NANSLO PROVIDES ONLINE STUDENTS A WEB-BASED LABORATORY OPTION USING REAL SCIENTIFIC EQUIPMENT, GENERATING REAL DATA IN REAL TIME

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ABSTRACT

Higher education institutions are facing growing pressure to expand online course offerings. This has led to a need for alternative ways to provide laboratory learning experiences for science courses due to high demand for them by both major and non-major students. At the same time, the high cost of expanding existing or building new laboratory facilities is making this prohibitive, resulting in enrollment bottlenecks. The North American Network of Science Labs Online (NANSLO), established in 2012, includes two web-based science laboratories available for use by institutions on a fee-for-service model. Using a web interface, students access an assigned lab activity and, using real high-end scientific equipment, generate real data, collaborate with other students, and collect information used to complete their labs—all done in

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real time. NANSLO currently has 28 lab activities available in biology, chemistry, allied health, and physics, and two lab manuals—NANSLO Survey of Chemistry and NANSLO Survey of Biology Lab Manuals, each containing 10 lab activities—used in non-science and science major courses. All of these can be used as-is or customized by faculty to meet course needs. With over 2,000 students served to date, NANSLO is capable of delivering high-quality NANSLO laboratory experiences to students via the Internet wherever they are located at a time convenient for them.

KEY WORDS: NANSLO, remote web-based science laboratories, online labs

1. NANSLO ADDRESSES KEY ISSUES FACING INSTITUTIONS

Pressures on higher education today are driving the need to look for alternatives to traditional face-to-face science laboratories. Enrollments are expanding, putting additional pressures on institutions to serve ever-increasing student numbers. In fall 2013, there were 10.5 million undergraduate enrollments at four-year institutions and 7 million at two-year institutions. Between 2013 and 2014 enrollment at two-year institutions was projected to increase by 15 percent (8 million students) and by 11 percent (11.6 million students) at four-year institutions (Kena et al., 2015).

The number of students taking classes online continues to increase, requiring courses to be redesigned to meet quality standards that are consistent with the same courses offered face-to-face. New approaches need to be considered for these online offerings, especially in the sciences, where face-to-face labs may be a hardship or impossible for students to complete. Joel Hartman, an administrator at the University of Central Florida and president of the Online Learning Consortium, notes that the 2014 Survey of Online Learning Grade Levels: Tracking Online Education in the United States "shows evidence that online learning has reached the mainstream" (Haynie, 2015). That study's co-author, Jeff Seaman, co-director of the Babson Survey Research Group, indicates that online learning accounted for nearly three-quarters of all US higher education's enrollment increases in 2014 (Seaman, 2016).

"The demand for online education is primarily student-driven" (Jeschofnig and Jeschofnig, 2011). Nontraditional and part-time students prefer online education

because it offers, among other things, flexibility and the ability to self-pace, characteristics that assist them in balancing work and family responsibilities, while traditional students that prefer technology are also attracted to online education (Edwards et al., 2015).

The number of associate's and bachelor's degrees awarded in health professions and related programs continues to increase. Over 1 million associate's degrees were awarded in 2012–2013. Of those, 214,000 degrees were in health professions and related programs. In 2012–2013, 1.8 million bachelor's degrees were awarded in postsecondary institutions. Of those, 181,100 degrees were in health professions and related programs. In these postsecondary institutions, a large number of degrees were also awarded in biological and biomedical sciences (Kena et al., 2015). Undergraduate academic programs for these degrees typically require students to take science courses with labs, putting added pressure on existing laboratory facilities.

Institutions face these realities—increased enrollment, demand for more online classes, especially science courses for nontraditional and part-time students, and in-demand programs that require additional science offerings with required labs. At the same time, due to financial constraints, colleges and universities are asked to reduce costs while faced with the need to maintain expensive equipment found in traditional laboratories to maintain the effectiveness of laboratory education (Ma and Nickerson, 2006).

Ogot et al. (2003) noted in *An Assessment of In-Person and Remotely Operated Laboratories* that the Internet provides students with the ability to remotely access experimental apparatus, allowing institutions of higher learning to offer more laboratories in the mechanical engineering curriculum while addressing the budgetary and space constraints faced when using traditional laboratory space.

By successfully delivering remote web-based science labs to these students, NANSLO is a proven solution ready to serve additional students and is positioned to assist institutions in addressing some of these key pressures while providing a quality laboratory experience to students through its online laboratories.

2. FILLING AN EDUCATIONAL NEED FOR QUALITY WEB-BASED SCIENCE LABORATORIES

Even though use of web-based delivery of laboratory activities has been widely used in the engineering field for quite some time, it has not been used in the hard sciences. Moving remote web-based science laboratories (RWSL) from a proof of concept to a viable solution has involved a number of institutions and experts working together to define the components needed to build a sustainable infrastructure and secure funding to make RWSL delivery in science courses a reality. The history below provides an overview of NANSLO's evolution in developing a quality web-based laboratory experience for students.

The RWSL concept began in the remote coastal community of Bella Coola, BC (Canada). Ron Evans, an instructor for North Island College (NIC), wanted students in his online courses for Space Science and Astronomy (SSA) to be able to complete the course lab work regardless of their location. With funding from various sources, technical support from Albert Balbon, supervisor of Distributed Learning and Interactive Technology at North Island College, and logistical support from the Tatlayoko Think Tank, the online observatory saw first light in 2004. Evans' students who were scattered across the province (and beyond) were able to maneuver a telescope, view a wide variety of solar system and deep-space objects, and collect real-time astronomical images and data.

The online SSA courses, with authentic telescope lab access, won the 2005 Innovation Award from BCcampus, a provincial consortium that supports innovation in postsecondary education. Growing out of the excitement over these courses, the Web-based Associate of Science (WASc) Project formed and was tasked with developing all of the curriculum required to deliver an Associate of Science degree, including labs, entirely online. Lab-based science courses in geology, physics, biology, and chemistry were created and offered, and an RWSL laboratory was developed at North Island College, allowing students to interact with and control remote lab equipment from anywhere using a computer to collect authentic real-world data in real time without attending a traditional laboratory classroom.

In 2010, the WASc and RWSL project came to the attention of the Western

Interstate Commission for Higher Education (WICHE). WICHE, with the Colorado Community College System (CCCS) and BCcampus as partners, applied for funding through a Next Generation Learning Challenges (NGLC) grant funded by the Bill and Melinda Gates Foundation and the William and Flora Hewlett Foundation to scale the project across the State of Colorado. The funding was granted in 2011, and the North American Network of Science Labs Online (NANSLO) was established.

NANSLO replicated and scaled up NIC's RWSL by establishing a NANSLO CCCS laboratory to serve students taking online classes through CCCOnline, a virtual education delivery system that is an extension of CCCS and serves 13 Colorado community colleges affiliated with CCCS. Equipment was purchased, and the NANSLO Colorado Laboratory began operations in spring 2012.

NANSLO also developed six RWSL lab activities that were designed for integration into online community college science courses in physics, chemistry, and biology to address NGLC's greater focus on the promotion of "innovative educational technologies" (Stokes and Helms, 2012; Edwards et al., 2015).

In the latter part of 2012, the United States Department of Labor (USDOL) Trade Adjustment Assistance Community College and Career Training (TAACCCT) awarded a grant to a multistate consortium of eight community colleges called the Consortium for Healthcare Education Online (CHEO). A portion of that grant funded the expansion and improvement of the capacity of the two existing NANSLO laboratories and the addition of a third laboratory in Montana. In addition to infrastructure, the grant also funded the development of 28 NANSLO lab activities for biology, chemistry, allied health, and physics courses, and two lab manuals —*NANSLO Survey of Chemistry and NANSLO Survey of Biology Lab Manuals*, each containing 10 lab activities—used in non-science major science courses.

Today, NANSLO's laboratories are located at Great Falls College Montana State University, Great Falls, MT (NANSLO's Montana Laboratory) and at North Island College, Courtenay, BC (NANSLO's British Columbia Laboratory), serving colleges in Montana, Wyoming, and Alaska.

NANSLO network's hub is based at the WICHE in Boulder, CO. WICHE serves as the public's primary resource for information about NANSLO, coordinates

communication among the network's laboratory partners, provides the centralized scheduling system, and oversees selected contracting and financial transaction services for the partners.

3. NANSLO LAB ACTIVITIES AND STUDENT OUTCOMES

With the assistance of faculty discipline panels from institutions in multiple states, NANSLO has developed a total of 28 lab activities—16 in biology, eight in chemistry, and four in physics—and two lab manuals for non-science major science courses (*NANSLO Survey of Chemistry and NANSLO Survey of Biology Lab Manuals*), all openly licensed with with Creative Commons BY 3.0 attribution. A list of all NANSLO lab activities with access to the digital versions is available for easy download. These NANSLO lab activities allow colleges and universities to provide online and hybrid students taking prerequisite and requisite science courses the ability to complete required labs without the need to come on campus.

Ma and Nickerson (2006), in reviewing a number of articles on remote laboratories, face-to-face laboratories, and simulations, found that there was a lack of a common foundation to evaluate the effectiveness of lab work in these various formats. As a result, they defined four-dimensional goal models for laboratory education referred to in research articles that compare these delivery formats. These goals are (Ma and Nickerson, 2006):

> Lab Goal 1: Conceptual understanding is the "extent to which laboratory activities help students understand and solve problems related to key concepts taught in the classroom."
> Lab Goal 2: Design skills are the "extent to which laboratory activities increase student's ability to solve open-ended problems through the design and construction of new artifacts or processes."
> Lab Goal 3: Social skills are the "extent to which students learn how to productively perform engineering-related activities in groups."
> Lab Goal 4: Professional skills are the "extent to which students become familiar with the technical skills they will be expected to have when practicing in the profession."

NANSLO's lab activities were designed by experts in the field of biology, chemistry, allied health, and physics to meet these goals.

3.1 CONCEPTUAL UNDERSTANDING

These labs provide students with information on key concepts to be investigated in the lab activity. In prelab exercises, students are asked to formulate hypotheses—an early phase of the scientific method. The exercises performed while connected to NANSLO's remote laboratory are used to investigate the hypotheses and, using data and observations, refine, alter, expand, or reject the hypotheses identified in the student's prelab work.

3.2 DESIGN SKILLS

As students work through these exercises online, all students are viewing the data being generated, specimens being observed, and actions taking place with the scientific equipment. For example, when using the microscope, the student in control of the web interface (NANSLO LabView control panel) selects the slide used for the assigned lab activity, places the slide on the stage using an automatic slide loader, moves the stage until it is positioned under the objective, selects the objective to use, and focuses in on the specimen—all through the control panel. All students on the team observe what is happening through the view window on that control panel. Each student is given the opportunity to adjust temperatures, focus in on slides, and make adjustments by sharing control of the web interface. Working together while viewing what is happening allows students to collaboratively work through exercises, bringing individual perspectives into play and allowing team members to suggest and experiment with new processes that come to mind as they are performing the lab activities.

3.3 SOCIAL SKILLS

Through the use of a teleconferencing capability and the sharing of high-end scientific equipment, students accessing the NANSLO laboratory remotely work together to complete lab activities, collaborate on how to complete them, discuss

results, and make observations together. Not only are they building social skills, but they are also building skills that are frequently used in science collaboratories.

3.4 PROFESSIONAL SKILLS

Even though students typically control laboratory apparatus manually in their science lab classes, it is increasingly rare to find laboratories equipped with similar equipment. Usually scientific laboratories use computer-mediated laboratory apparatus (Jona et al., 2010).

Science today is often conducted remotely, with scientists connected through Internet networks manipulating equipment that is either too expensive or cannot be controlled in a face-to-face environment. As early as 2000, Oak Ridge National Laboratory was funded by the Department of Energy "to conduct experiments involving collaboration by electronic means among geographically separated researchers, including the remote operation of research equipment such as electron microscopes and neutron diffractometers at a research reactor" (Krause, n.d.). Use of this type of technology brings the facility to the user rather than the user to the facility.

NASA's Exploration Rovers, NOAA Ocean Explorer, and many more scientific instruments are examples of how scientists use remotely controlled equipment to collect, analyze, and interpret data. Chemists connected through the Internet are developing cleaner chemical processes using sophisticated flow-chemistry equipment not available in many economically developing countries (Skilton et al., 2015).

Students controlling NANSLO's scientific equipment through a computer are gaining experience that can be applied in the workplace today. In some cases, the only difference between laboratories used in the workplace and NANSLO's remote laboratories is the distance between the experimenter and the experimental equipment. Online collaboration, online team activities and group projects, and participation in learning communities with students beyond their brick-and-mortar communities of learning provides opportunities for students to gain 21st-century skills (Edwards et al., 2015).

4. STUDENT OUTCOMES USING REMOTE LABORATORIES CONSISTENT WITH OUTCOMES IN TRADITIONAL LABORATORIES

The ultimate goal for students when performing laboratory experiments, whether the lab activity is delivered in a face-to-face environment or delivered remotely, is to learn through that experience. Some learning outcomes cannot be achieved as well or at all through a remote interface, while others can be better achieved by separating the students and the equipment (Lindsay et al., 2010). It is important to focus in on the desired learning outcomes rather than the method for delivery when determining whether RWSLs are right for students.

With respect to student outcomes, a number of studies have found that students using remote web-based science laboratories perform as well in science classes as those performing these labs in traditional settings. In their book, Jeschofnig and Jeschofnig note that "effective science-laboratory experiences are definitely achievable by fully online students, and students who acquire undergraduate lab science credits online have no problem progressing into graduate-level science careers" (Jeschofnig and Jeschofnig, 2011). A 2009 study by SRI International for the United States Department of Labor found that "on average, students in online learning conditions performed modestly better than those receiving face-to-face instruction" (U.S. Dept. of Education, 2010).

5. MAKING IT EASY TO USE NANSLO

Students use the Internet and NANSLO's control panel to perform lab experimentation using real scientific equipment to collect data and images used to prepare lab reports (NANSLO, 2015). NANSLO has made it easy for institutions, faculty, and students to access these laboratories through its centralized scheduling system.

An institution or its faculty reserve a block of time for students to perform assigned NANSLO lab activities using the centralized scheduling system. When a reservation is made, a unique URL and PIN is generated. Students use this

information to select an appointment time to complete the lab activity that works with their schedule and then to access the NANSLO laboratory.

Faculty have access to reports used to determine if a student made an appointment, if they accessed the assigned lab activity, and how long they were connected to the NANSLO laboratory while working through the lab activity. Often lab technicians also append notes to individual and team records that are available to review. Institutions can determine how often faculty use NANSLO capabilities and the number of students being served by course, section, and faculty.

All of this information is accessed through customized dashboards that deliver the information important to each audience.

6. WHAT STUDENTS DO ONCE CONNECTED TO A NANSLO LABORATORY

Using a web interface (NANSLO control panel), students:

1. *Connect*. Students connect by computer to control the movement of high-quality scientific equipment used to perform the assigned lab activities.
2. *Discover and Explore*. Students have the opportunity to think like a scientist —observing, interpreting, predicting, classifying, modeling, communicating, and drawing conclusions based on the data collected. Students watch their progress in real time on a webcam that displays what they are doing, and they gather real data to analyze, make predictions, and draw conclusions.
3. *Collaborate*. With lab partners nearby or around the world, students collaborate as each takes turns using the equipment, and students get immediate help from the NANSLO lab techs when needed.
4. *Engage in active learning*. As they work through the activities, students are actively performing their experiment, using their settings, experiencing their own observations, and collecting their own data.

7. BENEFITS OF NANSLO

7.1 NANSLO PROVIDES AN AUTHENTIC LEARNING EXPERIENCE USING REAL EQUIPMENT IN REAL TIME TO GATHER REAL DATA

In *Getting Real: The Authenticity of Remote Labs and Simulations for Science Learning*, a paper published in Distance Education (2013), Dr. Kemi Jona and several other Northwestern University colleagues reported on the results of a study of 123 undergraduate students taking physics and compared their experience using remote and simulated labs. Most students were first-year students taking physics, with the remainder a blend of sophomore, junior, and senior students. They note that remote laboratory users feel and behave as though they have completed traditional scientific experiments because of the authenticity of their experience. Students use real scientific devices, generate real data, and observe the experimental tasks as they are occurring. Students who watched live video of the device also felt more engaged when collecting data (Sauter et al., 2013).

7.2 NANSLO CAN PROVIDE SCHEDULING FLEXIBILITY FOR STUDENTS AND SAVINGS FOR INSTITUTIONS

Rather than spend large sums of capital dollars on additional laboratory space that will sit idle part of each day, institutions can provide laboratory access to students online through NANSLO. Not only can this help the growing number of online students to complete their studies, but it can help relieve bottlenecks in introductory gateway courses. Students can sign up for their lab activity at a time that is convenient for them, meeting the needs of nontraditional students for flexibility because of work and family responsibilities.

7.3 NANSLO HAS EXCESS CAPACITY AND A PROVEN TRACK RECORD

NANSLO has been providing online access to its laboratories since 2012, and in 2014 alone, it served over 1,500 students. NANSLO not only is positioned to serve its students (those attending the colleges where its labs are located), but also has the capacity to serve other institutions interested in using RWSL. Typically NANSLO's labs are open 8 hours a day, six days a week. Each of NANSLO's lab stations serves

up to five students per hour when working in teams, and each NANSLO laboratory has multiple lab stations.

7.4 NANSLO MAY BE HELPFUL IN ESTABLISHING ARTICULATION AGREEMENTS

In Colorado, use of NANSLO by CCCOnline students aided in the creation of articulation agreements in the science disciplines, because students accessing NANSLO laboratories use real equipment to conduct lab activities that generate real data. Since these lab activities are not simulations—a barrier to acceptance in an articulation agreement by four-year institutions in that state—online science courses taught by the two-year institutions using NANSLO were deemed acceptable by these four-year institutions.

7.5 NANLSO LAB ACTIVITIES OFFER STUDENTS THE OPPORTUNITY TO BUILD TECHNICAL SKILLS NEEDED IN THE WORKPLACE

Whether they continue their education in STEM-related courses or pursue careers in the middle-skilled job market, e.g., manufacturing, allied health care, etc., students gain valuable skills when performing NANSLO lab activities. An article in *Crunched by the Numbers: The Digital Skills Gap in the Workforce* states: "It has been clear for some time that technological illiteracy, much less technophobia, is no longer a sustainable option for the modern worker"(Burning Glass Technologies, 2015).

Today's workforce requires skills in collecting data remotely, using computers, and using an Internet interface. NANSLO's lab activities offer students the opportunity to collect, analyze, and report on data collected. These skills are becoming increasingly important. Based on LinkedIn's most recent research, the majority of in-demand skills by U.S. employers involved technology. " . . . cloud and distributed computing and statistical analysis and data mining were the top two skill-set categories employers were looking for . . ." (Brooks, 2016).

At the same time, using remote control devices is becoming increasingly important in collecting data, analyzing and reacting to the data collected, avoiding hazardous situations by controlling equipment at a distance, and providing the access needed to control equipment when it is impossible or impractical to be next to it physically.

Using the NANSLO control panel to complete a lab activity provides students with an experience that may be transferrable in future careers they pursue.

8. CONCLUSION

Through various surveys, students have commented on their NANSLO experience:

> "*It was amazing to be able to sit in the comfort of my own home and be able to work with this equipment. I believe this is the way of the future just because it is so fitting for people to be able to do this. Everyone in this world has busy lives and this makes it that much easier on people*." Kodiak College, University of Alaska Anchorage Student, AK
> "*What a great resource, it was way easier to use and much cheaper than buying the microscope for my class*." Flathead Valley Community College Student, MT
> "*This was great and I can see enormous potential for online students. Thank you for the opportunity*!" Community College of Aurora Student, CO
> "*I Think This Was A Great Experience. I Think It Comes Pretty Close To The Real Thing, Which Is Great*." Arapahoe Community College Student, CO
> "*Very convenient and easy to use*." Great Falls College, Montana State University Student, MT
> "*It is much easier using an online microscope than even one by hand ... You can zoom/capture images, and do things you cannot otherwise do unless the microscope is hooked up to a computer* . . . " Community College of Aurora Student, CO
> "*Great! Makes me feel like I'm in an actual lab*!" Lamar Community College Student, CO
> "*This type of unique 'hands-on' experience taps into parts of the brain that even person-person labs miss*." Kenai Peninsula College, University of Alaska Anchorage Student, AK

In sum, NANSLO can provide real value to institutions by:

1. Delivering high-quality lab activities online to students enrolled in science courses requiring a lab component.
2. Providing students with access to high-quality lab equipment that allows them to collect real data and think like real scientists.

3. Reducing the need to expend limited dollars, expanding science laboratories on campus.
4. Providing students with an experience that can be applied to many professions in today's job market.
5. Addressing students' need for flexibility in accessing and performing lab activities.

Institutions can contract for use of the existing NANSLO laboratories on a fee-for-service model or establish their own RWSL laboratory as a member of the NANSLO network. If you would like more information about NANSLO, go to www.wiche.edu/nanslo or contact Kay Hulstrom at khulstrom@wiche.edu or 303-541-0294.

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REFERENCES

Brooks, C. (2016), LinkedIn's Top 25 Most In-Demand Career Skills, Business News Daily, Retrieved October 4, 2016, from www.businessnewsdaily.com/5686-the-most-in-demand-career-skills.html.

Burning Glass Technologies (2015), Crunched by the Numbers: The Digital Skills Gap in the Workforce, Retrieved July 23, 2015, from www.luminafoundation.org/files/resources/digital-skills-gap.pdf.

Edwards, R., Mattoon, A., and McKay, H. (2015), Findings and Recommendations of the North American Network of Science Labs Online (NANSLO) Consortium for Healthcare Education Online, Education and Employment Research Center, School of Management and Labor Relations, Rutgers, The State University of New Jersey.

Haynie, D. (February 5, 2015), Study Shows Sluggish Online Learning Growth for Second Year, *U.S. News & World Reports*, Retrieved July 22, 2015, from www.usnews.com/education/online-education/articles/2015/02/05/study-shows-sluggish-online-learning-growth-for-second-year.

Jeschofnig, P. and Jeschofnig, L. (2011), Teaching Lab Science Courses Online: Resources for Best Practices, Tools and Technology, in Jossey-Bass Guides to Online Teaching and Learning, Hoboken, NJ: John Wiley and Sons, Inc.

Jona, K., Adsit, J., and Powell, A. (August 2010), NACOL Committee on Online Science, Goals, Guidelines, and Standards for Student Scientific Investigations, Retrieved July 23, 2015, from www.inacol.org/wp-content/uploads/2015/02/iNACOL_GoalsGuidelines_2008.pdf.

Kena, G., Musu-Gillette, L., Robinson, J., Wang, X., Rathbun, A., Zhang, J., Wilkinson-Flicker, S., Barmer, A., Velez, E., Nachazel, T., Dziuba, A., Smith, W., Nelson, V., Robles-Villalba, V., Soo, W., and Ballard, D. (May 2015), The Condition of Education 2015, U.S. Department of Education, Institution of Education Sciences, National Center for Education Statistics, NCES 2015-144, Retrieved July 22, 2015, from nces.ed.gov/pubs2015/2015144.pdf.

Krause, C. (n.d.), From a Distance: Remote Operation of Research Equipment, Retrieved July 23, 2015, from www.ornl.gov/sites/default/files/ORNL Review v30n3-4 1997.pdf#page=124.

Lindsay, E.D., Murray, S.J., Lowe, D.B., Kostulski, T., and Tuttle, S.W. (June 29–July 2, 2010), Derivation of Suitability Metrics for Remote Access Mode Experiments, Retrieved July 22, 2015, from www.labshare.edu.au/media/img/derivation_of_suitability_metrics_for_remote_access_mode_experiments.pdf.

Ma, J. and Nickerson, J.V. (2006), Hands-on, Simulated, and Remote Laboratories: A Comparative Literature Review, ACM Computing Surveys (CSUR), vol. 8, no. 3, Article 7, Retrieved July/August 2015, from www.stevens-tech.edu/jnickerson

/ACMComputingSurveys2006MaNickerson.pdf.

NANSLO (2015), Connecting Students to Scientific Apparatus Via the Internet [Digital Image].

Ogot, M., Elliot, G., and Glumac, N. (2003), An Assessment of In-Person and Remotely Operated Laboratories, J. Eng. Educ., vol. 92, no. 1, pp. 57–63.

Sauter, M., Uttal, D.H., Rapp, D.N., Downing, M., and Jona, K. (2013), Getting Real: The Authenticity of Remote Labs and Simulations for Science Learning, Distance Education, vol. 34, no. 1, pp. 37–47, Retrieved October 4, 2016, from http://groups.psych.northwestern.edu/uttal/documents/Sauteretal2013.pdf.

Seaman, J. (September 28, 2016), Babson Survey Research Group Higher Education Reports, Retrieved September 28, 2016, from www.onlinelearningsurvey.com/highered.html.

Skilton, R., Bourne, R., Amara, Z., Horvath, R., Jin, J., Scully, M., Streng, E., Tang, S., Summers, P., Wang, J., Pérez, E., Asfaw, N., Aydos, G., Dupont, J., Comak, G., George, M., and Poliakoff, M. (2015), Remote-Controlled Experiments with Cloud Chemistry, Nat. Chem. 7, 1-5, Retrieved July 23, 2015, from www.nature.com/nchem/journal/v7/n1/full/nchem.2143.html.

Stokes, L. and Helms, J. (2012), The North American Network of Science Labs Online (NANSLO) Project: Final Report of the External Evaluation, Inverness Research, Unpublished report (2012).

U.S. Department of Education (2010), Office of Planning, Evaluation, and Policy Development, Evaluation of Evidence-Based Practices in Online Learning: A Meta-Analysis and Review of Online Learning Studies, Washington, D.C., Retrieved October 4, 2016, from www2.ed.gov/rschstat/eval/tech/evidence-based-practices/finalreport.pdf.