

Chapter 9

Remote Control Teaching Laboratories and Practicals

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Introduction

A strong laboratory or practical component is at the heart of many university-level science courses. Yet, it is still also one of the more challenging elements of a course to deliver effectively at a distance (Kennepohl & Last, 1997). Experimentation is regarded as a fundamental part of the education and training of most scientists and so university science programs require practical components to be considered *bona fide* or recognized within the scientific community. The rationale for having practical work in the sciences, the role of the teaching laboratory, and its changing nature have been discussed and will continue to be discussed at great length (Bennett & O’Neale, 1998; George, 2003; National Research Council, 2003; Lagowski, 2005). A variety of methods have been employed to address delivery of practical components at distance, including (1) supervised face-to-face sessions offered in a concentrated format on campus or at regional sites or in the field; (2) home study laboratory kits; (3) video demonstrations of experiments; and (4) interactive computer simulations. 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 now directed their efforts toward allowing students remote access to real experiments via the Internet. These remote experiments have benefits for both distance and residential environments alike. They are increasingly appearing in a variety of disciplines and quickly becoming a viable part of a science educator's teaching arsenal. This work will provide a brief review of how remote controlled experiments are being used, some observations on creating remote experiments, the advantages and challenges associated with remote access, and expected trends for the future.

Remote control over the Internet

Remote control devices are well incorporated into our growing technological world. We have automatic car starters on our key chains, unmanned reconnaissance drones are used by the military, police bomb squads regularly make use of robots, and most of us use a remote control to change television channels. The idea of remote controlled experiments is not a new one for scientists either. Remote control is often used when an experiment or instrument is physically inaccessible by virtue of location or danger. For example, safety demands that all nuclear fission reactors are operated remotely, unmanned spacecraft and deep sea craft are used for exploration, and the location of the orbiting Hubble space telescope makes remote control a necessity. Scientists also find that remote access is an excellent method for sharing expensive equipment and facilities with other researchers.

Although remote control has been with us for some time, remote control over the Internet for teaching experiments was only first established in the early 1990s (Cox & Baruch, 1994; Penfield & Larson, 1996). Over the years it has primarily been used in the areas of robotics, computing, and engineering and, not surprisingly, the bulk of the literature contributions have come from these

fields. In addition to the use of these laboratories for teaching students, the disciplinary interest has focused on such topics that include: physical control and manipulations (Yeung & Huang, 2003; Sebastian, Garcia & Sanchez, 2003; Doulgeri & Matiakis, 2006), electronics and electrical engineering (Arpia et al., 1998; Ko et al., 2000; Jimenez-Leube et al., 2001; Ferrero et al., 2003; Nedic, Machotka & Nafalski, 2003), physical measurements (Chang et al., 2005), and the system architecture (Arpia et al., 1998; Das, Sharma & Gogoi, 2006; Yan et al., 2006). The examples cited give only an indication of the work being done and are not by any means an exhaustive listing. A summary of remote laboratory sites found online (Teichmann & Faltin, 2002) and an online bibliography of recent literature (DiscoverLab, 2007) give a good initial overview of what is available.

In contrast, the use of remote access for teaching laboratories in the natural and physical sciences has not been as common. A recent worldwide inventory done in 2006 indicates that about 60–70% is in engineering, 30% is in physics (this includes electronics labs), and less than 10% occur in other disciplines (Gröber et al., 2007). In the past, the complexity and technology involved have often dissuaded universal adoption of remote controlled experimentation as a part of regularly run university-level science courses. However, with the increasing availability and robustness of new technologies, the use of remote laboratories and remote access is being explored by many educators in the sciences as a viable method of offering a first-class practicum experience for the student. Despite the increasing interest, the formal literature on remote access for teaching in the sciences is meagre and sporadic. Much of the work being done in this area is presented at conferences or is quite often only reported on the website of the remote lab itself, rather than in refereed publications. In addition, the use of remote laboratories is often experimental and fleeting, resulting in many websites that are outdated or inaccessible. Jodl and co-workers carried out a worldwide remote controlled laboratory inventory in 2004 and

again in 2006. Although the total number of remote labs increased in that time from 70 to 120, free access to those labs dropped from 70% to 30%. More striking is that of those with free access only 20% worked without problems (Gröber et al., 2007).

Not a virtual 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; Jara et al., 2009). 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 the virtual realm and their 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:

1. to allow observations of natural phenomenon or experiments;
2. to carry out measurements;
3. to manipulate instruments or physical objects in experiments;
4. to facilitate collaborative work at a distance.

Observation

Facilitating observations remotely is by far the simplest and most robust version of a remote experiment. Usually the observer interaction is minimal and is often limited to controlling the camera. For example, the astronomical camera called “Stardial” delivers images of the night sky in real time (McCullough & Thakkar, 1997), and our own university houses a geomagnetic observatory to study the northern lights that includes spectacular 360° images of the night sky which can be accessed remotely (Donovan et al., 2006). There are also Internet controlled electron microscope sites such as “Bugscope” (Potter et al., 2001) and “POIT-EM” (Furuya et al., 2005), which accept and prepare mailed-in specimens for observation. Students then log on at scheduled times to carry out their observations. The importance of observation in supporting measurements and manipulations is also often cited (Lang et al., 2007).

Measurement

Other remote experiments go beyond observation, and the core activity is to carry out some measurements. A few examples include measuring the elasticity of a metal beam as a function of temperature (Alhalabi et al., 2001), reaction kinetics in chemistry (Senese, Bender & Kile, 2000), measuring and analyzing remote sound waves (Forinash & Wisman, 2005), thermal conductivity experiments in food engineering (Palou et al., 2005), chemical analysis using gas chromatography (Baran, Currie & Kennepohl, 2004), and carrying out single crystal X-ray diffraction measurements (Szalay, Zeller & Hunter, 2005). There is also an excellent series of online physics experiments on the RCL—Remotely Controlled Laboratories site, with such experiments as a wind tunnel, Millikan’s oil drop experiment, diffraction, and interference (Gröber et al., 2007).

Manipulation

In addition to observing and measuring, some remote experiments will require actual physical control of objects. This could be

the control of an electric motor (Yeung & Huang, 2003) or a scale model greenhouse for climate and irrigation control (Guzmán et al., 2005) or more interactive robotic operations, such as manipulating a mechanical arm or moving a toy vehicle through a maze (Gröber et al., 2007). It is important to note that although observation, measurement, and manipulation are separately identified and illustrated in our discussion above, it is common to incorporate combinations of these into one experiment. For example, a remotely controlled simple ball-drop apparatus used by physics students to determine g (gravitational constant) is described in the literature (Connors, 2004). A steel ball is physically moved to a specific height determined by the student and released (manipulation), the student reads the output from a timer which automatically starts upon the ball's release and stops when the ball passes by an optical sensor (measurement), and the entire process is captured on a Web camera (observation).

Collaboration

Certainly one advantage of Internet access is that it can facilitate sharing not only of experiments and instruments, but also of data. A recent remote laboratory example is in animal behaviour, involving following a mouse in an arena. This employed observation and measurement, along with collaboratively pooling individual student findings to gain better statistical results (Fiore & Ratti, 2007). Others are also taking advantage of the remote control environment to incorporate a collaborative component to their teaching practicals, such as collecting kinetic data from an entire class (Senese, Bender & Kile, 2000). Indeed, the idea of using remote laboratories to facilitate collaboration has already been employed to a limited degree by science researchers during these last two decades and is described as a “collaboratory” (Sonnenwald, 2003). Applying the concept of the collaboratory in a teaching environment is being explored by some groups (Johnston et al., 2001).

Pedagogy and learning

Among science educators, there is a collective wealth of practical experience in using the laboratory to teach undergraduate students. There is also an increasing awareness of teaching and learning models that underpins many existing best practices and can potentially lead to new approaches for improvement. Earlier parts of this book discuss some of these fundamentals of how science students learn that also extend discussion to the practical and laboratory components. Bailey and Garratt provide an excellent review of teaching and learning theories as they apply to chemical education and to science education in general (Bailey & Garratt, 2002). In addition, more generalized reference sources are available for those interested in how students learn (Driscoll, 2005).

Despite a general interest in the scholarship of learning, the literature around remote practicals and laboratories has mainly focused on the technology and feasibility of the access rather than on its educational value. Yet in developing a remote laboratory component for science students, educators should have many of the same aims and intuitively employ many of the same strategies, such as the incorporation of appropriate feedback, creating an active learning environment, and providing sufficient logical structure and guidance to form a cognitive foundation for the student to build on. They should also be aware of challenges surrounding the matching of teaching and learning styles (Krause 2003; Yeung, Read & Schmid, 2005) and feel compelled to provide a level of meaningful engagement that will motivate students (Newstead & Hoskins, 2003). However, the real question on everyone's mind is whether there is equivalent learning using remote access as opposed to the traditional supervised laboratories.

There are two criticisms often levelled against remote laboratories. First, they are seen as not offering the identical laboratory environment with all its atmosphere, noises, smells, and haptic experience of experimenting. Secondly, the student-student and student-instructor interactions are usually altered and reduced.

The underlying epistemological assumptions of these criticisms are that both laboratory environment and human interaction are needed to give the student an effective laboratory experience. Indeed, laboratory environment and human interaction can and do lead to both formal and informal learning. However, we know that other forms of interaction in other environments can also lead to learning. Our own experience has been that there are no substantial overall differences in student performance between proximal and remote modes. Other researchers have also reported similar findings (Ogot, Elliot & Glumac, 2003; Scanlon et al., 2004; Doulgeri & Matiakis, 2006; Fiore & Ratti, 2007). One well-controlled systematic study goes even further in its evaluation by identifying differences between learning outcomes of students carrying out the same experiment onsite, remotely, or as a simulation (Lindsay & Good, 2005). Overall learning is equivalent, but particular components of that learning are better suited to different modes of delivery. For example, students in the non-proximal modes of this experiment were more likely to identify and understand consequences of non-idealities in their results. Lindsay and Good also caution against using student surveys in evaluating learning by showing that their students' perceptions of learning objectives and actual learning outcomes are mismatched.

The challenge for the educator now becomes more than just building the technological means to carry out remote experiments or teaching the disciplinary principles through a remote laboratory. The student also needs to learn how to be comfortable with and effectively operate in that remote laboratory environment. Successful remote laboratories are self-contained, intuitive, and designed with a seamless pedagogical front end to facilitate the high level of student learning and skills development necessary to carry out an experiment at a distance. Some components employed to do just that have included FAQs and help sections, video or audio clips, tutorials, simulations, access to the instructor and other students, qualifier exercises, self-tests, library or database access,

supplementary materials or related links, note-taking functionality, and live images of the equipment and laboratory. It is vital that student interaction with the experiment be free of excessive time delays and have sufficiently clear feedback for the student to know their commands are being executed. The instructional design, reliability, and functionality of the online remote laboratory environment need to be at a level where the student is not distracted from learning or discouraged from exploring. As with any experiment in science or engineering, it does not necessarily need to be sophisticated or complex — just effective.

Creating a remote experiment

Developing the laboratory or a practical component of a course requires consideration of many factors. Each laboratory type (whether real, virtual, or remote) offers both advantages and limitations. Those associated with remote laboratories will be discussed in more detail later in this chapter. There are very basic logistical considerations that often seem very obvious in hindsight, but should be addressed up front. The experiment itself should be kept as simple and robust as possible, proper physical space needs to be secured to house the experiment, ongoing maintenance needs to be arranged, and certainly ongoing financing should be in place. As with any laboratory component, there should be a clear vision of what learning objectives and outcomes are intended for the remote experiment being developed. As we have discussed in the last section, a solid didactic foundation is desirable before moving to the technology solutions needed to achieve those intended goals.

There is a certain degree of novelty in the technology being used that has, in effect, become a double-edged sword. At the onset of introducing a new mode of experiment there is a Hawthorne effect. The laboratory designer, the teacher, and the student have a keen interest and usually respond positively for an initial period. That effect, coupled with the realization of the benefits a remote

laboratory can bring, has been identified by Lindsay & Good as an amplification effect. The downside, of course, is the attenuation effect, which results from technology getting in the way. That negative effect is often a result of focusing on the technology itself rather than what the technology is supporting (Lindsay & Good, 2005).

Still, technology needs to be properly addressed. There are several commercial software packages available (e.g., PC Duo, PC Anywhere, Labview) that allow clients to access and take control of a remote experiment with just a web browser. The strength of keeping the specialized software on the delivery side is that it allows more universal access for students, while removing other logistical problems associated with distributing software. Issues of security, multiple users, and compatibility with other software and hardware are certainly very specific to each situation. It is therefore imperative that professional information technology (IT) support be locally available to address issues like this and ensure success.

In contemplating the design for a remote laboratory environment used by the student, the educator who has the local and disciplinary knowledge is often best suited to lead its development. However, having an experienced instructional designer participate in the creation of the site is advantageous to the process. As much as possible, the technology should not get in the way of learning and everything needed to carry out the experiment should be readily available for the student. That usually means a self-contained site that is seamless and intuitive from the students' perspective. The following are a few online features that might be considered in building such a remote environment.

1. Public information describing the project, the researchers, and funding sources.
2. Password protection (if needed) to limit access to areas that may be damaged.

3. Scheduler function to help students and instructors assign unique and secure instrument time to qualified operators.
4. Searchable FAQ and Help sections to address common problems encountered by students.
5. Tutorials to introduce students to the software, the equipment, and the particular experiment being undertaken.
6. Experiment simulations (in some cases) to allow practice.
7. Qualifier exercises to establish a minimum skill level for students before moving onto actual instrument access.
8. Actual remote access to carry out real experiments.
9. Web camera to allow real-time viewing of the instrument during the experiment. The purpose is to make the instrument real for the remote student (i.e., “seeing is believing”).
10. Connection to the instructor and other students to further address problems and provide moral support.
11. eLogbooks to allow students to make comments and house data collected from the experiment. This is especially useful for the facile handling of large data sets collected, so students are not immersed in the details.
12. Supplementary resource materials provided for each experiment such as a database reference library or remedial resources (e.g., statistics review) or other useful links for further study.
13. An area to submit individual data and retrieve pooled results.

Advantages and disadvantages

Each laboratory type (whether real, virtual, or remote) comes with its own advantages and disadvantages (Nedic, Machotka &

Nafalski, 2003). Computer simulations in virtual laboratories have advantages over real laboratory work such as allowing students to do more complicated and hazardous experiments, obtain reproducible results more quickly, and acquire a deeper understanding of the experiments, just to name a few. Disadvantages such as the lack of human contact, boredom, and lack of experimental errors are also associated with laboratory simulations. Employing remote laboratories is way to add flexibility while still working on real experiments.

The importance of the opportunity to do real experiments as opposed to simulations cannot be understated and has often been stressed by researchers in the area (Nedic, Machotka & Nafalski, 2003; Kennepohl et al., 2005; Cooper, 2005). Since these remote laboratories exist in the physical world with real experiments on real samples, there is also the possibility of operational problems, errors, and non-ideal results. In moderation, this is beneficial for the student. Ironically, creators of some simulated experiments spend a lot of effort incorporating errors into their programs to make them more real and place the learner into a problem-solving environment. Real-life experiments, whether accessed in-lab or remotely, seem to do this automatically and we should see this as an opportunity to encourage learning.

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 are not only providing viable alternatives to a real laboratory experience, but also providing 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 trial and error;
- generation of real data.

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

- the ability to do more complicated and hazardous experiments;
- a network for learners and teacher to facilitate collaboration;
- increased access to experiments irrespective of geography;
- increased flexibility and the opportunity for more experimentation and exploration;
- better use of institutional resources;
- opportunities for students with disabilities.

Limitations and disadvantages in using remote laboratories include:

- a dependence on a reliable technological platform for delivery;
- the continued perception that there is a decreased educational value;
- financial commitment necessary to build and maintain the experiment;
- extra effort needed to design a high-quality learning environment.

Trends

Currently the use of remote laboratories over the Internet for teaching is just developing. There are examples of several initial efforts on various websites that reflect that interest. Unfortunately, the fact that many of those remote laboratory websites are currently not functional indicates the very exploratory nature of this mode of delivery and perhaps also a serious underestimation of what is needed to maintain working experiments. There has been little formal study on the effectiveness of remote laboratories, especially

from a pedagogical perspective. One recent review of engineering laboratories suggests we have been lingering at a technological crossroads awaiting the next generation of remote experiments that will hopefully address such issues as reusability, interoperability, collaborativeness, and convergence with Learning Management Systems (Gravier et al., 2008).

With newer technologies becoming more reliable and available, teachers will continue to explore remote laboratory use and develop more experiments. For example, one upcoming trend is the increased availability of mobile devices and interest in m-learning (Wu, Kuo & Lin, 2005; López-de-Ipiña, García-Zubia & Orduña, 2006; Wattering et al., 2006). Development in this area offers the possibility of increasing access to remote laboratories to an even larger degree. With a handheld wireless device one could literally be almost anywhere and carry out an experiment remotely. As current and new technologies become more commonplace, the emphasis should also shift from the novelty around the mechanics of setting up a remote access connection for a specific experiment to designing and evaluating the learning experience for the student in a remote environment. A more systematic evaluation of the learning experience will be absolutely necessary to inform the larger discussion on how remote laboratories can and should be used in science and engineering curricula.

Much of the continued exploration with new technology will no doubt be driven by interest, but there will also be increasing fiscal pressure to bring laboratory costs down. To do that, administrators will be constantly seeking cost-effective alternatives to the traditional teaching laboratory. Although the upfront investment in setting up a quality remote laboratory environment is significant, the ability to remotely share experiments and equipment would reduce costs for students and individual institutions. This aspect of remote laboratories is attractive not only to distance educators, but also to traditional residential institutions seeking to extend the use of current facilities.

Sharing experiments and equipment is not limited to single institutions. The accessible nature of remote laboratories also has the potential to foster collaborations at many levels. In fact, various inter-institutional collaborations and consortia have already been created to share the cost and the benefits of remote laboratories. 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). *ProLearn* is a network of research groups financed by the Information Society Technology program of the European commission dealing with technology-enhanced professional learning (ProLearn, 2007). The German *LearNet* initiative is a consortium of eight German universities sharing remote engineering laboratories (LearNet, 2007). 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 (Zürn et al., 2003). There are many more collaborations as well as some commercial interests in offering remote laboratory services. For example, the *World Wide Student Laboratory* has partial funding from the National Science Foundation in the United States and offers delivery of science and engineering education over the Internet. As remote experiments become more common one can envisage networks of laboratories sharing experiments. Rather than everyone duplicating experiments, there would be a coordinated system of hosting specific laboratories. One institution might host an electron microscope, another an analytical chemistry instrument, while another might have an interactive optics laboratory.

Conclusion

The use of remote teaching laboratories offers residential as well as distance educators another tool to integrate a strong laboratory

component within a science course. The experience is not necessarily identical to supervised on-campus laboratories, but it is equivalent. Students obtain real results using real substances to arrive at real conclusions, just as they would if they were in a physical laboratory with the equipment; this approach allows students to access to science experiments, thus providing them with an advantageous route to upgrade their laboratory skills.

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