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NANSLO: A Fully Actualized Remote Science Teaching Lab

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The North American Network of Science Labs Online (NANSLO) is an international collaboration between institutions in the United States and Canada. NANSLO is using open source licensing to construct a network of Internet controllable real-time teaching laboratories. NANSLO's goal is to provide real-time access to high-quality scientific instrumentation used to run inquiry-based laboratory procedures to students in traditional and nontraditional environments. The project currently has three operational laboratories running more than 20 activities. This paper will explain the development of the NANSLO project with a focus on how we developed our technology and laboratory procedures.

Keywords: remote science lab

Introduction

The modern teaching laboratory has its roots in the late 1800s. During this period of time teachers began to believe that modeling the behaviors and actions of scientists in their labs was beneficial to student learning. In 1892, Griffin wrote "the laboratory has won its place in schools"(Rosen, 1954). The usage and popularity of the laboratory continued to grow such that about 80 years later Schulman and Tamir wrote "the laboratory acquired a central role ... As the core of the scientific learning process"(Fraser et al., 2011). Just a few years later the importance of the laboratory in science education started to be questioned. Bates wrote "this paper is an invitation to systemic inquiry, for the answer has not yet been conclusively found: what does the laboratory accomplish that could not be accomplished as well by less expensive and less time-consuming alternatives?"(Bates, 1978). In many ways we are still dealing with the question that Bates proposed only nowadays we have gained additional questions and concerns.

While many of us are familiar with the problems related to the cost of equipment, laboratory space, and student throughput, perhaps the biggest issue affecting teaching labs in the last few decades has been online and distance education. While the face-to-face teaching laboratory is viewed as the "gold standard" by many teachers the recent growth of online education has generated a demand for science teaching outside the traditional classroom. In fact, compared to traditional education, the growth in online education could almost be viewed as staggering. Over the decade from fall of 2002 to fall of 2011 the number of college students that have taken at least one course online has grown from 1,602,972 to 6,714,792(Allen and Seaman, 2013). This equates to an average yearly growth of 17.6% for online education. As a comparison, traditional (face-to-face) education has had an average yearly growth of only 2.7%.

There are many reasons for this growth in online education: cost, work schedules, and the location of the students with respect to their schools, just to name a few. Like many schools that offer online coursework, the Colorado Community College System (CCCS) has seen similar growth in their online student population. One of the places where demand is especially high is in the STEM and allied health fields. This is not especially surprising sense many of the introductory level STEM courses are required for allied health degrees or certificates, which are some of the most sought after programs. Research from CCCS has shown that interest in the allied health fields is not particularly surprising, since students that complete a degree or certificate in the allied health fields can expect an average increase of 97% in their salary. This demand for STEM courses caused several issues for CCCS. If the systems' schools chose to not offer STEM online, they were prohibiting many of their students for moving forward with their educational objectives. One possibility would have been to offer STEM courses online without labs. However, these courses would not have been acceptable as transfer courses to four-year institutions. Because of this, CCCS has chosen to support the importance of laboratory education in the STEM fields by developing online laboratory activities.

However, CCCS had several obstacles to overcome in meeting these goals. Historically, if STEM courses were offered with labs online, the students would often have to travel to a campus for weeks of intensive laboratory course work while the rest of their course was conducted online. While this met some of the demands of online laboratory science, it didn't meet the needs of many students or prospective students. We needed another alternative. More importantly we needed an alternative in that as Peter Jeschofnig the co-founder of LabPaq (formerly Hands-on Labs) said "it is reasonable to expect that laboratory experiences that accompany online science courses should achieve levels of outcomes similar to campus-based laboratory experiences. No lesser standard should be acceptable in considering substitute laboratory experiences for online courses"(Jeschofnig and Jeschofnig, 2011). CCCS' first step in online laboratories was to use commercially available lab kits in their online science courses. These kits contain instrumentation and material that the students use to perform science labs in their homes. While these lab kits offer excellent learning experiences and can be configured to meet the learning objectives of many courses, there were still issues. For example students using lab kits are often performing their experiments alone and have limited or slow access to other students and instructors if they have questions. There is also a limitation on the quality of the instrumentation available to the students in a lab kits because of cost. The quality limitations on instruments means that if the learning objectives of a particular laboratory experiment require high precision data (as an example, sub-millisecond resolution in timing) the students are not capable of doing this out of their kits at home. Additionally, there can be pieces of equipment that students are expected to have a working knowledge of in particular fields, like a spectrophotometer in chemistry, which may cost thousands of dollars for just a basic model, which students could not afford.

In an attempt to address these remaining issues in 2011, with funds from a Next Generation Learning Challenges grant, CCCS in, collaboration with North Island College (NIC) Courtenay, British Columbia, Canada, replicated a Remote Web-Based Science Laboratory (RWSL) located at NIC to create the North American Network of Science Labs Online (NANSLO). The goal of NANSLO is to provide access to real-time high-quality scientific instrumentation. CCCS is using NANSLO in conjunction with lab kits to provide a more complete educational experience in their online STEM courses.

The model that CCCS is currently implementing involves analysis of learning goals to determine which learning goals require students to have hands-on interaction as part of the laboratory experiment, and which learning goals require access to high-quality instrumentation. Additionally, as part of its design NANSLO has real-time voice and chat functions that students use to communicate with each other and laboratory technicians while they are conducting their NANSLO labs. It should be pointed out that the ideas behind the NANSLO project were created completely from scratch. There have been several projects to create remotely controlled scientific instrumentation including iLabs (http://ilabcentral.org/), Library of Labs (http://www.lila-project.org/), and LabShare (http://www.labshare.edu.au/). Many of the labs created by these projects focused on engineering or only offer a single instrument sometimes not even with real-time access. Our approach is to build a laboratory that can support multiple activities in multiple fields all in real-time. NANSLO uses the programming language LabVIEW to build its remote laboratory activities. LabVIEW is a visual programming language designed for instrument control and data collection. It is in fact the programming language that many real research laboratories use to conduct remote science. The remaining sections of this paper will discuss the design philosophies of the NANSLO project including access and procedural design.

Notes for the Instructor

Scheduling and Control

One of the first questions that many instructors have when faced with the incorporation of NANSLO lab activities into their course is "What technologies do I need to know to use NANSLO?" closely followed by "How much work am I going to have to do to schedule my students?" The NANSLO project has worked very hard to make the answers to these questions as simple as possible. The only technology the instructor and students need to know how to use is a web browser (and how to install browser plugins). Access and use of the NANSLO laboratory equipment is mediated through a system of hardware and software. The scientific equipment is connected to a computer that is running the LabVIEW software, we refer to these machines as "lab-rooms". Remote access to the lab-rooms is mediated with Microsoft Active Directory. Accounts in Active Directory are created by a combination of two pieces of software: a cloud-based scheduler and local Node software. Within NANSLO a Node another word for a specific RWSL, as an example the RWSL in Denver CO is often called the Denver Node. The scheduler allows students, institutions, and faculty to schedule time on a NANSLO lab. While the node software creates the Active Directory accounts. When it is time for a faculty member to schedule a laboratory activity they log-on to the scheduler and simply select the activity they want from a drop-down menu and then select the dates and times they want the activity available and how many students they have in their class. The faculty member then gets a URL and PIN number that they give to all the students that will be performing that activity. The students then use the URL and PIN to create an account in the scheduler and register for a time to take their lab. When it is time for a student to take their lab, the student clicks a link that was emailed to them after they scheduled their lab. After entering their username and password, they will be presented with a screen that displays only the lab activities they are scheduled for (Fig. 1). All of the NANSLO software is created under the Apache open-source license.

We've also considered the development of the interfaces used to control the equipment when building NANSLO. We chose to use a modular framework that allows code and instruments to be reused in multiple experiments. For example we have developed a module that give students control of a pan, tilt, and zoom camera that they can use to explore the lab and experimental equipment (Fig. 2A). We have additional modules for other pieces of equipment like microscopes and spectrophotometers (Figs 2B and 2C respectively). This means each time a student uses a particular piece of equipment in any lab procedure the controls will always look the same. Modules are then assembled into control panels.

Just like the modules we've adopted, a standardized interface is used for all experiments. The basic layout of an interface has the video from the external camera on the right and the instrument controls on the left (See Figure 3) if a particular lab procedure requires control of multiple pieces of equipment or additional controls that will not fit one page, the additional controls are located on tabs (Fig.3B).

Procedure Design

The other aspect of the NANSLO project is the development of the laboratory procedures themselves. The NANSLO project is utilizing the recommendations from the National Research Council's National Science Education Standards report(National Research Council, 1996). Specifically, NANSLO is developing inquiry-based laboratory procedures. The NRC's report approaches inquiry by laying out particular emphases that should be followed. These emphases are used to replace emphases normally found in "cookbook" style labs. The specific emphases that NANSLO uses to design its procedures are listed in table 1.

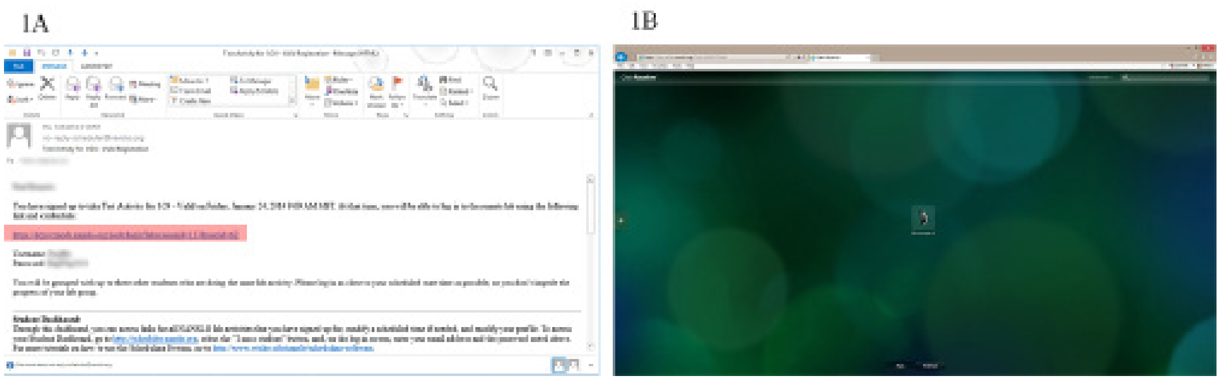

Figure 1. NANSLO Access. After a student creates an account and registers on the NANSLO scheduler they receive an email which contains a link 1A highlighted in red as well as their username and password 1A. When it is time for their lab they click the link and us their username and password to access the NANSLO Citrix system, where they are presented with icons for their lab activities 1B.

Figure 2. Equipment modules for NANSLO. 2A. Pan, Tilt, and Zoom camera module. 2B. Microscope control module. 2C. The Spectrometer Graph control module.

Figure 3. NANSLO LabVIEW Interfaces. 3A & 3B show the spectrometer interface. 3A shows the spectrometer graph module on the left while the Pan, Tilt, and zoom camera module is on the left. 3B displays the module from the same control panel only in this case the tab for the cuvette holder is displayed. 3C displays the control pane used to control microscope experiments. Here we see that the camera module remains the same on the right while the microscope module has replaced the spectrometer module on the left.

Additionally, we are scaffolding the scientific method for students in our procedures, at least for first and second your courses where the CCCS NANSLO node has been focusing most of its attention. NANSLO's laboratory procedures all start with a thorough and detailed background introduction. The reason for the detail of this background introduction section is that all of our procedures are written to be independent of any course or textbook, therefore any background information that the students need is provided as part of the introduction section. After the introduction section laboratory procedures are broken up into one or more activities. Each of these activities is divided into three sections a pre-lab, a data collection section, and an analysis section. As an example, the Mitosis and Meiosis lab procedure is about growth in the onion root. After providing a thorough background information section for the students to read, in the pre-lab we first asked the students to answer a question: "Based on your knowledge of the cell cycle, what kind of relationship do you think you will see between cell size and the mitotic index?" The students are then asked to create a hypothesis from their answer to the question: "Using the IF ... THEN ... format, write your answer to question one in the form of a hypothesis." During data collection, students are walked through collecting data that address the questions guiding the experiment. In the Growth of the Onion Root Tip activity, students are instructed to collect data to determine the mitotic index and the cell size in the four main regions of an onion root: the root cap, the meristem, the elongation region, and the maturation region. In the analysis section, the students are guided through the examination of their data. For this particular activity the two main tasks are "Calculate the mitotic index for each region. Modify your table from question one and enter the mitotic index in your new table." and "Calculate the size of the cells for each region and record that in your table from question 11. The total field of view for your microscope is 305 µm at 40X and 205 µm at 60X [insert your data table below]." The students then compare their results to their original predictions using these questions: "How does your prediction of the relationship of the mitotic index to cell size correlate with the data you collected?" The students then get a final task: "If needed, rewrite your hypothesis in light of the new data you collected." Unless a given lab activity is designed to be purely observational, this structure is embedded in the exercises along with questions that address scientific concepts we want the students to learn. Of course this does require the students to complete their per-lab before conducting the lab. To accomplish this, we have recommend that schools using our labs break the lab into two pieces: a pre-lab and a procedure/analysis section. In order to get the procedure, the students have to complete and submit their pre-lab. CCCS has adopted this policy for the NANSLO labs. To mediate this process using conditional releases in our learning management system. A complete list of all of the questions for this exercise is located in table 2 with the scientific method questions highlighted

Table 1. Inquiry-based emphases.

Less Emphasis	More Emphasis
Verifying Science Content	Investigating and analyzing science content
Getting the right answer	Using evidence to develop, revise, and support an explanation
Providing answers to questions	Communicating scientific information
Acquisition of facts	On understanding and use of scientific ideas and processes to explain information
Lecture, text, and demonstration	Guiding students in active scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for discussion and debate

The NANSLO project has developed 22 protocols in biology, chemistry, and physics. All our protocols are located at http://www.wiche.edu/nanslo and are freely available under the Creative Commons BY license (CC BY).

Future of NANSLO

The NANSLO project plans to continue building on its accomplishments along multiple fronts. A core objective of the NANSLO project is to expand through the addition of new nodes. This multi node approach is designed to produce robustness in the network since the project as a whole will not be dependent on any one individual node. Additionally, the usage of the NANSLO infrastructure can be used by new schools in one of two ways. Schools can contract with existing NANSLO nodes to incorporate activities into their classes. Alternatively, schools could take the open source materials and build their own NANSLO node. We also plan to add additional fields like geology, astronomy, and environmental sciences. All of our growth and development will be conducted alongside a comprehensive and rigorous program of educational research looking specifically at laboratory education and where remote real-time science fit into lab kits, and simulations.

In addition to the remote students that NANSLO was originally built for, over the last year, we've come to realize that NANSLO can also play a role in traditional face-to-face labs. By incorporating NANSLO projects into traditional face-to-face lab classes we can add additional skills often listed as "21st-century skills" to traditional face-to-face courses. Additionally, NANSLO could be used to provide access to equipment that is too expensive or rare for an individual school to own, allowing multiple schools to collaborate in the acquisition and use of this equipment. Lastly, NANSLO can be used to increase the throughput of existing face-to-face environments by allowing schools to use their face-to-face classrooms for those activities and lab procedures where it is justified and needed. This in turn could reduce the demand for building new laboratory classrooms.

Table 2. Scientific method scaffold questions.

Exercise Questions	Scientific Method
Pre-Lab	
Based on your knowledge of the cell cycle, what kind of relationship do you think you will see between cell size and the mitotic index?	*Observations (Pre-lab reading) and questions*
Using the If … Then … format, rewrite your answer to question on in the form of a hypothesis.	*Create Hypothesis*
Create a table to record your data. [insert the data table below]	
Data Collection	
Select the onion root tip slide (Slide Cassette 1: 8) using the slide loader tab. (Each member of the group should collect data from a region)	
Position the microscope so that you are looking at the cap cells (See figure #5: Onion Root Tip for a refresher).	
Count all the cells in the field of view; count how many of them are in mitosis.	*Test Hypothesis*
Determine how long each cell is.	*Test Hypothesis*
Position your sample so that you are looking at the meristem and repeat steps 5&6.	*Test Hypothesis*
Position your sample so that you are looking at the elongation region and repeat steps 5&6.	*Test Hypothesis*
Position your sample so that you are looking at the maturation region and repeat steps 5&6.	*Test Hypothesis*
Analysis	
Calculate the mitotic index for each region. Modify your table from question one and enter the mitotic index in your new table.	
Calculate the size of the cells for each region and record that in your table from question 11. The total field of view for you microscope is 305µm at 40X and 205µm at 60X.[Insert your data table below]	
How does your prediction of the relationship of the mitotic index to cell size correlate with the data you collected?	*Evaluate Initial Hypothesis*
If needed, rewrite your hypothesis in light of the new data you collected.	*Revise Hypothesis*
Based on your observations and pre-lab reading what stage of the cell cycle are the onion root cells located in the elongation region likely in?	

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About the Author

Dr. Bennett is currently the lab technology manager for the Colorado to me conscious of notable North American network of science labs online (NANSLO). His main job responsibilities are to develop new laboratory activities, maintain laboratory equipment including both scientific and information technology and supervise laboratory personnel. Previously he is been academic technology consultant (2012), assistant director of the graduate teacher program (2011-06), and lead graduate teacher for the graduate teacher program (2001-03) all at the University Colorado Boulder. He was also a laboratory technician for the National Institute of Child Health and Human Development (1997-99) at the National Institutes of Health. Currently he is focused on understanding the impact and uses of technology in education specifically science education. He also has a strong interest in improving science education with particular focus on the nature of science and teaching in the laboratory. In his free time he enjoys nature photography and cooking.

Mission, Review Process & Disclaimer

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