Remote Teaching Laboratories in Science and Engineering

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INTRODUCTION

For scientists and engineers, the idea of remote controlled experiments is not a new. Remote control is often used when an experiment or instrument is physically inaccessible by virtue of location or danger. It is also an excellent method for sharing expensive equipment and facilities with other researchers. However, employment of remote laboratory access to deliver the practicum components of distance science courses is much more recent and certainly not as common. Historically, the complexity and technology involved has often dissuaded universal adoption of this method in regularly run laboratory courses. However with the increasing availability and robustness of new technologies, the use of remote laboratories is being explored by many distance educators in the sciences as a viable method of offering a first-class laboratory experience for the student.

BACKGROUND

The ability to provide the student with an excellent laboratory experience is crucial in disciplines like biology, chemistry, physics, and engineering, which traditionally have a strong laboratory component. It is also one of the more challenging components to deliver effectively at a distance (Kennepohl & Last 1997). There is no one correct solution in delivering laboratories for distance students and often an assortment of methods are used in concert to overcome challenges (Kennepohl & Last, 2000). However, some educators have directed their efforts towards allowing students remote access to real experiments via the Internet. Remote experiments are increasingly appearing in a variety of disciplines at different institutions. In addition, various consortia have evolved to share costs and benefits of remote laboratories.

For example, a consortium of primarily undergraduate teaching institutions in the United States entitled the Science Teaching and Research Brings Undergraduate Research Strengths Through Technology (*STaR-BURSTT*) provides a network of shared resources to carry out structure determination using single crystal X-ray diffraction (Szalay, Zeller & Hunter, 2005). Although not operational since 2003, the *PEARL* project (Practical Experimentation by Accessible Remote Learning) was a consortium of European Union (EU) institutions developing remote experiments in spectrometry, cell biology, manufacturing engineering, and electronic engineering (Scanlon, et al., 2004). Another EU consortium called *Network for Education – Chemistry* uses mostly interactive simulations, but it is also exploring online remote process control using a residence time distribution experiment (Zurn, Paasch, Thiele & Salzer, 2003) and the German *LearNet* initiative consortium of eight German universities provides a variety of engineering laboratories (LearNet, 2007).

In some cases, the focus of the remote laboratory is to facilitate observations both large and small. For example, the astronomical camera called "Stardial" delivers images of the night sky in real-time (McCullough & Thakkar, 1997), whereas the "Bugscope" project provides electron microscope images of mailed-in specimens (Potter et al, 2001). In other remote experiments the core activity is to carry out measurements. Reported examples include measuring the elasticity of a metal beam as a function of temperature (Alhalabi et al, 2001), measuring and analyzing remote sound waves (Forinash & Wisman, 2005), and thermal conductivity experiments in food engineering (Palou et al, 2005) to name a few. One recent remote laboratory example in animal behaviour, involving following a mouse in an arena, employs observation, and measurement, along with collaboratively pooling individual results (Fiore & Ratti, 2007). The idea of using remote laboratories to facilitate collaboration has been around in the research context since the early nineties. It is described as a "collaboratory" and also affords benefits when used in an instructional context (Johnston et al, 2001). In addition, some remote experiments will also involve physical control of objects such as an electric motor (Yeung & Huang, 2003) or more robotic operations such a ball drop experiment in physics (Connors, 2004) or moving a toy vehicle through a maze (Gröber et al, 2007). Finally, remote laboratories are ideally suited to accessing sophisticated instruments that are already controlled locally by computer (Kennepohl et al, 2005).

THE REMOTE LABORATORY

With the advent of the World Wide Web there has been a great deal of effort placed on bringing the student laboratory experience online. In many instances, the online laboratory components are simulated and offer the virtual laboratory experience (Kennepohl, 2001). In discussing the role of remote laboratories it is vital to realize the difference between a virtual laboratory environment and remote teaching laboratories. A virtual environment is created through interactive computer simulations of instrumentation and experiments. The role of virtual laboratories can prepare students for a real laboratory environment or conversely reinforce concepts from theory or experiment. In contrast, remote access achieves many of the same things as a virtual laboratory, but also allows learners to physically carry out real experiments over the Web. Students obtain real results using real substances and make real conclusions, just as they would if they were in the laboratory with the equipment.

Remote laboratories are a step beyond computer generated laboratory simulations. They represent the best alternative to working in a real laboratory. Although there is a variation in use, remote teaching laboratories are being employed in four basic ways:

- To allow observations of natural phenomenon or experiments
- To carry out measurements
- To manipulate instruments or physical objects in experiments
- To facilitate collaborative work at a distance

Although identified separately above, various combinations of observation, measurement, manipulation, and collaborative work often come together in one experiment. For example, Jodl and coworkers have developed a wind tunnel experiment that combines three of these on their Remotely Controlled Laboratories website (rcl.physik.uni-kl.de) for physics students. The remote wind tunnel experiment allows comparison of air resistance and coefficient of air friction of different vehicle types (e.g. sports car, SUV, fire engine). With a camera the student views the experimental setup including a red thread and a small model of a vehicle in the clear plastic wind tunnel, as well as output displays of an anemometer and a multimeter (observation). Upon selection of one of three vehicle types, it is moved into the wind tunnel (manipulation). The student starts the wind generator (manipulation) and immediately sees the red thread move in the wind, as well as the numbers rapidly increasing on the anemometer and a multimeter (observation). When the displayed numbers on the anemometer (wind speed in km/h) and the multimeter (voltage related force of the wind on the vehicle) have reached a steady state, they are noted by the student (measurement). The student can then select another vehicle or change the velocity of the air flow (manipulation).

Advantages

The role of the laboratory experience is to promote learning and reinforce theoretical concepts covered in the course. It is also used to develop practical skills and encourage problem solving. Educators are reporting that remote laboratories not only provide viable alternatives to a real laboratory experience, but also provide their own distinctive advantages. As with a real laboratory a remote laboratory provides:

- An experience with real equipment and experiments
- Presence and control of experiments in the laboratory
- An opportunity to explore through trail and error
- Generation of real data

The remote laboratory also has other potential benefits when compared to a real laboratory and can also offer:

- The ability to do more complicated and hazardous experiments