The Virtual Laboratory: Technology Assisted Education

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Abstract

In theory a virtual laboratory could offer the learning experience of a physical laboratory but without the limitations, such as time, location, material, and equipment. Could a user interface be designed that would allow students to learn the intended lessons? Specifically, could an interface allow the student to do the following: 1. Learn the necessary experimental skills to undertake laboratory investigation in scientific research and engineering. 2. Have an experience technically equivalent to a physical lab exercise. 3. Relate the behavior of real experimental equipment to theoretical principles that are covered in course work. 4. Learn the proper principles of experimental design. This presentation will describe the design and development of such a user interface by the author as an undergraduate. The project included the creation of an open-ended framework to support an unlimited variety of laboratory exercises which would meet the previously mentioned criteria. It also included the development of laboratory experiments taken from preexisting simulations and packaged in such a way that students would relate to the experimental work in a meaningful way.

1. Introduction

1.1. benefits of laboratory coursework

Laboratory work is an important component in many science and engineering courses. While typically all of the material which is dealt with in laboratories is also covered in the classroom, laboratory work is valuable for teaching aspects which are not readily learned through reading or lectures.

In laboratories, students become the participants, rather than spectators. To a varying degree, almost all students learn better through hands-on exercises. Laboratories which excite many senses often make longer lasting impressions than lessons from textbooks. Also, students can recognize secondary implications not typically discussed when they conduct experiments themselves. Laboratories force students to make decisions. This causes them to thoroughly think through the principles. Often students become aware of weak areas of their understanding as they use the principles in a lab.

Laboratories also are valuable in providing students with an understanding as to how the knowledge in their field has been gained. This gives students a better appreciation for the material in their textbooks and lectures, and helps them to understand what it would take to further understanding in their field.

Lab work is essential for instilling proper research skills in students. Through laboratories, students learn how to design experiments effectively. This is an important skill for engineers and scientists. Students also learn proper experimental techniques. Many skills, like how to take a representative sample,
are only taught in laboratories. It is only through experience that students learn which aspects of laboratory procedure require extra care.

1.2. advantages of a virtual laboratory

Virtual laboratory work offers many advantages over conventional laboratories. A majority of these advantages are matters of convenience, but as will be shown, the increased convenience offered by a virtual laboratory yields a better learning experience for the student.

Time is possibly the largest advantage of virtual laboratories. The time savings offered by virtual labs are often results from its other advantages. Many times in the course of laboratory, a student will find that they missed or incorrectly performed an important step. This realization comes can come late in the lab, or afterwards, when preparing the report. This also happens to students using virtual laboratories. But in a virtual laboratory, the time invested is less and the effort required to restart or redo the exercise is much less. It is reasonable to expect students to conduct another experiment when these mistakes are discovered in a virtual lab, whereas it may be impractical for students to do so in a physical laboratory.

This also brings up another time advantage. Students often need to be supervised when in a physical lab. Typically the laboratory is only open to students for a brief amount of time for a particular assignment. Often students can not redo a lab or make up a lab that they have missed. A virtual lab allows the students the ability to conduct the lab as many times as is required and at their convenience.

Since virtual laboratories do not need to be conducted in physical laboratory, laboratory work is available to students who can not physically attend the lab classes. This advantage will become more and more important as Internet based distance learning expands.

Time can also be compressed for certain labs. Many experiments require more time than is typically allotted for a lab. Some experiments require data to be taken over a period of hours, days, weeks or even years. In a virtual lab these laboratories can be conducted using time compression.

Another advantage of virtual labs is that they use virtual equipment. Real equipment ages, breaks down, takes up space, must be maintained, and can be expensive, damaged and dangerous. Virtual equipment will not break down (unless designed to do so), does not cost time or money to maintain and the parts will not wear. Institutions can afford to provide each student with their own virtual equipment, even if the institution can not afford the real equipment for themselves. Equipment which is typically too sensitive or too delicate for general lab classes can be used virtually.

Virtual equipment can be more flexible than real equipment. In some experiments not all variables are actually variable, due to limitations in equipment. For example, in a fluid flow lab used in the Department of Metallurgical Engineering at the University of Utah, a large centrifugal pump is used. In order to change the pump speed, an afternoon would be required to change the fly wheel and readjust the belts between the motor and the pump. In our virtual lab the pump speed can quickly be adjusted with a few mouse clicks. Using the virtual lab students can investigate the affect of pump speed on flow characteristics of the system.

Virtual equipment allows students to explore more freely. Without concern for equipment or bodily harm, students can be encouraged to examine extreme conditions. When properly modeled, the laboratory could inform the student when they have cause an explosion which has cost them, and many of their class mates, their lives. Then the student can start over and try again.

Virtual laboratories use virtual material, which have many advantages over real material. Since virtual material costs virtually nothing, exotic materials can be used in exercises where they were previously unfeasible. Students can investigate what happens if they leave experiments running too long, and they can conduct as many experiments as they desire without worrying about material cost. Virtual materials are also much easier to dispose and do not cause the real environment any harm.

1.3. challenges of a virtual laboratory

While there are many advantages to virtual laboratories, can they still provide a technically equivalent laboratory experience for students? Specifically, can a user interface be designed and developed which will provide the same benefits to students that are offered in traditional laboratories? This question will be explored in this paper. To do so the virtual laboratory must allow students to:

- Interact with the experiment as they would in a physical lab
- Make the same connections between principles and applications
Develop the skills of proper experimental design and procedure

2. Theory

A virtual laboratory should have the following characteristics to meet the above requirements.

2.1. design requirements of the experiments and equipment

A virtual laboratory experiment should require that the student make the same decisions which they would in a non-virtual laboratory experiment. Each significant step which is taken in a conventional lab should also be taken in a virtual lab. The equipment should be modeled such that it responds realistically to the decisions which the students make. Experiments must be allowed to fail. Students must be allowed to fail.

For example, in an electro-chemical laboratory conducted in the Department of Metallurgy, students often mistakenly switch the electrode wires when setting up a potentiostat. In a virtual lab this type of mistake should be allowed, and the output from the virtual potentiostat should mimic what is produced by an inappropriately set up potentiostat. This response is much more valuable to the student’s learning than an error box popping up informing the student of the mistake.

The virtual lab and equipment should be set up in an open ended way. An example from our mineral processing labs illustrates this principle. An ore could be processed by a ball mill, split with a hydrocyclone and then characterized with screens on a Rotap. Alternatively, the ore could be passed through the hydrocyclone and the oversized material ground in the ball mill and then the two samples characterized with the screens. As a third scenario, the screens could be used to obtain a specific size range of the ore and then it could be passed through the hydrocyclone and then the ball mill. While this last sequence wouldn’t make much sense, it is still physically possible. A virtual laboratory should allow a student to mix and match steps in this manner, and always give realistic results. Just like many different experiments can be conducted on the same equipment or combinations of equipment, many virtual experiments should also be possible.

2.2. practical requirements for a virtual laboratory

In order for a virtual laboratory to be widely useful it must support a wide variety of experiments. A flexible modular framework is necessary so that chemistry professors can implement their own experiments along side mechanical engineering experiments.

The software should be set up in such a way as to allow professors who are not expert software engineers to develop their own experiments. The interface between the virtual laboratory and its experiments should be small and simple, while flexible enough to support a variety of experiments.

Tools, templates and reusable components could facilitate experiment development. For example, a stop watch is a necessary tool in many experiments. If a stop watch is carefully simulated and implemented, it could be made available to others who are designing their own experiments. The program should be written in a common language which is accessible to the general public. This increases the motivation for lay professors to learn the skills required to encode experiments and increases the chances that the professors already have experience with the language.

The laboratory and associated experiments need to be easily distributed. Ideally the program would be platform independent and small enough to be easily downloaded over the Internet by even a dial-up modem. This increases the potential student pool which is important for many distance learning programs.

3. Design and Development

A virtual laboratory has been developed at the University of Utah, which meets many of the design requirements discussed in the previous section. It has been titled, the Virtual Laboratory. The author designed and implemented the user interface for this program.
3.1. genealogy

The origins of the Virtual Laboratory can be traced back to ModSim, a program originally developed by Dr. R.P. King in the 1970’s. ModSim is a mineral processing plant simulation tool. The plant layout...
is inputted through a flow sheet, see figure 1, and then the characteristics of the input streams and parameters for the equipment are entered through forms.

Dr. King recognized that the same models which he used to simulate large industrial equipment could be used to simulate the smaller laboratory equipment used in his lab classes. The VLab was developed directly from ModSim and the user interface was very similar, equipment icons were placed on the flow sheet and then all parameters were entered at once, see figure 2. The student response was sufficient to warrant the development of this program beyond its infant state. Dr. King employed the author over the summer semester with the charge to develop an interface which will allow students to interact with the exercise in the same manner they do in real laboratories.

3.2. overall layout

The Virtual Lab’s layout is analogous to a laboratory building. It is a collection of rooms, benches and equipment used for conducting experiments. A large area of the main window is a multiple document interface (MDI). This space allows multiple screens to be open and alternatively in focus. From the main window you can enter three different areas of the virtual lab, which can be thought of as three different floors of the building. These areas include stockrooms, experimental laboratories and analytical laboratories. From these floors you may enter individual rooms where samples can be obtained and equipment used.

Besides the MDI, the main window of the Virtual Lab contains a laboratory notebook and a sample holder. The laboratory notebook is used in the same manner as it would be in a real laboratory. As a design principle, students are responsible for putting all information into the notebook. Sloppy note taking should make it difficult for students to later interpret their results. The sample holder allows for samples to be moved between different areas in the virtual laboratory. Some basic sample-type specific information is displayed, along with the sample name and icon.

Figure 3  Screen shot from the Virtual Laboratory showing some sample stockrooms and the major interface components
3.3. example experiment – batch grinding

Material is first obtained by selecting Mineral Processing Stockroom, from the Sample Stockroom list. Students must decide which mineral they wish to investigate, and how much material to put in their sample holder. The students then move to the batch grinding laboratory by choosing it out of the Experimental Laboratories list. Students can choose from five different ball mill sizes. They will next fill the ball mill. Decisions must be made as to which sample is to be added, the quantity of sample, as well as the grinding media size and quantity, and the amount of water to add. The mill rollers can hold up to four mills at a time. This allows students to prepare four mills, each with a different set up, in order to investigate the response to different parameters. The mills are placed on the rollers and the motor is started by clicking on the stop watch button. The mills are stopped in similar fashion. The mills are unloaded and the samples, which now contain water, are returned to the sample holder.

The students are required to use the Particle Characterization Laboratory, from the Analysis Laboratories list, to obtain the particle size distribution. A typical run through this laboratory requires the students to use a wet screen, a pressure filter, a drying oven, a Rotap, and a Cyclosizer. Students need to make several decisions as they do so.

Figure 4 Screen shot of the Batch Grinding Laboratory

3.4. comparison to theoretical design specs

The Virtual Lab can be compared back to the theoretical design specifications laid out in section 2. Section 2.1 mainly discussed the design aspects of the laboratory experiments. So far the implemented lab experiments have followed these principles well. Most of the laboratory instructions, originally drawn up for a real laboratory, are used with minimum changes. The changes typically increase the number of trials undertaken to better investigate the system. The Virtual Lab has shown that it is flexible enough to accommodate the many laboratories implemented so far.
One professor has found that she can also implement laboratory exercises, which are much simpler and guided than the typical laboratory experiments. These experiments do not follow the guidelines of section 2.1 and are designed to quickly illustrate a specific principle. While these exercises were not intended when the Virtual Laboratory was designed, it shows the flexibility of the program, and the freedom of a professor to implement different types of laboratories.

There are other aspects where the Virtual Lab has fallen short. Many of the requirements listed in section 2.2 have not been fully implemented yet. The Virtual Lab is not fully modular. Individual laboratories need to be compiled with the main program. Since several professors are separately developing laboratories there has been some confusion as to which version of the Virtual Laboratory is the latest. Different versions are distributed with each course. These problems will only get worse as other departments and universities begin using the Virtual Lab. The laboratories need to become separate files which can individually be loaded into the program. This way only one program is current and each course can deliver its own experiments.

The Virtual Lab is written in Microsoft Visual Basic. The language was inherited from ModSim. While the Virtual Lab can be run on most desktops, it is not compatible with computers running Mac, Linux, Unix or other operating systems. The use of Visual Basic conflicts with other practical requirements. Professors need to have access to Microsoft Visual Studio or other comparable software in order to develop laboratories. While the price of the software is not unreasonable, it is a disincentive for a professor who would like to experiment with the software before committing time and money into a project.

4. Results

Even with its faults, the Virtual Lab has proven that a user interface can be developed which provides all of the advantages of a virtual laboratory without sacrificing the quality of the learning experience. In fact professors report that the students are getting much more out of laboratories conducted in the virtual laboratory than they do with conventional laboratories. One professor noted that before using the Virtual Lab, most of the laboratory reports submitted by students were haphazard, were missing data, and had little analysis. He couldn't expect much more from the students since a report can only be as good as the data obtained. The data obtained from many labs were incomplete and sloppily taken as several students rushed to complete the required procedures in the allotted time. This professor now receives reports which are focused on analyzing the trends observed and how they relate to the principles discussed in class.

Another professor finds value in the Virtual Lab by assigning laboratories for a course in which it was previously impractical to do so due to time constraints. She noted that before the Virtual Lab her Introduction to Extractive Metallurgy students never fully grasped the concept of obtaining a particle size distribution using a series of screens, even though there were problems on nearly every homework and test. Now, by assigning exercises using the Rotap in the Virtual Lab, she feels her students finally grasp this concept.

The Virtual Lab has proven its value for different audiences. It is used in freshman, introductory courses, advanced, graduate-level courses as well as professional development courses offered over the Internet. It is an important component of the distance-learning, masters of engineering program which is under development in the Department of Metallurgical Engineering.

5. Summary and Conclusions

Laboratory work is an important component of many science and engineering courses. Virtual laboratories could provide many advantages over conventional laboratories. Virtual laboratories can be developed to offer all of these advantages without diminishing the laboratory experience. The Virtual Lab developed by the author is an example of such a program. The Virtual Lab has been used by different professors in a variety of courses. The feedback has been overwhelmingly positive from both professors and students. Laboratory experiments are continually being added. Further development on the Virtual Lab itself is necessary to allow the full potential of this program to be realized.
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