Virtual Labs

Scenario

Lin Chien chairs the chemistry department at Deer Canyon Community College. Over the past 10 years, the enrollment has increased considerably. As an institution that relies heavily on tuition, the college has not been able to add to its physical infrastructure to match the rising demand. As a result, much of the growth has been enabled by an expansion of the college's online offerings. Chien finds herself in a difficult position. More students want to take introductory chemistry courses, but the physical lab on the college's campus is not able to accommodate any more students. As a stopgap, the college leases lab space from a nearby university, but that institution is also being squeezed for space and resources.

Chien turns her attention to a commercial service that provides virtual labs for disciplines including chemistry. She confirms that an online lab will satisfy the provost and doesn't raise any concerns about accreditation, and a pilot of the program begins. Initially, students are staggered between the physical lab and the virtual lab, with all students doing at least a portion of their lab work in a physical setting. After one term, Chien and the other chemistry faculty see enough value in the virtual lab that they drop the requirement that some work must be done in the campus lab. They agree that students are able to learn the concepts and the practices of lab work virtually, and this decision allows the college to open the chemistry courses to the growing pool of online students, many of whom never set foot on campus. Faculty in the biology department take note of the success of the chemistry labs, and the following year, Deer Canyon begins offering biology courses with virtual labs.

In addition to online students, virtual labs are extremely valuable for commuter students, many of whom have responsibilities that complicate scheduling in the on-campus lab, which isn't available at times that work well for all students. Two other groups of students benefit, as well. Deer Canyon participates in a bridge program with several local high schools, allowing juniors and seniors to earn credit for courses they take at the college, and virtual labs fit nicely into those programs. The college also offers its online courses to inmates at a state prison. Previously, those students were not able to take lab-based science courses while incarcerated, and Deer Canyon's virtual labs enable those students to participate fully in the learning experience.

1 What is it?

Virtual labs are interactive, digital simulations of activities that typically take place in physical laboratory settings. Virtual labs simulate the tools, equipment, tests, and procedures used in chemistry, biochemistry, physics, biology, and other disciplines that include a laboratory component in the curriculum. A key characteristic of virtual labs is their interactivity—video recordings or renderings of lab activities that cannot be manipulated by users fall outside this discussion. Similarly, physical equipment such as radio telescopes or electron microscopes that can be controlled by distant users is considered remote instrumentation rather than a virtual lab. By accurately representing the actions, reactions, and consequences of manipulating materials and equipment, virtual labs provide a way for students to participate in lab-based learning activities without the overhead of a physical lab.

2 How does it work?

Virtual labs operate online, often embedded into an LMS. As with a physical lab, faculty members determine which lab assignments are required to support learning objectives at various points in the syllabus. Students have access to virtual representations of the equipment and supplies they would find in a physical lab. In a virtual chemistry lab, for example, students might find beakers, pipettes, cylinders, and other glassware; a collection of acids, bases, and other solutions; and Bunsen burners, scales, and other needed hardware. Students follow the steps of an assigned procedure and observe and record the results. Students see digital simulations of the results of their actions—or of their missteps if they make a mistake. Most virtual labs allow users to stop, start, and replay an activity. Many virtual labs integrate with a course's curriculum, recording students' progress and assigning credit toward learning goals and grading. Virtual lab applications and the content within them can be bought from vendors or developed in-house. Some vendor tools allow instructors to add or adjust the content to suit their courses, and other systems enable faculty to co-develop resources with a commercial developer. The amount of technical skill required for faculty to participate in the development or customization of virtual labs varies, depending on the tools involved.

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3 Who's doing it?

A range of commercial, nonprofit, and educational organizations have developed virtual lab applications and content, and a growing number of colleges and universities are offering virtual labs in various disciplines. Companies such as Labster and PraxiLabs offer virtual labs for various subjects. The PhET Interactive Simulations project at the University of Colorado Boulder has developed a collection of online simulations in physics, chemistry, math, earth science, and biology. Some publishers of academic materials have begun to provide virtual labs, such as Macmillan Learning's Hayden-McNeil Lab Simulations. The American Chemical Society (ACS) hosts links to virtual chemistry and simulations, and MERLOT curates a collection of virtual lab learning objects and resources. Colorado School of Mines maintains a growing collection of links to simulations and virtual labs across a wide range of disciplines. Some institutions have turned to Sketchfab to create 3D models of artifacts such as bullets and cartridge casings, which are used in labs for forensics courses. Other institutions use virtual reality (VR) tools as part of virtual labs. Faculty at Case Western Reserve University have developed educational resources that use Microsoft's HoloLens to help teach anatomy through interactive, 3D simulations. Similarly, UbiSim develops VR-based interactive simulations focused on nursing education.

4 Why is it significant?

Virtual labs allow students to participate in lab-based learning exercises without the costs and limitations of a physical lab. If an institution enrolls several hundred students in an introductory chemistry course, for example, the ability to send at least some of those students to an online lab could decrease the amount of physical lab space needed and/or significantly increase flexibility for students, given that they could do the work at their convenience. Virtual labs can provide access for students in online programs or who are unable to attend physical labs due to illness or injury. Institutions in areas prone to severe weather, wildfires, or earthquakes use virtual labs to support continuity of education when such events occur, and—as was demonstrated during the COVID-19 pandemic—virtual labs can fill gaps in education at any institution due to a public-health crisis or other disruption. For some lab activities, the consequences of a mistake can be significant, and virtual labs relegate that risk to the online environment. In some ways, virtual labs can offer more functionality than a physical lab, such as the ability to include quizzes and access to additional educational resources within the simulation.

5 What are the downsides?

Despite their increasing levels of realism and fidelity to the physical world, virtual labs cannot equal the full experience of being in a physical lab. The actual risks of working with physical solutions are part of the learning, and a student who wants to be a chemist must study in a physical lab. Commercial products for virtual labs can be expensive, and some don't allow customizations. When they do, making and testing those customizations can be time-consuming and add further costs; meanwhile, developing new labs from scratch is even more resource-intensive. In some disciplines, virtual labs don't provide a compelling, effective experience. Virtual labs require students to have reliable internet access, and the applications that run the labs sometimes experience glitches. Notably, most of the virtual lab tools available today are not accessible to students or faculty with disabilities—even as such tools extend access to certain groups of users, they disenfranchise others.

6 Where is it going?

Virtual labs are not a novel technology, but the COVID-19 pandemic has created significantly more demand, as institutions scramble to maintain learning in lab-based courses. This new level of attention will lead to new developments in the applications and content that allow virtual labs to operate. Some virtual lab applications already include augmented reality or VR elements, which can deepen the engagement and thus the learning. VR-based science labs can require headsets, however, presenting a potential barrier to widespread adoption. Another area of potential growth is the incorporation of gamification and role-playing elements into virtual lab experiences.

7 What are the implications for teaching and learning?

Virtual labs can be an important element in institutional efforts to expand access to lab-based courses to more and different groups of students, as well as efforts to establish contingency plans for natural disasters or other interruptions of campus activities. At the same time, a virtual lab can provide different and additional resources for courses that have traditionally been particularly difficult for some students to comprehend. Making mistakes is an important part of learning, and virtual labs create a wider margin for errors than a physical lab. Virtual labs are often not a good substitute for sophisticated, highly complex lab activities, but in many contexts, they are an increasingly viable alternative to physical labs for introductory and mid-level courses.