of computers such as the execution of an instruction, which are all invisible and therefore cannot be observed by conventional physical means of experiments. Therefore, we use 3D modeling and animation techniques to demonstrate the invisible micro-structure of computers, and use human-machine interaction and visualization techniques to present the internal process of information evolution.

Besides, virtual experiments offer much higher efficiencies over physical experiments because they typically require less setup time and provide results of lengthy investigations instantaneously [10], which enables more efficient and effective understanding on the important and difficult points. This is very important for the course of Introduction of Computing which has very much knowledge and very limited course hours.

II. DESIGN OF VIRTUAL EXPERIMENTS

The development of computing technology has caused enormous impact on education, especially when it comes to the virtual reality technology, which is greatly changing the ideas and methods of education. Based on the virtual reality technology including visualization, human-machine interaction and simulation, we have designed and implemented the experimental system for the course of Introduction of Computing.

In this course, virtual experiments are beneficial in the following three aspects.

- Describing abstract concepts in the realization of computing.
- Presenting the organization and micro-structure of computers in the working principles of computers.
- Visualization of the unobservable process of the information storage, transmission and processing.

Using the virtual reality technology, 18 virtual experiments including demonstration experiments, verification experiments and interaction experiments are designed and implemented, which are listed in Table I.

TABLE I
LIST OF VIRTUAL EXPERIMENTS

No.	Virtual Experiment	No.	Virtual Experiment
1	Turing machine and virtual assembling of computers	10	Computer animation
2	Representation and calculation of data	11	Word processing
3	Character coding and information processing	12	Data management and data base
4	Execution of a computer instruction	13	Computer based problem solving
5	Process management and virtual machine	14	Execution of an algorithm
6	File management and disc recovery	15	Object oriented approaches
7	Communication in WAN and transmission of emails	16	Simulation and MATLAB
8	Cloud computing and virtual service	17	Computer virus and fire wall
9	Image generation and processing	18	Intelligent optimization

Some examples of the above experiments are shown in Fig.1. With respect to the invisible process of information evolution, such as the running process of an algorithm, visualization techniques are used to develop verification experiments. With respect to the organization and micro-structure of computers, 3D animation and human-machine interaction techniques are used to develop interaction experiments. With respect to network security such as virus generation, transmission and attack, simulation techniques are used to develop demonstration experiments. Besides, various experiments are also developed to present the concepts and principles in data overflow, file management, process scheduling, network routing, etc., enhancing the understanding of knowledge for the students.

(a) virtual assembling of computers (b) searching for Chinese characters

(c) computer virus (d) ant colony optimization

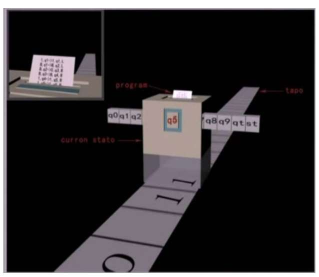
Fig. 1. Some examples of the virtual experiments

III. CASE STUDIES OF VIRTUAL EXPERIMENTS

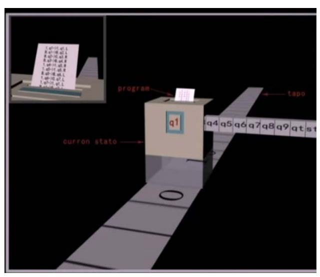
A. Experiment 1: Turing Machine

The model proposed by Turing presents the essential concept and principle of computing, and is a milestone for computer science. However, because it is not a real machine but an abstract model, physical experiments can hardly be conducted on Turing machine, which brings about difficulties in understanding such important knowledge.

Computer animation is a method to produce the effect of moving objects using a sequence of static images. In this experiment, 3D animation is applied demonstrate the Turing machine and its working process. The computation of 2^x is used as an example, and the rules, states, inputs and outputs are visualized. The experiment includes four 3D models, i.e., the punched tape, the read/write head, the state storage, and the output device. This universal machine model is put onto the screen, and its working process is demonstrated by 42 seconds of animation, which presents the components of the Turing machine, the input of the punch-tape coding, the states of the read/write head, and the output results. Fig. 2 shows the process of the animation, in which (a), (b) and (c) represent the frames at the 32nd, 34th, 36th and 39th second, respectively. The concept and principle of the Turing machine is demonstrated in this experiment, which is beneficial for both learning and teaching.

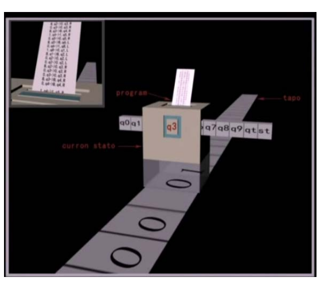


(a) Status at the 32nd second



(b) Status at the 34th second.

(c) Status at the 36th second



(d) Status at the 39th second

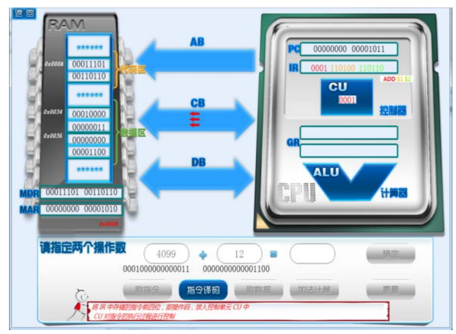
Fig. 2. Working process of the Turing machine

B. Experiment 2: Execution of an Instruction

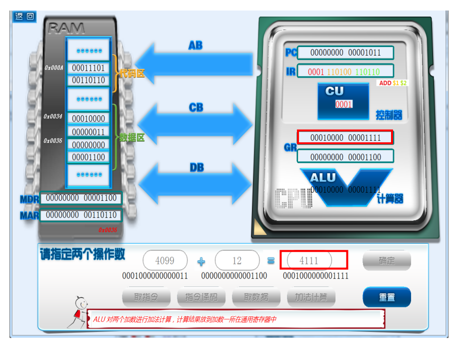
Even if non-major undergraduate students have the basic idea of 0s and 1s in computers, it is still difficult to perceive the whole process of the capture, transmission, integration, processing, and output of information. This is because the invisibility of the internal micro-structure of computers and the evolution of information. Therefore, interactive experiments are developed to mimic and present the unobservable working processes.

For example, a computer handles the instructions by repeating instruction fetching, instruction decoding and instruction executing. In order to mimic this process, the interactive experiment, i.e., the execution of an instruction, is designed and implemented, which demonstrates how the components collaborate with each other and how the information flows inside the computer.

The design of this experiment is as follows. Using visualization and human-machine interaction techniques, five stages are incorporated, i.e. interactively specifying the operands, fetching instruction from memory, decoding the instruction, fetching the operands from memory, and executing the instruction. Several important components of the computer, e.g., controller, adder, and storage, are illustrated, and the flow and evolution of the information are visualized. Fig. 3 shows the execution of an instruction, in which decoding and execution of the addition instruction are presented in (a) and (b), respectively.



(a) Instruction decoding



(b) Execution of the addition micro-instruction

Fig. 3. Emulator for the execution of an instruction

As illustrated by Fig. 3, the interface of the experiment is divided into two main parts. The internal structures of the computer are shown in the upper part, and the human-machine interaction interface is provided in the lower part. The internal structure of the computer mainly includes the RAM and the CPU. Some details such as the sections in the RAM, the ALU and controller of the CPU, are also demonstrated. In addition, the three buses connecting the RAM and the CPU are emphasized, and the information flow can be dynamically displayed during the experiment. For example, Fig. 3(a) shows the decoding stage in the execution of the instruction, when the controlling information flow for instruction decoding is transmitted on the control bus. Fig. 3(b) shows the status of the ALU and the information flow in the controller when executing the addition instruction.

Since this experiment involves a wide range of information, the experiment report is important for guiding the students to achieve the purpose of this experiment.

The recording sheet of this experiment is shown in Table II.

TABLE II
RECORDING SHEET OF THIS EXPERIMENT

Question	Result
Step 1 Assign two operands	
Operand 1, operand 2	
The address of the instruction in the program counter	
The instruction code at the corresponding instruction address in RAM	
The address of operand 1 in RAM	
The address of operand 2 in RAM	
Step 2: Fetch the instruction	
On which bus does CPU send the memory address to RAM?	
Where is the instruction received from CPU stored in RAM?	
What information is stored in MAR? What is its binary code?	
What is the memory address corresponding to the binary code in MAR? What data is stored at that memory address? Which register is the data stored in?	
What happens to the content in the program counter after it is accessed? Why?	
On which bus does RAM send the data in MDR to CPU?	
Where does CPU strore the instruction received from RAM?	
What is the binary code in IR?	
Step 3: Instruction decoding	
What are the memory addresses of the operation code and the two operands in IR, respectively? (Please denote them by six binary numbers and four hexadecimal numbers).	
Where does decoding happen? On which bus does it send the result to RAM?	
Step 4: Fetch operands	
On which bus does CPU send addresses? Where is the address stored in RAM?	
Which register does RAM use to store the first operand? On which bus dose RAM send it to CPU?	
Where is the first operand stored in the CPU after it is fetched from the RAM?	
Step 5: Calculate the addition of two operands	
Where does CPU calculate the two operands?	
When the addition is completed, where is the result stored in the CPU?	

IV. APPLICATION RESULTS

We have designed and implemented 18 virtual experiments which have applied software copyrights and served more than 12,000 students from five universities of China since 2013. These students come from more than 60 majors, and the results presented in this section are collected from 1,158 undergraduate students and 40 teachers in Beijing Institute of Technology. Two types of surveys were conducted, one of which was for the students and the other for the teachers.

The feedback from students is shown in Table III. As indicated in Table III, the motivation of study was enormously promoted with the application of virtual experiments, and most students found it easier to learn the knowledge and perform the experiments, and more effective to communicate in the group and with the teachers.

TABLE III
EVALUATION RESULTS FROM STUDENTS

Evaluated Factors	Items in the Factor	Results	Methods
Motivation	Experiment design	87% were interested in the virtual experiments.	Student survey
	Usefulness of experiments	83% found virtual experiments help them understand knowledge.	Student survey
	Grading criteria	75% were satisfied with grading.	Student survey
Knowledge and Experiment Process	Understanding of knowledge	85% found it easier to understand knowledge via virtual experiments.	Student survey
	Performability of experiments	98% completed the virtual experiments.	Student survey
	Setup experiment environments	89% found it easier to setup experiment environments.	Student survey
Collaboration in Teamwork	Teamwork in experiments	83% were satisfied with the shared environments.	Student survey
	Discussion in teamwork	80% found the discussion more effective via virtual experiments.	Student survey
Interaction with Teachers	Effectiveness of interaction	85% found the interaction more effective via virtual experiments.	Student survey

The feedback from teachers is demonstrated in Table IV, which indicated that most teachers found it more efficient and effective in teaching, as compared with the previous semesters without the assist of virtual experiments.

TABLE IV
EVALUATION RESULTS FROM TEACHERS

Evaluated Factors	**Items in the Factor**	**Results**	**Methods**
Efficiency	Knowledge contained	85% included more knowledge in the course.	Teacher survey
	Experiments completed	96% students completed more experiments in unit time.	Checked by teachers
	Preparation of experiments	98% spent less time in preparation of experiments.	Teacher survey
Effectiveness	Explanation of knowledge	85% found it easier to explain knowledge via virtual experiments.	Teacher survey
	Understanding of knowledge	The average scores increased 12%.	Quiz and exams
	Creativity	8% students contributed to the improvements of experiments.	Grading
Interaction with Students	Efficiency of interactions	85% found the interaction more efficient via virtual experiments.	Teacher survey
	Effectiveness of interaction	82% found the interaction more effective via virtual experiments.	Teacher survey

V. CONCLUSION

With the rapid growth of computing technology, various disciplines require computer science and technology to provide more powerful support, resulting in the innovation and reformation of the course of Introduction to Computing. In order to present the unobservable, abstract and complex concepts and principles, virtual experiments were designed and implemented. The application results show that the virtual experiments are beneficial for both learning and teaching.

REFERENCES

[1] Reed D A, Bajcsy R, Fernandez M A, et al. Computational science: ensuring America's competitiveness[R]. PRESIDENT'S INFORMATION TECHNOLOGY ADVISORY COMMITTEE ARLINGTON VA, 2005.

[2] Wing J M. Computational thinking[J]. Communications of the ACM, 2006, 49(3): 33-35.

[3] G Chen, R Dong. Computational Thinking and Computer Education in China [J], Education of Chinese Universities. 2011(1), 7-11 (in Chinese).

[4] De Jong T, Linn M C, Zacharia Z C. Physical and virtual laboratories in science and engineering education[J]. Science, 2013, 340(6130): 305-308.

[5] Xu L, Huang D, Tsai W T. Cloud-Based Virtual Laboratory for Network Security Education[J]. Education, IEEE Transactions on, 2014, 57(3): 145-150.

[6] Zacharia Z C, Constantinou C P. Comparing the influence of physical and virtual manipulatives in the context of the Physics by Inquiry curriculum: The case of undergraduate students' conceptual understanding of heat and temperature[J]. American Journal of Physics, 2008, 76(4): 425-430.

[7] Jaakkola T, Nurmi S, Veermans K. A comparison of students' conceptual understanding of electric circuits in simulation only and simulation‐laboratory contexts[J]. Journal of research in science teaching, 2011, 48(1): 71-93.

[8] Zhang Z H, Linn M C. Can generating representations enhance learning with dynamic visualizations?[J]. Journal of Research in Science Teaching, 2011, 48(10): 1177-1198.

[9] Deslauriers L, Wieman C. Learning and retention of quantum concepts with different teaching methods[J]. Physical Review Special Topics-Physics Education Research, 2011, 7(1): 010101.

[10] Zacharia Z C, Olympiou G, Papaevripidou M. Effects of experimenting with physical and virtual manipulatives on students' conceptual understanding in heat and temperature[J]. Journal of Research in Science Teaching, 2008, 45(9): 1021-1035.