Remote Labs

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Overview

Labs are widely considered to be essential to learning science and engineering, because labs can provide a key context in which students experience science as a process of inquiry and get the opportunity to work "hand-on" with authentic tools and materials. However, it is not always easy to provide students with high quality laboratory experiences — labs can be too expensive, dangerous, difficult, or time-consuming. A remote laboratory is an increasingly common alternative that enables a student to conduct a scientific experiment over the internet. A remote laboratory is not a simulation; students control physical scientific equipment and collect data from physical phenomena. Among the many strong reasons to consider remote labs, they can enable students to access sophisticated scientific apparatus at low cost, with greater safety, and more convenience. Further, remote labs can overcome constraints that are hard to overcome in a school lab. Because remote labs are controlled by a computer, then can be precisely executed (whereas students often struggle with the procedures in school labs) and can allow time for students to replicate or extend experiments (because it is easier to precisely vary conditions and efficient to run multiple experiments). Remote labs can be accessed equally well from home and school, and can reduce logistical issues related to scheduling lab time for students. Remote labs offer new possibilities for joint engagement with students, teachers, and mentors, who could use social networking and online communication tools to interact before, during and after labs. Further, displays for remote labs can be augmented (or layered) with additional displays that helps students make sense of what is going on.

The Radioactivity iLab is one example of a remote lab that features pedagogical innovation to enhance students psychological and learning experience. In the lab, students measure radiation from a sample of strontium-90. Obviously, working with radioactive materials is dangerous. In this iLab, students in the United States were able to control apparatus in Australia. Students were able to control a Geiger counter to measure the sample, and could watch what happened over a live video. The learning goal was to observe and infer that the intensity of radiation from a point source decreases proportional to the inverse square of the distance. The iLab is designed as a multi-step, interactive application that supports this learning goal. Research with the lab showed that students prefer the remote lab to a simulation, that the video presence supports their experience of the lab as authentic, and that the video helped them to understand how varying the distance relates to the measured amount of radiation. A follow-on project engages students in the design and development of their own scientific instruments using Arduino-compatible hardware and software, and how that might afford insight into the phenomena (how you measure it, if you're getting reasonable data, how you calibrate it, etc.)

Another example is the interactive biotechnology project at Stanford. What happens in most schools labs is microscopy, where students passively observe. It's hard to do experiments and for teachers to bring in biological organisms—harder than physics, for example, where you can put something back in a drawer at the end of the class. The Riedel-Kruse Lab has developed a platform to make remote, two-way interaction between humans and microscopic organisms not only possible, but easy. The platform lets students and teachers to do free-play experimentation, including exploration, guided experiments, making hypotheses and models, and making measurements to test hypotheses — and by being freely available online, it takes some load off of the teacher because students can do experiments anytime, even in the evening.

In higher education, remote labs could be considered to be a mature use of technology to support learning. Labs have been developed in many topics, including astronomy, biology, chemistry, computer networking, earth science, engineering, hydraulics, microelectronics, physics and robotics. For example, the Labshare group in Sidney has a fairly robust strategy where they are using remote labs in their undergraduate engineering curriculum. Research on teaching and learning with remote labs is largely positive. Across many studies that compare remote and local labs in higher education, little or no differences have been found in learning outcomes and students experience remote labs as being equally effective. Research in secondary schools also shows the promise of remote labs, but notes the need to focus on support materials for both teachers and students to frame student learning and that secondary students find the tactile engagement with laboratory equipment motivating.

Further, labs are now being consolidated onto common platforms. These platforms, such as Go-Lab, WebLab-Duesto, LiLa, and PEARL offer the potential for many more users to discover and access remote labs, with greater consistency in the user interface. Consequently, use of remote labs is expanding not only in higher education, but also into K-12 science and engineering education. While Europe, North America, and Australia were earlier leaders in exploring remote labs, use is now spreading to places like remote areas of Brazil, where connections to the internet are available but scientific equipment is scarce. The attractiveness and growing availability of remote labs means now is an ideal time to focus on the pedagogical innovations that will be necessary to realize the full potential of remote labs for developing students' interest in science and engineering as well as students' learning of key disciplinary concepts and practices.

Key Lessons

One of the appeals of the remote lab concept is that it can appear to be an easy substitution — whereas a teacher and her students previously conducted a lab in their own classroom, now they do the same thing but substituting online apparatus for local apparatus. While this view may make it more comfortable for teachers to consider trying remote labs at first, in the long run, it undermines the potential for pedagogical innovation. Below, we consider some of the ways in which remote labs change the game, and the pedagogical factors that can be important to realizing their transformative potential.

What is the purpose of the lab? For some physical labs, the purpose of the lab is to learn to handle scientific equipment safely, appropriately, and precisely. This work is necessarily taken out of students' hands in a remote lab. Consequently, educators more often focus on conceptual understanding and inquiry goals in remote labs. Students often appreciate that it is now easier to obtain a high quality data set (and that they may spend less time frustratingly explaining why they could not get the apparatus to work), and it can become possible for students to more easily focus on comparing multiple experiments (as less time may be consumed by setup and cleanup). More generally, the first generation of innovators in remote labs found that sometimes sticking with local, physical experiments is better — not all phenomena merit the complexity of setting up remote equipment and a mix of physical and remote investigations benefits students. For example, in a remote lab students have less opportunity to design how they will evoke and measure phenomena — typically the capabilities of a remote lab are preset or parameterized; however, in a physical lab, students can be challenge to find the best way to set up an experimental condition or to design their own methods of measurement. So there should be a clear reason to choose a remote lab instead of a conventional lab, and the learning objectives should fit the possibilities of the environment.

Presence. Researchers have noted that in successful remote labs, students often feel a sense of presence with the scientific equipment. Indeed, students sometimes report that interacting with remote equipment feels more authentic that using the less sophisticated versions they can access at their own school. To some extent, seeing is believing: it is unsatisfying to merely turn some knobs and receive a data set back. More advanced remote labs often provide a live video that shows students what is happening as they control the experiment. And in the future, virtual reality goggles or glasses may extend the sense of presence. Presence is also not merely a matter of visual perception. Because students did not physically set up the lab, more attention may need to be given to how they will become familiar with the apparatus and to learning how they can control it. Sauter and colleagues (2013) showed that students preferred remote labs to simulation given identical user interfaces because they felt more sense of ownership over the data produced – it was “their data”, not data produced by a simulation programmer. Teachers also have a key role in introducing and orienting students to the remote lab so that it will feel real.

Formative assessment. Researchers have noted that in traditional place-based labs, teachers typically walked around to identify difficulties students were having with the lab, and to intervene appropriately. In a remote lab, students still need the benefit of formative assessment during their engagement with the lab, but the teacher may not be physically present. One approach can be to build formative assessment resources into the lab itself, as an additional digital resource that supports students in checking their own understanding and progress. An area for innovation is to also support human intervention, for example through analytics dashboards and conferencing (chat or video).

Collaborative learning. Likewise, traditional place-based labs could be places where students socially interact in support of each others’ learning, though in practice, this is not always realized (Kozma, 2000). Collaboration can also be challenging with a remote lab. As in the discussion of formative assessment, a basis for communication can be set up via chat or online calling. Yet, research in the area of computer-supported collaborative learning (CSCL) suggests that only providing a communications infrastructure will not be enough. Successful CSCL approaches emphasize defining structures to support students’ collaboration, which can include assigning specific roles to students, providing a shared workspace, orchestrating when students should communicate in the course of their work with the lab, and helping students to monitor and improve the state of their social engagement.

Flipping the classroom. In a conventional K-12 science classroom, most of the classroom time available for doing a lab must be devoted to using the lab equipment. Often students are expected to organize and interpret their data as homework. However, with remote labs it becomes possible for students to run the experiments outside of class (for example, using computers in the school library after school or from home). This potentially can free up class time to focus on making decisions about what to investigate and discussing the resulting data.

Framing the broader learning activity. One literature review observed that prior work in remote labs developed many resources for guiding students during the labs, but most of the resources focused on the process of doing the lab. Much less attention has been paid to the nature of the guidance students need before and after the lab. For example, students need support for orientation to the lab and to plan meaningful experiments and investigations before they begin using the remote equipment. Students need support for conceptualization, such as support for concept mapping and for elaborating hypotheses. They also need considerable guidance in making sense of the data that results, relating the data back to their original driving questions, and deciding what to do next. Overall, pedagogical innovation is needed to support self-regulated learning as student engage with remote labs.

Leveraging unique possibilities. As previously noted, remote labs bring some unique capabilities that are hard to achieve with local physical labs. For example, labs can focus more on comparing data from several experiments, because it becomes easier to run a small series of carefully controlled experiments. Likewise, since the data is collected in an online format, it can be easier to contrast data sets collected by different students or to merge them into one larger data set. Whereas physical labs often consume all the time available just to complete one cycle of data collection, with a remote lab it may be possible for students to design follow up experiments. Remote labs also can augment the displays coming back from real phenomena with additional visualization that may help students to interpret the underlying processes. Further, teachers can support students who want to go farther with a particular lab by letting them continue their investigation after the formal school assignment is completed.

Analytics. Moving the work of experimental design and data analysis online creates “digital breadcrumbs” that provide new opportunities to support students through the learning process — both in automated ways, and by providing teachers with greater insights. Analytics dashboards and other tools operating over these breadcrumbs give teachers new ways to inspect and comment on student work, and can help them gain deeper insights into students learning in ways that may not be possible or easy to do in traditional labs. Digital breadcrumbs also provide researchers with new data (beyond interviews and surveys) to better understand and unpack the learning process.

Supporting teacher learning. Researchers have also noted that remote labs offer some new possibilities for teacher learning. For teaching candidates who are studying at university, they can practice with a remote lab on their university campus and then teach students with the exact same lab during a practical teaching experience in a school. Remote labs can also offer teachers examples of data sets that students collected, so they can anticipate what will happen during the lab. Further, since teachers in different classrooms or in different schools can use exactly the same remote lab, they can more easily engage in discussions of their pedagogical approach to teaching the lab. Tools like ilabstudio supports novice teachers by providing pre-authored feedback that can be used to model sophisticated feedback.

Issues

Tradeoffs of place-based vs. remote labs. What is lost and what is gained when moving from hands-on to remote labs? Advocates of place-based labs extol the benefits of real data, unexpected clashes, and opportunities for collaborative learning. Detractors point out that hands-on labs are costly, and observations of students show that lab partners often talk more about equipment setup and procedural problems than concepts of inquiry (Chinn & Malhotra, 2002; Kozma, 2000). Further, in bioscience labs, maintaining live specimens (like microorganisms) in and of itself is a hassle for teachers; there are affordances for having that offloaded to the remote provider that teachers have found very appealing. Other challenges, like accessibility (see below) still exist, just in different ways, in both formats.

Accessibility. While hands-on labs can pose problems for students with special needs, computer interfaces are that are not easy to use can also present difficulties for students. Overall, in choosing (as well as in designing) remote labs, educators should pay attention to both the physical and cognitive demands of interacting with the apparatus through the interface. Computer-based remote lab interfaces could offer increased accessibility for disabled students who would nother otherwise be physically able to access traditional labs — for example, for a blind student, a remote lab coupled with a screen reader and other tools could provide greater access than a physical lab environment. Remote interfaces can support access in ways that may not have been possible (or too dangerous) before, while in other instances, physical, tactile engagement may be preferable.

Complexity. Students in tertiary education are already on the path to specialization and can be expected to manage panels with many different controls and a higher degree of abstraction between the control interface and the apparatus being controlled. As remote labs move to secondary or primary education, simpler controls with less abstraction may be needed. When well designed, remote labs can also adapt to a student's pace instead of requiring work on a pre-defined schedule –and can allow students to make up labs they missed due to illness. Opportunities for innovation include exploring new interface modalities, such as touch interfaces or haptic (motion-feedback) interfaces. New opportunities for scaffolding are also possible: A layer of software interface that can be tailored to the specific level and pedagogical goals of the student, rather than forcing all students to use a fixed physical interface, provides much greater adaptivity to the teacher and the software designer to introduce professional caliber equipment into classrooms at different levels and hide or release access to different versions of the interface to control that instrument.

Projects

Examples of NSF Cyberlearning projects that overlap with topics discussed in this primer.

- EXP: Transforming High School Science via Remote Online Labs
- DIP: Collaborative Research: Taking Hands-on Experimentation to the Cloud: Comparing Physical and Virtual Models in Biology on a Massive Scale
- DIP: Using Dynamic Formative Assessment Models to Enhance Learning of the Experimental Process in Biology
- DIP: Collaborative Research: Mixed-Reality Labs: Integrating Sensors and Simulations to Improve Learning
- EAGER: A Prototype WorldWide Telescope Visualization Lab Designed in the Web-based Inquiry Science Environment

Other relevant cyberlearning-themed projects:

EAGER: MAKER: The Design and Engineering of Scientific Instrumentation as a Pathway for Introducing Making into High School Science Classrooms.

Resources

Remote Labs – A Lab in Every Pocket (From the NSF Video Showcase)

Labshare Institute

CIRCL Webinar: Interactive Biotechnology with Ingmar Riedel Kruse

International Conference on Remote Engineering and Virtual Instrumentation

International Journal of Online Engineering (iJOE)

Readings

References and key readings documenting the thinking behind the concept, important milestones in the work, foundational examples to build from, and summaries along the way.

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