PROVIDING EFFECTIVE TEACHING LABORATORIES AT AN OPEN UNIVERSITY

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Abstract

As more science courses in higher education are being redesigned to move online, there is growing interest in effectively handling required practical components such as teaching laboratories and field work. Athabasca University (AU) is an open university and has been delivering science laboratories at a distance for over four decades. This paper reviews the various methods employed at AU to provide high quality laboratory experiences to students in science courses using a variety of delivery modes such as face-to-face, home-study kits, virtual simulations, mobile devices for fieldwork/clinic, and remote controlled laboratories. Although the selection of an individual delivery mode is driven by both practicality and need to create an effective learning environment, the author also encourages experimentation with blending of modes to potentially enhance learning in the laboratory. Major emerging trends such as new technologies, access to ubiquitous information, and a move to open learning will certainly shape future innovations in laboratory design for online courses. So while currently still on the horizon, novel components like open educational resources (OER), learning analytics, citizen science, and connection to dispersed knowledge networks are imminent for the laboratory of the twenty-first century.

KEY WORDS: science, laboratory, field work, clinic, experiential, open, online, distance learning

1. INTRODUCTION

Athabasca University (AU) is Canada's Open University and is dedicated to increasing accessibility to university-level study and equality of educational opportunity for adult learners worldwide. Founded in 1970, it has been offering science courses since 1976. The university has over 40,000 students, no formal prerequisites for entry-level courses, and year-round continuous registration for undergraduate courses. In 2006, AU became the first Canadian public university to receive accreditation in the United States.

In the 1970s and 80s AU was one of the few universities worldwide that had an exclusive open- and distance-learning approach since its inception. The initial model was independent study courses with print-based material and telephone tutor support. As newer technologies became available, they were experimented with and, if found useful, adopted. Assignments originally sent through the postal system can now be submitted electronically. Courses (and some laboratory components) saw the introduction of stand-alone technologies such as videos (later DVDs), computer assisted learning modules, and CD-ROM tutorials/simulations. However, adoption of new technologies usually varied across the university, with the technology essentially considered an add-on or modification to the original working model (Kennepohl et al., 2012).

It was not until this past decade that AU has truly moved online. This was precipitated by a number of system-wide changes across the university including adopting a standard learning management system (Moodle) to house courses (including electronic versions of all AU learning materials), the preference of both students and teachers to move away from telephone communications, the move towards e-textbooks and/or open educational resources (OER) textbooks to replace commercial print materials, and finally the integration of a student relationship management system.

The sciences at AU certainly adopted many of these changes in the theory part of their courses, but, unlike their non-science colleagues, they must also consider the practical components of their courses. Indeed, the successful delivery of quality science courses containing a substantial laboratory component has always been a very real challenge—especially at a distance. As more institutions of higher education move to online modes in the science disciplines, there is universal growing interest in how science can truly be taught and learned in the twenty-first century. This article reviews some of the approaches that have been employed successfully at AU.

2. ROLE OF PRACTICAL WORK

A strong laboratory component is at the heart of any science program, but it is also one of the most challenging aspects to do effectively at a distance. How practical work-whether laboratory, field work, design projects or clinical work-is used or even if it is needed in the first place has always been a pressing consideration for any science educator. The role of the teaching laboratory, its changing nature and its intended learning outcomes has been discussed and will continue to be discussed at length (Kirschner and Meester, 1988; Nakhleh et al., 2003; Whitworth and Wright, 2015). The added challenge of delivering an effective laboratory experience in a distance environment was recognized early on with the emergence of open universities (Kember, 1982). Over the decades a number of strategies for practical work at a distance have been explored and exploited, but the more recent move to online courses has given renewed urgency to also provide the learner with corresponding accessible laboratories (Downing and Holtz, 2008; Jeschofnig and Jeschofnig, 2011; Kennepohl, 2016). It is interesting to note that the surge in demand for these laboratories is not coming so much from the open and distance institutions, but from the traditional campus-based institutions who now wish to also offer students distance, online and blended options of study for their students.

3. TYPES OF LABORATORY MODES AT ATHABASCA UNIVERSITY

3.1 Face-to-Face

Despite a growing body of literature showing that alternative laboratory modes are essentially equivalent and in a few cases better than face-to-face with respect to achieving stated learning outcomes (Doulgeri and Matiakis, 2006; Fiore and Ratti, 2007; Lindsay and Good, 2005; Corter et al, 2011; Smetana and Bell, 2012), AU continues to employ this mode primarily for logistical and safety reasons on an as-needed basis. In some cases, there is a requirement for direct learner interaction with chemicals, equipment, and specimens/samples, or for student supervision. It is still a *bona fide* mode of delivery that should not be abandoned, but used intentionally rather than by default.

3.2 Home-Study Kits

The idea for AU home-study laboratory kits evolved from having students do practical exercises in their home environment for AU science courses. This could be doing a series of kitchen chemistry experiments (done with commonly available household items and ingredients), classifying plants in the home, garden or nearby park for botany/ecology, or keeping a personal food diary for a nutrition course. Eventually kits were built and sent out for courses which normally had face-to-face laboratories. This has included rock and mineral kits for introductory geology; geological maps, compass, and three-dimensional graphical calculator for structural geology; sphygmomanometer, stethoscope, spirometer, lung volume bag, simulated bloods and urine for Human Physiology (BIOL 230); and chromatography paper, dialyses tubes, enzymes, corn seeds, pH paper, etc. for basic introductory biology home kits. However, the more sophisticated and popular laboratory kits have been those for introductory physics and chemistry. The chemistry kit (Fig. 1) is self-contained and comes with the needed chemicals, microscaled equipment (including electronic scale and mini spectrophotometer) and a video guide that is also available online. The physics kits (such as in Fig. 2) was originally based on a graphing calculator included in the kit, which can be attached to sensors to track and record various physical phenomena, produce graphs, and perform analysis (Al-Shamali and Connors, 2010). However with the current kit students connect components like the magnetic field sensor and differential voltage probe via the USB sensor interface Go!Link (all shown in Fig. 2) to their own computer and employ Logger Pro software.

FIG. 1: Components of the first-year general chemistry home-study kit (CHEM 217)

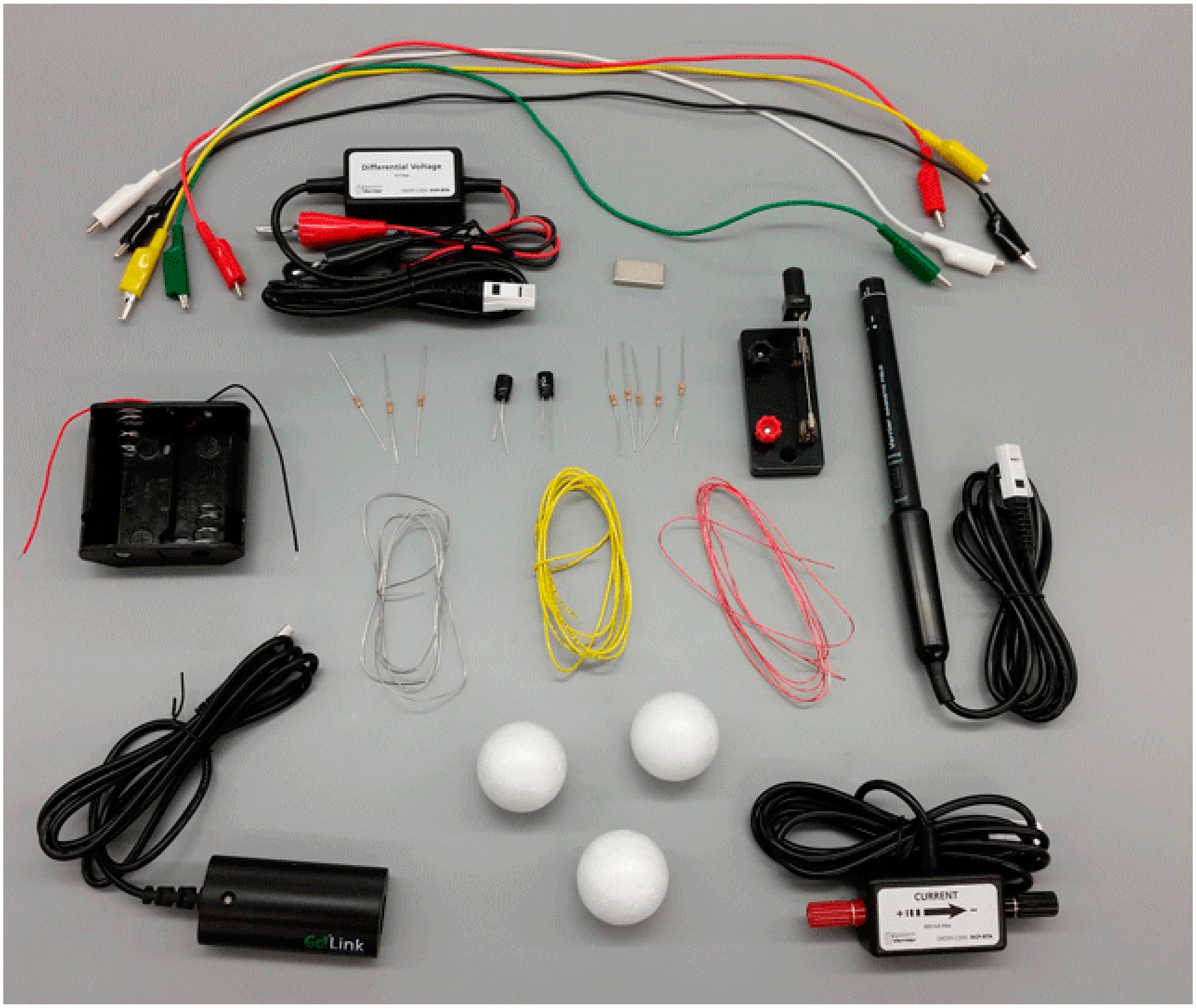

FIG. 2: Contents for one of three introductory physics home-study kits (PHYS 205)

These kits are very popular with students and have resulted in dramatic increases in student enrollments (Kennepohl, 2013). The fact that students valued the increased accessibility and flexibility of working at home was not new or surprising. However, we did run across another big advantage to the home-study laboratory that was totally unexpected. Our studies indicate that home-study laboratories contextualize the learning and also encouraged experiment participation by other household members in the student's home (Kennepohl, 2007).

3.3 Virtual Laboratories

Although computer simulations and visualizations offer a myriad of advantages (e.g. reduced costs, safety, immediate feedback, learner control, analytics etc.), they have only been used sparingly at AU and often in a supporting role. In courses like Immunology

(BIOL 480) or Introduction to Astronomy and Astrophysics (ASTR 210) students do complete their entire practical work using computer simulations. However, in many other courses like Human Physiology (BIOL 230) or Introductory Microbiology (BIOL 325) or the previous version of Chemical Principles II (CHEM 218) course there is a blend of simulation, online activities and hands-on work. In the chemistry course half the laboratories were at one time effectively replaced by experiments using interactive digitized video (Kennepohl, 2001). In the microbiology course there is an extensive series of online interactive learning activities with the Learning Taxonomy Tree and Clinical Case Studies (http://ocw.lms.athabascau.ca/mod/resource/view.php?id=319) followed by attendance at supervised face-to-face laboratories. For human physiology, the learners carry out simulated experiments (NelsonBrain.com), but then also physically do home-study experiments with a kit as previously mentioned.

In certain cases virtual resources just supplement the course rather than act as a complete stand-alone laboratory. For example, geography students can interact with a wide range of software (http://science.athabascau.ca/Labs/resources/geography.php) to assist them in their courses, while botany students can access the digital herbarium (http://digiport.athabascau.ca/herbarium/) as an online reference for fieldwork. Environment Chemistry (CHEM 330) students regularly explore a number of visualizations on global climate change at the King's Centre for Visualization in Science (http://kcvs.ca/concrete/visualizations/global-climate-change). Finally, there are a few virtual laboratory resources designed exclusively to train the learner for the laboratory. For example, several biology courses make use of the video How to Use Stereo and Compound Microscopes (https://www.youtube.com/watch?v=dNdcriMUTDc&lr=1), while many home-study kits come with a video guide. Computer simulations have also been used in online tutorials to instruct organic chemistry students to operate remote laboratory equipment via the Internet.

3.4 Fieldwork and Clinics

Portable GPS-enabled mobile gadgets have not only generated interest in mobile learning (Almeida and Araújo Jr., 2016), but have found strong support for their practical and educational applications in areas such as health, medicine (Scott et al, 2017), and several field-sciences (Thomas and Fellowes, 2017). An open application is currently being developed for AU's physical geography courses (GEOG 265 and GEOG 266) that would allow mobile devices to facilitate technology-guided field trips in Alberta. It not only will allow students to make observations, collect and record data, and solve problems directly in the field, it will possess a location-based adaptive learning platform that is ideal for situated learning. That is, GPS technology allows the device to know where it is and then provide information relevant to that particular site.

While this technology is just being introduced to fieldwork in some science disciplines to enhance situated learning, it has been an integral part of clinical work for some time now. Indeed, nurses have been early adopters of mobile devices for information support (e.g. to access laboratory results, drug interactions, prescription schedules, patient data) and communications while on the move. Because mobile devices have become ubiquitous and a professional expectation, their integration into the training and education of nurses was natural. Moreover, nurse educators employ mobile devices to manage student assignments, form checklists for tasks, and access learning analytics like tracking current student progress. In some programs, like nurse practitioner, the use of mobile devices has become a mandatory requirement (Lamarche and Park, 2012).

3.5 Remote Laboratories

Remote laboratory access is more than just simulations found in the virtual experience. It allows the learner to physically carry out real experiments online to obtain real results using real substances and make real conclusions, just as they would if they were in the laboratory with the equipment. While remote laboratories have been used in a few courses, they are primarily exploratory and experimental in nature. A remote introductory mechanics laboratory in physics was developed to allow students to control, operate, and observe a custom-built piece of equipment to pick up and drop a steel ball (Connors et al., 2011). Each run would give raw data for the time to fall, valid at the microsecond level, to allow calculation for the value of the acceleration due to gravity.

In chemistry the approach was to employ sophisticated analytical instruments already controlled by computer and then make them accessible via a browser through the Internet (Kennepohl et al., 2004). While remote access was easy to establish, the challenge was to teach students both the chemistry and how to operate effectively in a remote environment. An early study had general first-year chemistry students remotely access an ultraviolet-visible spectrophotometer to measure sample concentrations. The students noted that learning the instrument interface, whether on site or remotely, was too much to ask for an experiment in a general first-year chemistry course where only a handful of measurements would need to be made. Since then the focus has been on more senior students, but providing a seamless pedagogical front-end to instrument access is still a challenge.

Organic chemistry students can carry out a dehydration reaction of an alcohol that generates a mixture of several products that can be separated and analyzed by gas chromatography (GC). Students do the synthesis in a supervised laboratory and leave their samples, which are loaded onto an autosampler of the GC instrument to be remotely selected and examined later at their leisure. Together with collaborative research partners we have explored access to a variety of different analytical instruments and have found in general that the remote experience is equivalent to the in-lab experience (Meintzer et al., 2017). It is interesting to note that one of the most valued components reported by students has been the real-time video image of the instrument as they are controlling it, as seen in Fig. 3. It makes the experiment more ‘real’ for them.

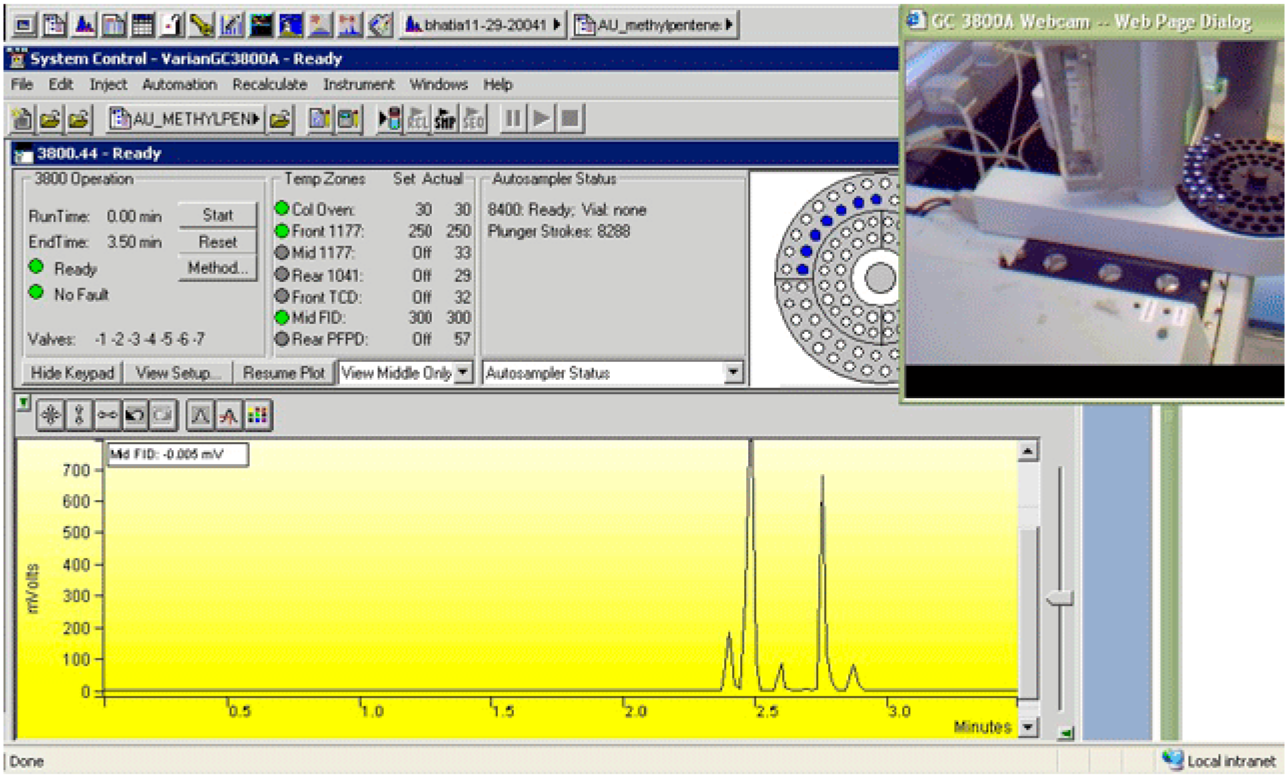

FIG. 3: Actual remote instrument access of gas chromatography experiment in progress for Organic Chemistry I (CHEM 350) with web camera view (insert) in real-time. Seeing is believing!

3.6 Blending Laboratory Modes

Although different distinct modes of laboratory delivery are identified (Fig. 4), in several of the previous AU examples, combinations of modes are used in a single course. For example, organic chemistry students carry out a synthesis in the laboratory (face-to-face) and leave the sample to be analyzed later from home (remote laboratory) after learning to control the analytical instrumentation with an online tutorial (virtual laboratory). The blending of modes not only offers more flexibility, but potentially affords greater opportunities for learning. A very common blend that is often reported in the literature is some sort of virtual experience followed by a face-to-face laboratory. Studies have shown that a combination of the two modes works better than either on its own (Jaakkola and Nurmi, 2008; Zacharia et al., 2008). It is interesting to note that the best order for the combination is not always from simulation to reality. In at least one case, starting with face-to-face afforded better learning (Smith and Puntambekar, 2010). However, there are numerous other combinations of laboratory modes yet to be explored. Blended learning can be applied to the practical component of the course—not just the theory.

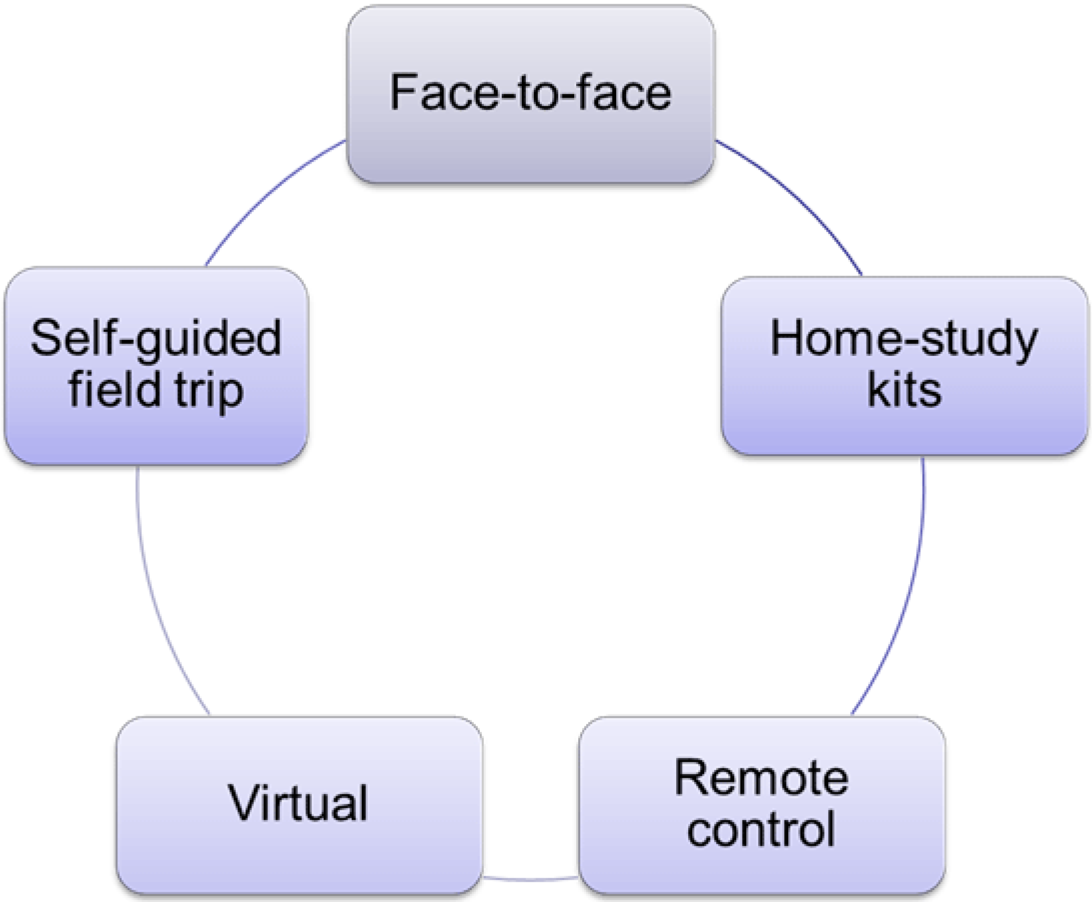

FIG. 4: Laboratory delivery modes can be blended to get the right mix of access and learning

4. TEACHING LABORATORIES IN THE TWENTY-FIRST CENTURY

While we continue to build on solid scientific tradition and methodology, three emerging trends will fundamentally shape how we will approach the laboratory component of online science courses in the near future. It is no secret that there has been a massive increase to both new technologies and information, so that digital assistance and knowledge are ubiquitous. These first two trends are well known and have been thoroughly discussed in the past and will continue to be discussed in the future. For example, not only have new technologies facilitated alternative practical work such as field and clinical work with mobile devices or virtual and remote laboratories, but once you have the digital data you can readily apply techniques such as learning analytics to track and adapt the learning environment. These sorts of direct measures provided through learning analytics are much more compelling than having to rely only on surveys of student perspectives and self-reporting (Siemens and Long, 2011).

The third trend, although not as immediately high profile as the first two, is simply the move to ‘open.’ It is an important factor and, in many ways, a natural result of the other two trends. The recent movement to open educational resources (OERs) exemplifies this trend. Sharing of resources (small learning objects to entire courses) not only saves costs and gets around unnecessary duplication of effort, it comes with the strong social mandate of access for all (D'Antoni, 2009). The idea of open is not limited to content and can also reflect connectivity to people in digital networks. This has introduced a proposal for a new type of learning model called ‘connectivism,’ which sees knowledge as distributed over a network of connection points of information or ‘nodes’ (essentially content and people). Learning then occurs as one links and traverses that network of nodes (Downes, 2007). While it is debatable that this is a new independent learning theory (Kop and Hill, 2008), one should keep in mind that the teaching and learning of science seems to be already well centred in constructivist learning (Bailey and Garratt, 2002). Still, what is more important for our discussion on practical work is that increased connectivity also means resource sharing similar to the OER movement, but expanded to include instrumentation (e.g. remote laboratories) and people or knowledge networks (e.g. e-science and cyberinfrastructure-enhanced science initiatives (Atkins et al., 2007)). In future a science student may well carry out laboratory work hosted at another institution or be involved in off-campus collaborations or share instrumentation remotely—all of which are activities that they will likely encounter in their own work as modern scientists.

A final aspect to consider in the trend to open is the melding of formal, informal and non-formal learning. While historically there has been incredible value placed on the formal learning of science, most people (including scientists) get most of their science knowledge through informal and non-formal sources such as discussions, science centres, museums, popular science magazines, television programs, newspapers, and various science outreach initiatives. So the emphasis now becomes ‘what is learned’ rather than ‘how it is learned.’ This may potentially mean increased demand for online laboratories for more than formal learning. It is also a natural step towards citizen science where the public (amateur scientists) participate in a research project that is effectively crowdsourced (Bonney et al, 2014). Conversely, that same crowd-sourcing approach can also be used to engage science students in practical work involving collaboration and real research projects.

5. SUMMARY

Teaching and building an effective learning environment while contending with serious logistical considerations is a real challenge within any practical laboratory or field component in the sciences—even more so when that component needs to support a course that is online or at a distance. As an open university, the courses offered by Athabasca University (AU) are completely online and at a distance, including those in the sciences. We have provided a brief survey of several modes to the delivery of our laboratory components (i.e. face-to-face, home-study kits, virtual, fieldwork/clinic, remote) across various science disciplines. No one approach is correct and combinations of modes are often employed. Future laboratory design at AU will not only rely on continued blending of modes to get the right mix, it will be influenced by trends such as new technologies, access to ubiquitous information, and a move to open learning and open science. This will mean integrating into future teaching laboratories elements like appropriate new technologies, OERs, learning analytics, citizen science, and connection to knowledge networks outside the university.

Dietmar Kennepohl is Professor of Chemistry and former Associate Vice President Academic at Athabasca University—Canada's Open University. Most of his teaching experience has been in a distributed and online setting and he holds both university and national teaching awards. Dietmar is a well-published and sought-after presenter at local, national and international conferences, on topics including learning design, learning outcomes, assessment, PLAR, transfer credit, distance and online education, and emerging educational technologies.

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