Infrastructure of Web-based VR-form Virtual Laboratory

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Abstract

With the recent technological advancing, E-learning has been enabled to operate via the World Wide Web (WWW). Being an important education method, online virtual experiment system is also greatly developed in these years. It has been used to aid the education in some areas, for example, control engineering, physics phenomenon comprehension.

For the sake of aiding the education of undergraduate's engineering experiment curriculum, we have developed an infrastructure of Web-based VR-form Virtual Laboratory (WBVL). Using this infrastructure, we have successfully implemented several virtual engineering chemical and mechanical experiments.

With its four important features, three-dimension, interactivity, web basing and virtuality, WBVL can make its users feel as if they are performing a real-world experiment. VRML is used to build the virtual 3D scene, and Script node, EAI and SDK are used to extend the VRML's interactive and computational ability. Using client/ server model, WBVL has well-defined system architecture. The set-up of WBVL is composed of user's guide, laboratory experiment, online help and experiment report. Combined model is the mostly used virtual experiment operation model of WBVL.

Keywords: Virtual Experiment, Virtual Laboratory, Virtual Reality, VRML, Curriculum, Education, Web

1 Introduction

The recent technological advances in the Internet have enabled a multitude of applications to operate via the World Wide Web (WWW). E-Learning is such an application. To this end various institutions and universities are offering on-line courses which student from all over the world could subscribe to and attend. Various teaching methods and tools are appeared, such as Web Courseware, On-line Answer Machine, Web Classroom, etc. Being an important education method, Web-based Virtual Laboratory (WBVL) is also greatly developed in these years. Several recent articles have described the design of Virtual Experiment systems and its' use in academe [4], [5], [6], [7]. In these articles, Virtual Experiments have been used to aid the education in some areas, for example, control engineering, physics phenomena comprehension.

In order to aid the education of undergraduate's engineering experiment curriculum, we have developed an infrastructure of Web-based VR-form Virtual Laboratory (WBVL). Using this infrastructure, we have successfully implemented several virtual engineering chemical and mechanical experiments, such as The Measurement of Water's Degree of Hardness.

In section 2, four basic features of WBVL are presented. We give some technical details in section 3. Section 4 deals with the set-up of WBVL. The next section introduces the virtual experiment operation model of WBVL. In the last section we give some concluding remarks.

2 Features of WBVL

Education in areas of engineering, physics, chemistry, biology faces severer problem because the ideas and phenomena involved in such areas are complex and hard to demonstrate on the conventional blackboard. Traditional 2-dimension Web Courseware faces the same problems. For example, it is hard to let students to understand the structure of molecules by 2D graphics. In order to make students understand and master the experiments easily, it is demanded to implement virtual experiments in 3D form. In 3D scenario, students can observe any objects from any view points and any angles at any time. This feature makes a great contribution to help students accomplish experiments.

When performing experiment, student should run the experiment instruments, observe experiment phenomena, record experiment data and complete experiment report. This means that student should interact with experiment environment in every stage of an experiment. For this reason, interactivity is an important feature of WBVL. Each virtual experiment is capable of receiving student's operation and giving certain reaction according to the student's action. Only using a virtual experiment with good interactivity, can student feel as if he was really "doing" an experiment.

Because of the special education manner of E-Learning, students cannot go to laboratories to perform experiments. If they want to do some experiments, the only way is through Internet. So network basing is another important feature of WBVL. With network based virtual experiments, the arena of experimental education does not have to be limited to the laboratory.

Virtuality is the last important feature of WBVL. In some articles mentioned above, a kind of virtual experiment that allows user to control actual hardware and instruments via Internet is put forward. It is not realistic, however, in E-Learning. In E-Learning, experiments of almost all subjects should be implemented. Some experiments take a long duration time, and some cost expensively. The most severe drawback of that kind of virtual experiment is it cannot allow multiple users to perform an experiment simultaneously. This means that E-Learning center should operate and maintain more than one set of plant for a virtual experiment. This is a big burden for E-Learning center. So only "pure virtual" experiments are realized in WBVL.

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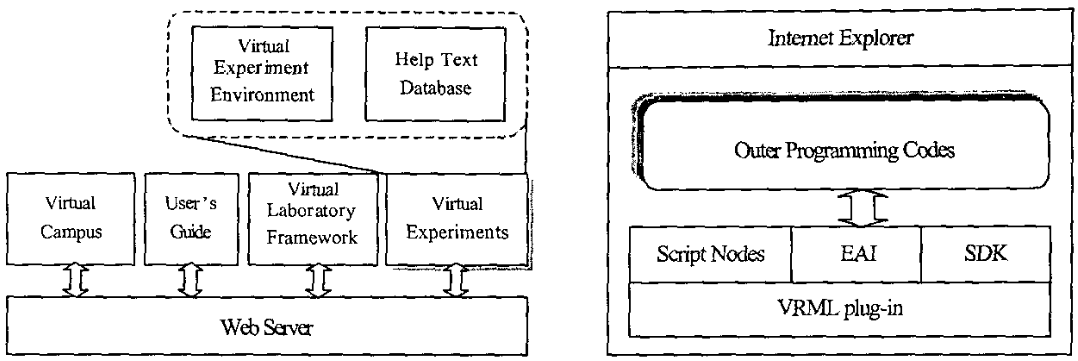
3 Technical Realization and System Structure

Being a web-based application, Server/Client model is employed in WBVL. Server side is based on a web server, as shown in Figure 1 (a). All the virtual experiments stuff is kept on the server side. When student wants to load one experiment, client sends a request to the server, and server delivers the certain experiment data to the client. The benefit of this approach is that updates and revisions are done centrally on the server and the latest version is always available to all clients.

The architecture of client side is shown in Figure 1 (b). Microsoft Internet Explorer is the only user interface on the client side. All the experiment stuff is interpreted and represented in 3D form on the client side. 3D scenes of the virtual laboratory and virtual experiments are described by VRML, for VRML is the only standard for describing interactive 3D objects and worlds on web. A VRML plug-in is needed on the client side to interpret the 3D scenes. Additional software components in forms of Java applets and Scripts are shown in Figure 1.



(a) Server Side System Architecture (b) Client Side System Architecture

Figure 1: System Architecture

In the following we give a brief description of each of these components:

3.1 Web Server

Web Server is used on the server side to deliver virtual experiment curricula to the client side.

3.2 Virtual Campus

Virtual Campus is a 3D virtual environment of a university campus in which students can navigate and go to the different laboratory to perform different experiments just like in the true world. In virtual campus, there are many buildings and laboratories, and some of the laboratories have hyper-links directing to different experiments.

3.3 User's Guide

User's guide teaches students how to use WBVL and some relative knowledge of each virtual experiment.

3.4 Virtual Laboratory Framework

Virtual laboratory framework is the common framework of most virtual experiments. Like in the real world, many experiments are performed in the same laboratory, so most of the virtual experiments in WBVL share a common virtual laboratory framework. This approach brings three benefits. First, it can reduce the design complexity of virtual experiments. The designer of virtual experiments need only concentrate on the experiment content, model and private 3D scene of each experiment while regardless of the whole system organization. Second, with the centralized laboratory framework, the updates of the laboratory scene and function are much easier. Third, the shared laboratory framework make the graphics user interface of virtual experiments uniform. This is helpful for students to quickly master the usage of WBVL.

3.5 Virtual Experiment Environment

Although WBVL has uniform virtual laboratory framework, each virtual experiment should have its appropriative characteristic. Different experiments use different instruments and devices, so experiment scenes must be different. Concurrently, experiment contents and models are also different from each other. These private properties of each experiment make up of virtual experiment environment.

3.6 Help Text Database

Help text database contains the text of online help of the virtual experiment.

3.7 Internet Explorer and VRML plug-in

In order to use WBVL, a general web browser on the client side is a basic requirement. Here we use Microsoft Internet Explorer. We use ActiveX technology to organize several parts of WBVL together, and Internet Explorer acts as an ActiveX container. Also Internet Explorer is the uniform Graphics User Interface (GUI) of the WBVL.

Real-looking three-dimensional model of virtual laboratory scene and virtual experiment private scenes are developed using VRML. The Virtual Reality Modeling Language (VRML) is a file format for describing interactive 3D objects and worlds. VRML is used on the

Internet, intranets, and local client systems. VRML is also intended to be a universal interchange format for integrated 3D graphics and multimedia. So VRML fits the WBVL's features well.

Although VRML is designed to describe interactive 3D objects and worlds, its interactive ability and 3D modeling ability are still somewhat limited. For example, standard VRML can only receive user's mouse action, such as mouse click, touch and drag. Also VRML doesn't support curved surface modeling. Such a simple interactive and modeling ability is insufficient to WBVL Fortunately, some VRML extensions are developed to extend the function of VRML greatly, including keyboard input node and drag & drop node. Geometric NURBS node and geometric spline nodes that can model more complex and higher quality shapes with fewer surfaces and less file size are also introduced into VRML extensions. With VRML extensions, we can realize WBVL more easily and efficiently.

VRML plug-in is necessary on interpreting 3D scene, including laboratory scene and experiments appropriative scene, described by VRML. Now there are many VRML plug-ins available, but not all of them support VRML extensions and SDK. So the selection of VRML plug-in is very important for the interactivity of WBVL.

In the 3D Virtual Laboratory Scene (VLS) assembled with the 3D scene in virtual laboratory framework and virtual experiment scene, students can operate all kinds of virtual instruments, such as beakers, test tubes in chemical experiments, which are also shaped as 3D objects by VRML. Through these operations, students can control the virtual experiment progress, observe phenomena and record data. Because a VLS is consist of many virtual instruments and other 3D objects, the whole 3D scene is possibly very complex. Under this condition, a good VRML plug-in can make the navigation and operation fluently.

3.8 Script Nodes

The Script node is a kind of important node in VRML used to program behavior in a scene. Each Script node has associated programming language code that is executed to carry out the Script node's function . In WBVL script node have 4 purposes:

1. Communication with objects outside the VLS. VLS is only one composition of a whole WBVL system. In order to make WBVL work, the cooperation between VLS and other elements of WBVL is very important. So communication ability is absolutely necessary for VLS. For example, VLS should communicate with Online Help to change the help text with the process of experiment. Such communication ability is achieved by the programming language code in the Script node together with EAI or SDK technology mentioned below.
2. Animation generation. Many actions in WBVL, for example, object moving, coloring, shaping, etc., are shown using animations. Most of these animations are generated using Script nodes, which can manipulate attributes of other objects in a scene to generate various animations. This is a efficient and flexible way in animation generation.
3. Reception of student's control. In the most cases, student's control to the 3D scene is received by var ious sensors in the scene. Sensor is a standard way in VRML to interact with user. In 3D experiment scene many sensors have been used, such as TouchSensor, CylinderSensor, PlaneSensor, etc., which can receive students' mouse action and send one or more events to a script node. Script node interprets student's intention according the context and experiment model, and carry out corresponding action, typically, sending another event to one node.
4. Simulate calculation in WBVL. Script nodes, which have simple computational ability, are used to carry out some uncomplicated simulate calculations. Although the computational efficiency is somewhat low in Script node, but the calculation result can be used directly to change the representation of VLS. So the simulations that have low computational complexity and large data input/output can be realized using Script nodes.

3.9 EAI

EAI (External Authoring Interface), which is designed to allow an external environment to access nodes in a VRML scene using the existing VRML event model, is a part of VRML97 standard. Using EAI, we can extend the interactive ability and computational ability of VRML. VLS, together with another important and powerful element, Java Applets, are all embedded in a same HTML page. Most of the numerical/symbolical computations, analysis and simulation of virtual experiment are the responsibility of Applets. EAI enables Applets and VLS to communicate with each other. Applets can exchange events with VLS and get notified when node fields changed inside VLS. Thus, VLS and other elements in HTML page can cooperate together. By means of using EAI, WBVL can obtain extensible interactivity. Students can interact with experiment environment via the normal controls in an HTML page. For example, students can adjust experimental parameter by inputting data in a textbox, or change viewpoint in the experiment environment using buttons of an Applet.

3.10 SDK

Although EAI can extend the interactive ability and communicative ability of VRML, these abilities are still very limited. If we want EAI is inability to be used to create some advanced interactive object such like a popup menu. EAI cannot access any nodes in a scene. In addition, EAI is somewhat complicated in using. Compared to EAI, SDK is a better solution because it is easier to be used and much more powerful. So the latter is more frequently used in the design of WBVL.

Software Development Kit (SDK) provides Application Programming Interface (API) that enables developers to int egrate 3D technology and VRML into HTML. SDK treats the VRML plug-in inserted into a HTML page as an ActiveX control and enables outer VBScript, JavaScript and Java Applet code to access and manipulate any objects of 3D scene at runtime, and can also use VRML event model to exchange events with 3D scene. At the same time, some low-level function provided by SDK are necessary in building advanced interactive means, such as popup menus, hints, toolbars, and so on. These advanced interactive means are very useful in building a friendly user interface in WBVL. For example, when student click a test tube, a popup menu will be displayed to let student select what to do with this test tube next, to dump it or to move it.

3.11 Outer Programming Codes

Outer programming codes are requisite in the script node, EAI and SDK to perform their functions. Cooperation of each part of WBVL is also achieved using outer programming code.
Considering the web-based and cross-platform features of WBVL, Java and Script languages are used in WBVL for outer programming codes. These codes can be transferred via the web and run on the client side.
Script node of VRML can use Java classes as its associated programming code. A scheme of exchange data and events with 3D scene is employed. Java applet use EAI to communicate with VLS. By using SDK of VRML plug-in, Java applet and JavaScript/ VBScript can also collaborate with VLS. In the design of WBVL, we use SDK to realize Online Help system.

4 WBVL Set-up

Similar to the traditional experiment education set-up, WBVL is composed of four parts: user's guide, laboratory experiments, online helps and experiment reports. The user's guide tells the students the basic rule and relative knowledge about virtual experiments. After mastering necessary knowledge, students can use it to perform virtual laboratory experiments. On the processing of the experiments, online help can provide help message to students at any moment. After finished experiments, students are required to fill the experiment reports, and the mark of the experiments will be given immediately by WBVL.

4.1 User' s Guide

The setting up of user' s guide has two main goals. The first, in user' s guide, students can learn the basic information about the experiments they will perform. The user' s guide is intended to be the extension of the traditional curriculum held by the teachers. The second, user' s guide can help students to be familiar with the WBVL. Although WBVL is designed to simulate the true world of experiments as possible as can, it is still not easy for novice to learn how to perform experiments on web. So user' guide teaches students how to use this system.
The user' s guide is divided into 3 parts:

1. Introduction of the WBVL. This part describes the basic usage of the WBVL. Students read this part to be familiar with the whole system.
2. Virtual devices library. Introduction to the virtual devices is provided in virtual devices library. Virtual devices are those devices used in virtual experiments that have some specific functions and can interactive with students. A lot of virtual devices are used in WBVL. Without the learning of how these virtual devices looked like and how to use them, students wouldn't be able to cope with virtual experiments. So the introduction of virtual devices is a very important part in the user' s guide.
3. Specifications of virtual experiments. This part describes the detail of each virtual experiment of WBVL, including the experiment goals, principles, contents, methodologies and emphases. This part has great contribution to the students' understanding of the experiments they will perform.

4.2 Laboratory Experiment

In WBVL, a virtual laboratory environment and appropriative virtual experiment environments are simulated, so that a variety of experiments can be performed virtually. Now we realized several chemical engineering experiments in WBVL as a sample. The main aim of virtual experiments is to let students get perceptual knowledge besides the theory classes.

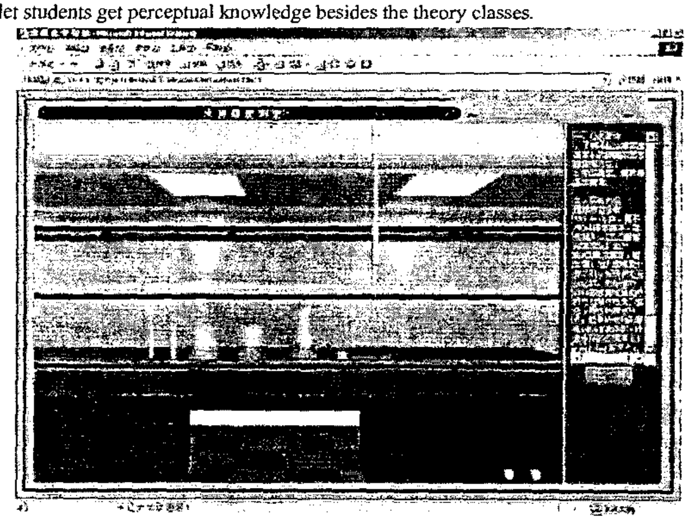


Figure 2: One experiment of WBVL: "The Measurement of Water' s Degree"

An example is the chemical engineering experiment "The Measurement of Water's Degree of Hardness" shown in Figure 2. In this experiment, students can operate beakers, graduated cylinders, pipette, burette, and so on to measure the degree of hardness of the water sample contained in a beaker. In the process of experiment, students should observe the phenomena and record the necessary data. The origin data of this experiment is given randomly to make the experiment more authentic.

4.3 Online Help

In virtual experiments, students, especially those novices, are sometimes confused by so many experiment steps and data. They need a help mechanism which can give them instruction at any moment they need. Online help that can guide students to complete virtual experiments is such an important part of WBVL. Along with the process of experiment, online help will load help texts from the help text database and display it in the help frame as shown in the right part of Figure 2. Help texts will tell the students what to do and how to do next step. Relative knowledge about the experiment is also provided in help texts. Using online help, students can perform virtual experiments more easily and can learn more from experiments.

4.4 Experiment Report

In conventional experiment education curriculum, students should submit a report as the last step. The content of experiment report includes the design of the experiment, phenomena record, data record and analysis, and experiment conclusion. Experiment report is a sum-up of the whole experiment, from which student can know whether he reaches the experiment goals and how well he has done. Experiment report can also make teacher know the level of students' knowledge.

Because of the experiment report's importance, it is realized in WBVL. Once a student finishes the operation of virtual experiments, a template of experiment report prepared beforehand is presented to him to fill. WBVL will grade his experiment according to the record made in the process of experiment and the experiment report he submitted. For the convenience of computer grading, the templates of experiment report are compiled in a standardized form, that is, the templates are composed of groups of multiple-choice tests and blank quizzes. These tests are carefully designed by skilled teachers.

5 Virtual Experiment Operational Model

Virtual experiment operational model means the manner of the control of the operation sequence in the virtual experiment. For students, this model can greatly affect the difficulty of performing the virtual experiments. For the designers of virtual experiments, this model determines the complexity of the whole system. So the choice of operation model should be carefully considered in the systems analysis.

Generally, the operation model can be divided into three categories: concurrent model, serial model and combined model.

5.1 Concurrent Model

In concurrent model, all virtual devices in experiment scene can be operated concurrently, that is, student can choose an arbitrary device to operator by his own discretion at any time. Figure 3 (a) shows the architecture structure of this model.

A skilled student usually prefers this model because he can get maximum degree of freedom under this model. Real-world experiment can be best simulated when adopting this model. However, this model will also bring some disadvantages:

1. Under this model, student cannot get any implication about what he should do next because there is no restriction to his action. Some interior restriction in the real-world experiment cannot be set out to the student. The result is that he is always facing such many choices that sometimes he will be bewildered, especially for unskilled student.
2. Because the action to the virtual experiment can be arbitrary chosen, abnormal operations, even illegal operations are inevitable. For example, a chemical experiment requires that reagent A should be mixed with B then with C, but in virtual experiment using concurrent operation model, student may break this sequence. Under the concurrent model, virtual experiment system has to cope with these extra operations and give appropriate responses. If the category and quantity of virtual devices are large, these extra operations and their combinations may be too many to be dealt with. This problem is critical to the design of WBVL.

Because of these disadvantages, the concurrent model is seldom used in WBVL. Only those virtual experiments that don't restrict the sequence of each experiment step use this model, for instance, "The usage of analytical balance" experiment.

5.2 Serial Model

A contrastive operation model is serial model, which means student should strictly obey the predetermined operation sequence in the process of virtual experiment. Under this model, in a certain stage student can operate only one virtual device, as shown in Figure 3 (b). Which device student can operate is determined by operation sequence database. After student finishes the operation on this device, another device become capable of operating, while the rest devices are "blind". Thus, the student is forced to perform experiment in the correct sequence that is predetermined and stored in operation sequence database at the design-time of virtual experiment.

Compared to the architecture structure of concurrent model, that of serial model inserts a valve between user interface unit and virtual device. An opened valve enables student control corresponding virtual device, while a closed valve makes the corresponding device be a blind device, which cannot be controlled by student. The opening sequence of valves is controlled by the operation sequence database.

The benefits of the serial model are:

1. The experiment process is perspicuity to student. Under this model, students are guided step by step to finish the experiment, so they can finish the experiment more easily and efficiently. At the same time, serial model will move students' concentration on the experiment phenomena and data but not how to finish the experiment. This feature is especially useful for novices who are not familiar with either WBVL or experiment.
2. Simplifying the design of WBVL. By limiting the choice of student's operation in a certain moment, serial model can avoid the possibility of illegal operation. So the design complexity of WBVL is greatly simplified. This can shorten the development period of WBVL and reduce its price.

The shortages of serial model are obvious:

1. Reduction of reality sensation. Under serial model, students cannot choose which virtual devices they control. This will definitely upset student.
2. Serial model disables the experiment's variability. Serial model makes student strictly follow the experiment step predetermined in the time of design. Any slight changes are impossible. Student's initiative cannot be behaved.

Virtual experiments using serial model are subject to the risk of being treated as mere television show. So pure serial model is only used in exhibitive experiments.

5.3 Combined Model

Normally, pure concurrent model and serial model are rarely used in the design of virtual experiments because of their advantages. The alternative one is combined model, which is the combination of concurrent model and serial model.

Considering operation sequence of each model, concurrent model has no predetermined operation sequence, while serial model defines a straightforward operation sequence without any branches. The operation sequence defined in combined model is much more complcated compared to the former two.

The quantity of controllable virtual devices in a certain stage under combined model can be large than one, as illustrated in Figure 3 (c) From the architecture structure in Figure 3 (c), we can find that although the global structure is serial, concurrent model is presented in a certain stage. The global serial operation model insures the experiment can reach a certain end, while the partial concurrent model enables students to select the best way they find to accomplish the experiment. The students' selection and the operation will affect their final scores. So this model is suitable for the most of the virtual experiments.

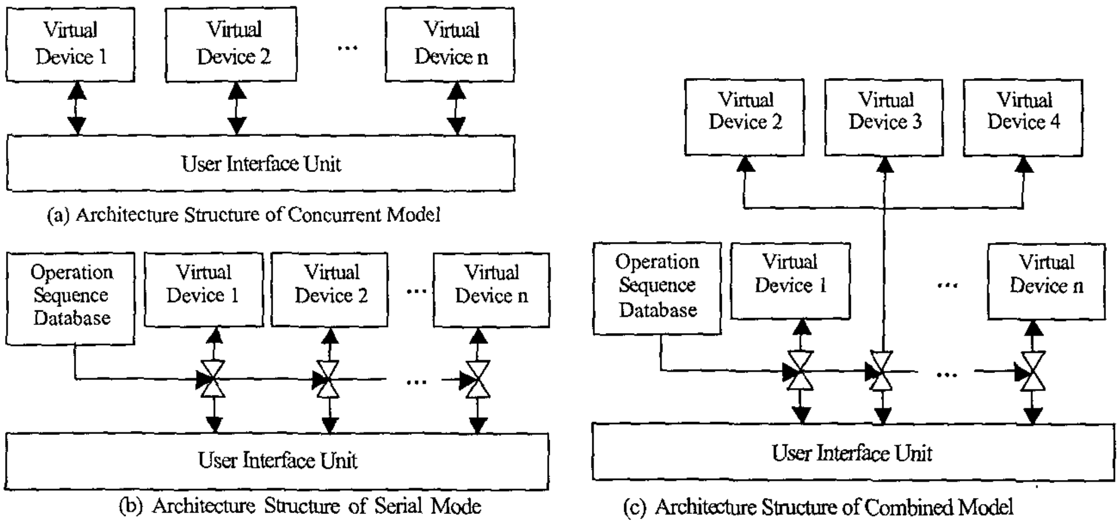


Figure 3: Operational Model Architecture Structure

6 Conclusion

Being a computer-based learning system, WBVL should be considered as a supplement rather than a replacement of conventional experiment course. With its four important features, three-dimension, interactivity, web basing and virtuality, WBVL can make students feel as if they are performing a real-world experiment. WBVL is realized in client/server architecture, with experiment curriculum stuff held on the server side. Because the only requirement on the client side is a general web browser and a VRML plug-in, WBVL is easy to use. The set-up of WBVL is similar to the conventional curricula, so students can master its usage quickly. Operational model used in most of the virtual experiments in WBVL is combined model, which can achieve a better compromise between virtuality and system complexity.

Acknowledge

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