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Article *in* Research in Science Education · June 2012

DOI: 10.1007/s11165-012-9301-6

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Res Sci Educ
DOI 10.1007/s11165-012-9301-6

The Nature of Laboratory Learning Experiences in Secondary Science Online

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Abstract Teaching science to secondary students in an online environment is a growing international trend. Despite this trend, reports of empirical studies of this phenomenon are noticeably missing. With a survey concerning the nature of laboratory activities, this study describes the perspective of 35-secondary teachers from 15-different U.S. states who are teaching science online. The type and frequency of reported laboratory activities are consistent with the tradition of face-to-face instruction, using hands-on and simulated experiments. While provided examples were student-centered and required the collection of data, they failed to illustrate key components of the nature of science. The features of student-teacher interactions, student engagement, and nonverbal communications were found to be lacking and likely constitute barriers to the enactment of inquiry. These results serve as a call for research and development focused on using existing communication tools to better align with the activity of science such that the nature of science is more clearly addressed, the work of students becomes more collaborative and authentic, and the formative elements of a scientific inquiry are more accessible to all participants.

Keywords Online science · Learning with laboratory · Virtual schooling

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Published online: 08 June 2012

Introduction

Over the last 25 years, scientific literacy has been the international emphasis in science education (Laugksch 2000; NRC 2006). This movement, including the development of reasoning and understanding the nature of science, has included considerable emphasis on inquiry as the primary learning mechanism (IAP 2003; NRC 2000). The intent is to promote an understanding of the nature of science through a process that is consistent with authentic scientific practice. Historically, laboratory work has been the primary vehicle for enacting inquiry-based instruction. However, translating inquiry-based instruction and laboratory experiences to formal, online education in a K-12 context is a relatively recent phenomenon with important implications for science education. Though the barriers to implementing inquiry in face-to-face instruction are well documented (Roehrig and Luft 2004; Welch et al. 1981), little is known about the nature of online science learning in K-12 contexts. With the perceived link between inquiry-based learning and laboratory experiences, the recent proliferation of online education has created an imperative for translating practical laboratory work meaningfully into this environment.

Though the mode of online delivery is different because students are separated from teachers by distance and time, the laboratory experience remains a defining and often required component of science courses (IAP 2003; NSTA 2007). Therefore, as online schools emerge and proliferate, school personnel are faced with the issue of how to provide meaningful science laboratory experiences. Internationally, as higher education has embraced online learning, the dominant means for providing the laboratory component of science courses includes shipped curriculum kits of physical supplies and proctored face-to-face experiences at certified locations (Kennepohl and Shaw 2010; Jeschofnig and Jeschofnig 2011). However, these practices are quite costly, labor intensive, and are based on the assumption that manipulation of physical objects is a requirement (Zacharia 2007). As an alternative, the affordances of networked computers (i.e. cyberinfrastructure) are being aligned with inquiry-based instruction and are touted as an important component for advancing educational goals in science and mathematics (Martinez and Peters Burton 2011). Since networked computing supports all forms of communication for a virtual school, it offers great transformative potential for changing the paradigm of how laboratory experiences are enacted. Despite these developments, reports of empirical studies of this phenomenon are noticeably missing.

The current study was designed to address the scarcity of empirical work related to online science in K-12 contexts. The study advances our understanding by using the perspective of a geographically diverse sample of teachers in the U.S. to describe how laboratory activities are used in delivering science in a secondary school setting. Participants represent a sample of the current population of virtual educators who are responsible for teaching secondary science entirely in an online format, without the use of face-to-face instruction. Because learning from laboratory experiences is a necessary part of online science in virtual schools, the relevant literature for this study is drawn from the following areas: the scope and nature of K-12 virtual schooling, inquiry-based science education, learning in the physical laboratory and learning in the online laboratory.

Review of Related Literature

The recent technology revolution has vastly changed the way we communicate, learn, and engage with one another. One of these changes has been the addition of online education, specifically the proliferation of virtual schools in K-12 settings, allowing students to complete entire levels of schooling via the Web. In the case of virtual high schools, students are able to earn their diplomas via online distance education programs. Clark (2001) defines a virtual school as "an educational organization that offers K-12 courses through Internet or Web-based methods" (p.1). To incorporate this mode of education, various formats have emerged from a variety of sources including state, local, private, for-profit, and non-profit agencies.

To gauge the scope of virtual schools, it is helpful to gain an overall picture of the current status of online K-12 education in the United States. Currently, all 50-states and the District of Columbia offer K-12 students some form of online learning (Watson et al. 2011). According to the latest data (2009-2010), 55 % of public school districts reported having students enrolled in online distance learning courses equating to 1,816,400 enrollments. Of these, 74 % were at the high school level (Queen et al. 2001). In addition to these supplemental enrollments, over half of a million full-time enrollments were recorded in statewide virtual schools (Watson et al. 2011). These figures are expected to increase as more districts explore the potential advantages of online classes, including addressing growing student populations, dealing with limited space, scheduling conflicts, failed courses, and meeting the needs of specific groups of students (Queen et al. 2001; Setzer and Lewis 2005).

As K-12 online learning proliferates, the need for research and development has also increased. This situation is created because the current understanding of what teachers should know and be able to do is based on a traditional classroom setting (Rice 2006). Research that focuses on teachers' knowledge of content, pedagogy, and technology as it pertains to teaching in an online environment is going to become increasingly central to the quality of K-12 online education (Archambault and Crippen 2009). Due to the increasing number of virtual schools at the elementary and secondary levels, teacher development must begin examining the issues related to preparing teachers for virtual environments. Laferrière et al. (2006) agree, "Despite much enthusiasm given to the use of technology in education, the potential of e-learning in transforming teacher learning is neither sufficiently explored nor well understood" (p. 77).

To address the demand and number of students taking online classes, teachers have had to change their roles within the virtual classroom. According to Watson and Ryan (2007), "As the nature of learning (and working) changes due to the explosion of available information via the Internet and new ways of managing and accessing information, the focus of education must continue to evolve from passing along information to students to helping students be better thinkers and learners" (p. 11). To do this, the roles of online teachers have evolved to include developing course content and structure, delivering material, communicating with students and parents, guiding and individualizing learning, and assessing and grading student work.

However, being able to teach in an online environment is a relatively new experience for most teachers and one for which they were not significantly prepared (Archambault 2011). Less than 1 % of teachers throughout the U.S. have had training for how to provide online instruction (Smith et al. 2005), and as these authors attest: "Many of the teachers currently teaching in online environments lack both the theoretical and practical understanding and are 'learning on the job'"(Smith et al. 2005, p. 59). It is this role of the K-12 online teacher that is of particular concern. Although limited, research has begun to examine teaching in K-12 online environments (Archambault 2011; Archambault and Crippen 2009; Dawley et al. 2010; Kennedy and Cavanaugh 2010), with particular attention to issues related to online pedagogy. Germane to this study, is inquiry-based instruction for science education.

Inquiry-Based Science Education

Inquiry, with its structure and emphasis on thinking and working like a scientist, has become a signature pedagogy of science education (Abd-El-Khalick et al. 2004; Shulman 2005). Internationally, scholars have called for more open-ended inquiry as an opportunity for students to gain a better understanding of the nature of authentic scientific work (Hodson 1996; Hofstein and Lunetta 2004). According to the U. S. National Science Education Standards (NSES), inquiry-based instruction should involve students in developing and practicing scientific inquiry skills as well as knowledge of science content (NRC 1996, 2000). These changes are designed to develop scientifically literate citizens who can make informed decisions on socioscientific issues (Duschl and Grandy 2005; Gott and Duggan 1996).

For K-12 environments, the definition most often used for inquiry emanates from the NSES. According to NRC (2000), the essential features of inquiry include: 1) Learners are engaged by scientifically oriented questions; 2) Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions; 3) Learners formulate explanations from evidence to address scientifically oriented questions; 4) Learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and 5) Learners communicate and justify their proposed explanations. The degree of authenticity in application of these features can vary and is described as occurring along a continuum from a closed form with teacher provided questions and direction to a more open form that is entirely student proposed and directed.

Regardless of the context, the enactment of inquiry has proven difficult (Anderson 2002) and teacher beliefs are often cited as a key component of the problem (Crawford 2007; Kang and Wallace 2005). In particular, knowledge of the nature of science has been identified as a barrier (Roehrig and Luft 2004). Science instruction in face-to-face classrooms is often characterized as a teacher-centered process, relying on a textbook as the primary source of information, and involving the use of jargon to transmit information (Akkus et al. 2007; DeBoer 1991). Using data from the 2005 National Assessment of Educational Progress (NAEP), more than 40 % of the 8th grade students in the U.S. reported that the following instructional strategies were used almost every day for science: reading a textbook, taking a quiz or test, having a teacher conduct a demonstration, hands-on exercises and investigations, talking about results from hands-on exercises, and working with other students on a science activity or project (Braun et al. 2009). The majority of these students (55 %) reported that they conduct an experiment or investigation in about half of their science lessons or more, and less than 20 % reported using a computer for science. Internationally, at the 8th grade, science teachers report that lecture, teacher-guided student practice, and students working on problems on their own are the most used forms of instruction (Martin et al. 2004). Further, these teachers reported that it is not likely that computers were available and rarely used for science, even in countries where they were considered available.

Inquiry-based instruction is consistent with the accepted best practices for online learning. A recent conceptual framework for online learning, proposed as part of a meta-analysis of practices sponsored by the U.S. Department of Education (Means et al. 2009), defines the following three types of technology-supported learning experiences: (1) expository learning, where content is transmitted to a student by an authoritative source; (2) active learning, where the student has control and builds knowledge through inquiry and the manipulation of artifacts; and (3) interactive learning, where learners interact with one another and authoritative sources and build knowledge through collaboration. The NSES vision of inquiry aligns best with interactive learning, but more likely takes the form of active learning. Textbook descriptions that detail strategies for addressing online laboratory in undergraduate education are beginning to appear (Kennepohl and Shaw 2010; Jeschofnig and Jeschofnig 2011). Consortia of universities, like the North American Network of Science Labs Online (NANSLO) (http://www.wiche.edu/nanslo) are forming in an effort to share software for enacting science laboratory online. Partnerships, such as Northwestern University and MIT's iLabCentral (http://www.ilabcentral.org/), are also offering materials and remote access to high-end equipment.

The inclusion of a physical laboratory experience as a component of science instruction has a long history, tied to the basic definition of science and originating from the use of college research laboratories for undergraduate students. Traditionally, teachers in face-to-face classrooms have used the physical laboratory experience as a primary medium for enacting inquiry-based instruction (Hofstein and Lunetta 2004). Originally intended as a practice rooted in the observation of the natural world, it is assumed that a laboratory experience promotes formal learning outcomes. Regardless of the delivery mechanism, our understanding of how they might produce learning as an outcome influences the current use of laboratory experiences. Since K-12 online teachers are likely to have been experienced face-to-face teachers first (Archambault and Crippen 2009), a consideration of learning in the physical laboratory is merited as an antecedent to learning in the online laboratory.

Learning in the Physical Laboratory

The value of laboratory work for science education lies in the notion that observation of the natural world defines the fundamental practice of science (Hofstein and Lunetta 1982). As described in Arzi (2003), the potential role of laboratory experience includes: developing practical skills, developing content knowledge, supporting scientific inquiry, and impacting student attitude. Consistent with these varying roles, Lunnetta et al. (2007) provide the following definition of laboratory experience that they describe as having been acceptable in the 19th century: "Learning experiences in which students interact with materials or with secondary sources of data to observe and understand the natural world." (p. 394).

While the notion of learning from a laboratory experience has long been considered an important component of science education, empirically demonstrating this causal connection has proven difficult. In their review of research from 1982-2002, Hofstein and Lunetta (2004) conclude: "the assumption that laboratory experiences help students understand materials, phenomena, concepts, models, and relationships, almost independent of the nature of the laboratory experience, continues to be widespread in spite of sparse data from carefully designed and conducted studies." (p. 46). Though their review failed to establish a causal link between laboratory experiences and student learning, Hofstein and Lunetta (2004) remain optimistic about the use of laboratory in school science. They cite our ever-increasing understanding of human learning and this influence on curriculum and instruction, advances in methods of teacher professional development and "inquiry empowering technologies" (p. 41) as reasons to believe that laboratory experiences are an important learning intervention, especially in the 21st century. Alignment of activities to learning goals, scaffolding of critical ideas, and implementing research supported models and strategies were added as recommendations for improving the likelihood of learning from laboratory experiences (Lunnetta et al. 2007).

The theoretical perspective for the current study emanates from a recent U. S. National Academy of Sciences report by the Committee on High School Science Laboratories titled

America's Lab Report (ALR). This volume provides the most extensive review of the history of laboratory and it sought to establish the value of laboratory experiences for student learning (NRC 2006). However, citing weak methodologies and fragmented results, the committee could not establish a causal link between use of what they term as *typical laboratory experiences* and student learning outcomes. Instead, the committee proposed *integrated instructional units* as a means to measurable student learning from laboratory experiences and identified four effective instructional design principles: design with clear learning outcomes, sequence experiences into the flow of instruction, integrate the learning of content with learning about the processes of science, and incorporate ongoing student reflection and discussion.

The findings and suggestions provided in ALR have had important implications for K-12 online learning. The International Association for K-12 Online Learning (iNACOL), an advocacy group and professional organization for virtual schooling used the suggestions from ALR to produce guidelines and standards for investigations in online science (Jona et al. 2008). These guidelines identify simulated, virtual, remote, and physical hands-on experimentation as appropriate science learning experiences.

Using the principals provided by ALR and a discussion among the researchers, the following definition was developed for a laboratory activity: *A type of scientific inquiry that requires students to setup and manipulate equipment for the purpose of data collection.* Following the direction of the iNACOL guidelines, a description of each of the classifications of simulated, virtual, remote and physical hands-on laboratory activities was developed (Table 1). These four categories provided a framework for classifying the types of laboratory activities used by teachers and allowed the researchers to make connections concerning how use of such materials could meet the NSES vision for inquiry.

The use of America's Lab Report in developing the guidelines and standards for investigations in online science implies that learning in the online laboratory emanates from our history of learning in the physical laboratory. This view more directly addresses the problematic assumptions and design issues that have limited our ability to empirically assert the impact of laboratory as a learning intervention. The concept of *learning in the online laboratory* is intended to embody the vision of the guidelines for simulated, virtual, and remote experimentation.

Table 1 Definitions used for types of online learning activities

Type of online laboratory activity	Explanation
Virtual experiments	Students are required to setup virtual (not real) equipment. Students manipulate virtual equipment to complete a laboratory experiment that requires them to collect and analyze data.
Hands-on, real world experiments	Students are required to setup physical (real, not virtual) equipment. Students manipulate physical equipment to complete a real-life laboratory experiment that requires them to collect and analyze data.
Simulated experiments	Students do not setup equipment. Students manipulate virtual equipment to complete a laboratory experiment that requires them to collect and analyze data.
Remote experiments	Students do not setup equipment. Students manipulate real equipment virtually (the equipment exists somewhere, but the students do not touch it) to complete a laboratory experiment that requires them to collect and analyze data.

Learning in the Online Laboratory

Although the phrase "learning in the online laboratory" describes the goal, delivering a laboratory experience over the Web has proven to be more than simply changing the delivery medium. Current digital tools have blurred the lines between *actual* natural phenomena and virtual experiences that model phenomena (Lunnetta et al. 2007). This implies the potential for a significant paradigm shift in how we conceptualize all components of science education. Lunnetta et al. (2007) suggest that discriminating between real and virtual realities may be a new goal for students of the 21st century, and science laboratories may play an important role in helping students accomplish the goal. To this end, a sound empirical basis for any technology-mediated laboratory experience is merited.

Ma and Nickerson (2006) reviewed 60-articles and found that few studies evaluated learning outcomes of laboratory experiences. Of this limited research base, only small numbers of participants were evaluated. Findings suggest a different function for different forms of activity. Hands-on laboratory activities tend to emphasize design, while virtual laboratory activities emphasize conceptual understanding. However, the boundaries among the classification of activities (e.g. virtual, simulated, hands-on, remote) are blurred because of the ubiquitous use of computer mediation. The most intriguing finding across these studies implied that the psychology of presence (i.e. believing that you are in a place, doing an activity) might be more important for producing a learning outcome than the form of technology used to deliver the activity.

Since 2006, the positive impact of the online laboratory experience has been demonstrated primarily with two very different student populations. A small number of international studies have shown that elementary school students learn equally well with virtual experiments as with hands-on experiments (Klahr et al. 2007; Triona and Klahr 2003). A similar trend has been demonstrated with college students in engineering (Corter et al. 2007; Lindsay and Good 2005; van der Meij and de Jong 2006; Zacharia and Olympiou 2011; Zacharia et al. 2008), physics (Finkelstein et al. 2005) and chemistry (Pyatt and Sims 2012). Recent studies have shown that students view virtual laboratory experiences as realistic, complex and effective (Pyatt and Sims 2012). This finding contradicts claims that these experiences are not authentic and thus, not a replacement for hands-on experiences (NSTA 2007). In situations where a virtual laboratory has been used as a preface to a face-to-face activity, this intervention has shown to improve student familiarity with equipment and the environment, but did not result in improving confidence or decreasing anxiety (Dalgarno et al. 2009). This supports Corter et al. (2007) who suggest that while learning outcomes are equivalent among different forms of laboratory activities, students express a preference for hands-on laboratories. Interestingly, their reported satisfaction favors the convenience of remote laboratories.

What students believe about a laboratory activity may be an important indicator to its effectiveness. Ma and Nickerson's (2006) review also questioned the role of presence as a mediating variable for student performance. Other research has shown that students may perceive simulations as not real and thus do not draw the connections implied by an assumed physical presence (Srinivasan et al. 2006). Early work by Lindsay and Good (2005) demonstrated that the physical presence of laboratory hardware in either a face-to-face or remote condition changed student expectations, outcomes and focus. Students in the remote condition focused on the laboratory experience as an opportunity to reinforce their theoretical knowledge, while students in the simulation condition focused on the process of learning. According to the authors, "They valued being made to think and to answer questions" (p. 629).

In a paradigm that assumes that different forms of laboratory leverage the affordances of the particular medium (i.e. physical vs. virtual or virtual vs. simulated), studies show an advantage for using a combination of hands-on, virtual, and simulated laboratory activities (Cohen and Scardamalia 1998; Riffell and Sibley 2005). These findings emphasize the design of the learning environment and the use of multiple representations of data, concepts, and relationships among elements (Russell et al. 2004; van der Meij and de Jong 2006). However, recent work has begun to question the inherent assumption for touch as part of hands-on learning. Zacharia and Olympiou (2011) have demonstrated that manipulation, not physicality (i.e. touch) is a key component in the essentially equivalent learning gains with either physical or virtual manipulates. This justifies experiments that offer an interactive element, such as simulated or virtual aspects, and implies that the amount and degree of virtual manipulation of equipment be dictated by the learning objectives for the activity. However, it also calls into question the assumed value of remote experiments.

Most recently, Corter et al. (2011) investigated the effectiveness of traditional and technology-mediated lab practices on individual learning outcomes and the potential differences between individual and group work. In a large randomized study in undergraduate engineering, hands-on group work showed the best overall results, but individual work with remote experiments was the best combination. The hands-on laboratory condition yielded the highest mean effectiveness rating, followed by simulations, then remotely operated labs. Group work conditions were rated as higher in satisfaction than individual work. Findings suggest that group process and individual perception of immersion may be key factors.

While research is emerging that informs our understanding of learning in the online laboratory and the design of appropriate learning environments, a broad scale empirical study of online science in K-12 contexts is noticeably missing. The current study uses the tradition of phenomenography (Orgill 2007) to address this gap by using our understanding of learning in the laboratory under the guise of inquiry-based instruction to interpret the perspective of a geographically diverse group of educators who are teaching in this context. This framework allows us to focus on how these individuals who are charged with fulfilling the intent of online laboratory learning perceive, interpret, and conceptualize the process. Our purpose is to document and classify their ideas, explore the meaning and inherent relationships among those ideas while limiting our assumptions about the nature of their reality.

Method

The purpose of this study was to use the perspective of those who teach secondary science online, through data collected via a survey of national scope, to develop a description of how and why laboratory activities are enacted. Accordingly, teachers who worked in U.S. state-sanctioned virtual schools were surveyed with regard to the types of laboratory activities they use and the nature of their instruction with these activities. Through the gathering of these data, this study sought to answer the following research questions:

1. What is the type and frequency of laboratory activities used by online secondary science teachers?
2. What elements most influence teacher decisions regarding the use of laboratory activities in online secondary science?
3. What barriers, unique to online environments, do teachers cite regarding the use of inquiry-based practices?

The goal of this research was to develop a description of how and why online secondary science teachers in the United States enact the use of laboratory activities in their instruction. To accomplish this, a Web-based survey instrument was developed encompassing questions that asked teachers to describe the types of laboratory activities they used, provide examples, and to rate the degree of influence certain variables had on their use of such activities.

Survey Development

Because an appropriate instrument measuring the intended variables did not exist in the literature, a survey was developed (Appendix). This was a follow-up study with a subset of previously established participants, so demographic information was drawn from the original survey published by Archambault and Crippen (2009) and included the following variables: gender, years of experience, and highest education level attained. The survey contained the following four main sections: (1) time spent on laboratory activities, (2) examples of laboratory activities, (3) teaching with laboratory activities, and (4) thoughts about online inquiry-based teaching. Section one, *Time Spent on Laboratory Activities*, included seven open-form items that asked respondents to first, report the amount of time spent per week on science and laboratory activities, then to report the percentage of time spent on each type of laboratory activity. Sections two and three were adaptive and only asked about the types of activities that had been indicated in section one. Specifically, section two, *Examples of Laboratory Activities*, included open-ended items that provided a definition and asked for "a detailed example of what students do and the materials they use for completing these activities (either as a description and/or URL)". Section three, *Teaching with Laboratory Activities*, part-A included open-ended items that provided a definition and asked "Please describe how you teach with {type of activity} or provide a brief lesson plan." Section three, part-B included a list of 18-potential resources with a scale that included: heavily considered (2), somewhat considered (1), not considered (0), and not applicable (0). Respondents rated the degree to which they considered each resource for determining how to integrate laboratory activities in their online science instruction. Section three, part-C included a list of seven-standard elements of instruction (e.g., teacher lecture, homework, student projects) and respondents rated the degree to which laboratory activities were connected with these elements of their online instruction using a scale that included: heavily connected (2), somewhat connected (1), not connected (0), and not applicable (0). Two-open ended questions at the end of section three, part-C, asked for an explanation of the thinking process behind the rankings and the decision making process for determining the use of laboratory activities. Finally, section four, *Thoughts About Online Inquiry-based Teaching*, provided the five-essential features of inquiry from the NSES and included an open-ended question asking about unique barriers to achieving this form of online science instruction.

Content validity of the items was established through expert review, in addition to piloting the instrument using a think-aloud protocol. Two-university faculty with content expertise reviewed and commented on the items during two rounds of revision. A teacher from a local K-12 virtual school who had extensive experience teaching science in face-to-face as well as online programs agreed to take the survey while sitting with the third author and describing her thoughts and explaining her responses. Field notes were recorded and revisions were completed to ensure that items were understood and interpreted in a consistent manner.

Sample

This study focused on secondary science teachers from virtual schools within the U.S., including those that are sponsored by states, universities, lead educational agencies (LEAs, such as individual school districts), and virtual school consortia. Using Dillman's (2007) Tailored Design methodology, the survey was deployed to previous respondents to a national survey of K-12 online teachers who self-reported as teaching secondary science (Archambault and Crippen 2009). As described by Patton (1990), a non-random purposeful sample was used for selecting specific information-rich cases. Criterion sampling was used to select participants who currently teach at least one secondary science class in a state-sanctioned K-12 virtual school.

The survey was sent to 80-science teachers employed at virtual schools from across the U.S. and 35-responses from 15-different states were gathered, representing an overall response rate of 44 %, considered acceptable for a Web-based administration (Manfreda et al. 2008; Shih and Fan, 2008). Participants represented the following states: Arkansas (1), Arizona (4), California (2), Colorado (2), Georgia (1), Idaho (7), Illinois (2), North Dakota (1), Nevada (1), Pennsylvania (3), South Dakota (1), Texas (2), Virginia (2), Washington (5), and Wisconsin (1). While geographically diverse, it is important to note that this sample is limited and not representative of all online teachers. The next section describes the analysis of data, followed by results, and a discussion of findings.

Analysis

The first research question was addressed with descriptive statistics for survey responses to items related to the type and frequency of activities. Responses to open-ended questions about examples of activities were coded using a content analysis based upon the guidelines described in America's Lab Report. The second research question was addressed with descriptive statistics for survey responses to closed items asking about the degree of consideration and connectedness for known variables. For research questions two and three, responses to open-ended questions about thinking process, decision making for responding to the Likert-type items, and barriers to inquiry were first open coded, then refined through a constant comparative method between two of the researchers (Lincoln and Guba 1985). For research questions one and two, the open-ended responses were used to address construct validity of the frameworks used in creating the closed response items and to address the internal validity of research question two.

Limitations

This study was potentially constrained by several limitations that must be considered when interpreting the findings. Though geographically diverse across the U.S., this sample does not support generalization beyond the respondents, and a sizable group of online science teachers exist in locations of the U.S. that are not represented. In addition, the constructed survey limits our understanding of the learning environment that was described by respondents. While we took every measure to ensure validity and reliability, this first attempt is constrained by the questions that were asked and the use of open-ended responses to capture the most informative set of data. Elements of this data were reported with an unanticipated degree of variability that required our interpretation and discussion to reach a consensus opinion. For example, certain respondents chose to submit only a URL for describing a laboratory activity while others provided more detailed lesson plans of information. Our interpretation of URLs was further confounded by the use of proprietary resources and inaccessible materials locked behind firewalls. Despite these limitations, the current study presents an initial examination of laboratory activities in online secondary science classrooms, and as such, represents a starting point for this line of inquiry.

Results

The self-reported demographics indicate that this sample of online science teachers is consistent with the findings of previous studies (Archambault and Crippen 2009). They were most likely Caucasian (91 %) and female (69 %), had an average of 14.5-years traditional teaching experience, only average 4.4-years of online experience, and are well educated (57 % masters degrees). However, they reported teaching predominately at state sanctioned, state level virtual schools (60 %) and were nearly split between part-time (44 %) and full-time (56 %) positions.

Time Spent On Laboratory Activities

Participants reported that they require students to spend an average of 324-minutes per week per course on science (5.4 h.), with an average of 90-minutes of that time on laboratory activities (28 % of total). Hands-on laboratory activities were reported as favored significantly (48 %) over any other type, and remote laboratory activities were not reported as being used (Table 2). These results suggest that this sample of online teachers predominately use hands-on and simulated experiments as the laboratory component to their science teaching.

Examples of Laboratory Activities

In total, respondents included a description and/or URL for 86-example laboratory activities. This data was intended to provide authentic examples and to verify the accuracy of responses. The research team blindly coded these examples into the four categories of types of laboratory activities and compared our interpretation to the estimates offered by the respondents.

As described by respondents, examples from each category are included in Table 3.

Table 2 Comparison of average percentage of use for laboratory activities by type.

	Type of laboratory activity			
	Simulated	Remote	Virtual	Hands-On
Reported	26.7 %	0.0 %	25.3 %	48.0 %
Coded	45.7 %	0.6 %	7.5 %	46.2 %
Difference	-19.0 %	-0.6 %	17.8 %	1.8 %

Table 3 Narrative descriptions of laboratory type activities by secondary science online teachers

Type of online laboratory activity	Narrative description by individual respondents
Virtual experiments	"Mass minerals on a virtual balance, then measure their volume in a virtual beaker to determine specific gravity and stuff like that "(#21)
	"I have students selected [sic] the correct equipment to use for the experiment. They then use this equipment to conduct the experiment and collect and analyze the data. These are usually done in a Flash program that we purchase from outside vendors. " (#116)
Hands-on, real world experiments	"I have students use equipment from a lab kit that is sent to each school and download a set experiment from our communication tool. Most of the hands on experiments use Vernier probes and software" (#4)
	"I have students determine the dew point inside and outside their homes." (#10)
Simulated experiments	"the PhET site http://phet.colorado.edu/index.php" (#35)
	"gizmos by explorelearning.com" (#6)
Remote experiments	"manipulate DNA electrophoresis and microscopes for example." (#43)

Defining the nature of the experiment in each activity was the first step toward considering the potential value of each form for learning and the overall online science experience. While the coding of examples supported hands-on and simulated experiments as the primary activities, this analysis indicated an overestimation of the use of virtual activities and underestimation of the use of simulated activities. We assume that the precise nature of our definitions may have produced the discrepancy, in particular, the requirement to "setup virtual (not real) equipment" as the distinguishing factor between virtual and simulated experiments. This distinction was intended to connect these results to the historical view that involved the manipulation of equipment.

Our coding based upon the guidelines described in America's Lab Report reveals both encouraging and discouraging results. The reported examples were most likely student-centered (63 %) and involved the collection of data (52 %), but less often developed practical skills (22 %,) required the demonstration of skills (16 %) or were deemed as cultivating an interest in science or in learning science (14 %). If we accept that personal interest and self-efficacy are antecedents to students perceiving science as something for them (Koballa and Glynn 2006), then these activities are problematic. The examples rarely involved the use of scientific discourse (6 %) and did not require student collaboration (2 %), the analysis of sources of error (1 %) or understanding the complexity and ambiguity of empirical work (0 %). These missing attributes are considered key elements of the nature of science (McComas et al. 2002) and their absence indicates a potential lost opportunity for content learning.

Teaching with Laboratory Activities

When asked directly, respondents indicated that laboratory activities were strongly connected to other curriculum materials (Table 4) and this finding was substantiated by the coding results of their teaching descriptions. Regardless of the form, class discussion again appeared as a theme minimally connected to the use of laboratory activities. Though the activities were student-centered, descriptions of how the activities were delivered suggest that they were strongly teacher directed; little collaboration among students was noted. As

Table 4 Average response for the degree to which elements of instruction are connected with lab activities

Rank	Element of instruction	N	Average response
1	Curriculum Materials	23	1.65
2	Homework	23	1.43
3	In-Class Work	23	1.04
4	Student Projects	23	1.00
5	Teacher Lecture	23	0.91
6	Synchronous Class Discussion	23	0.78
7	Asynchronous Class Discussion	23	0.78

illustrated in the following quotation, a high occurrence of traditional teaching elements, including students being given a set of directed activities followed by an assessment are common:

> They read in the book and they do an on line experiment usually using the gismo program. After they do the lab, they write a lab report and then often take a quiz using the data they collected to make sure they are understanding the concept being explored (#32)

This form of instruction is reminiscent of the well-documented traditional classroom discourse of teacher initiation, student response, and then teacher evaluation (IRE) (Hall and Walsh 2002).

The most cited reasons for why laboratory activities were connected to other parts of instruction included a general belief that all elements of curriculum and instruction need to be connected (28 %), the asynchronous nature of the coursework (32 %) and inflexibility of the curriculum (24 %). Participants often described their curriculum as mandated and this sentiment seemed to indicate a lack of freedom or choice in what was required of students. As illustrated by the comment below, curriculum often involves the use of proprietary commercial products and a specialist or designer who serves the role of central authority for courses that are used by multiple teachers. Considering the limiting role that available technologies play in determining the nature of the learning environment, it is difficult to understand how the use of a curriculum specialist or instructional designer as central authority does not also limit the forms of instruction that could be employed by these teachers.

> The course is developed by a curriculum specialist. She takes into consideration internet/bandwith issues and supplies needed. The whole course is designed in units. All of the curriculum material, labs, projects and discussions are centered around a state standard. Everything is designed to tie in together with the inclusion of a teacher-directed, mandated curriculum. (#36)

As evidenced by the types of activities they chose, coupled with the resources they most considered, the perception of these teachers about learning from laboratory work appears to have been most influenced by the technologies used to create the learning environment and made available to them for communication. Since hands-on, real world experiments are the most likely form of experiment, it is not surprising that available technologies for students and teachers as well as physical supplies for students were reported as the resources most considered when integrating laboratory activities (Table 5). However, it is encouraging that state standards, learning goals, and student learning were reported as also being heavily considered. The low consideration for student ability to collaborate could explain the lack of collaboration coded in the example activities.

Table 5 Average response for degree to which resources are considered when integrating laboratory activities

Rank	Resource	N	Average response
1	Student Technology Resources (i.e. software)	23	1.78
2	State Science Standards	23	1.74
2	Student Physical Resources (i.e. materials)	23	1.74
3	Teacher Technology Resources (i.e. courseware)	23	1.70
4	Learning Goals	23	1.61
5	Understanding of Student Learning	23	1.57
6	Student Technology Skills	23	1.43
7	National Science Standards	23	1.35
8	High-Stakes Assessments	23	1.13
9	Curriculum Consultant	23	1.00
10	Available Assessment Strategies	23	0.96
11	My Curriculum Materials	23	0.91
12	Teacher Knowledge & Comfort with Labs	23	0.87
13	Teacher Knowledge & Comfort with Technology	23	0.74
14	Science Education Colleague	23	0.65
15	Student Ability to Collaborate	23	0.61
16	University or College Professor	23	0.39
17	Non-Science Colleague	23	0.30

Thoughts About Online Inquiry-Based Teaching

Participating teachers suggested that inquiry-based learning in online science is constrained by the nature of the student-teacher interaction, which predominately occurs as text-based forms of interaction that mediate an activity occurring outside of the teacher's presence. In responding to the barriers for implementing the inquiry vision of the National Science Education Standards, the top three coded topics included: lack of student-teacher interaction (22.6 %), student engagement (15.1 %), and effectiveness of nonverbal communication (11.3 %). The following remark illustrates the perceived barrier associated with the student-teacher interaction:

> I cannot see the development of conclusions. Only the conclusion itself. It is hard to be a part of the process when I basically only see a finished project; and can only respond to what they [students] have already concluded. (#77)

These comments imply a need to witness and be involved in monitoring the process and development of the experiments. While the communication tools reported as available do not preclude this form of interaction, responding teachers indicated that they struggled with how to monitor and motivate students without being physically present. While they recognized the similarities of student behavior despite the learning environment, online teachers noted the challenge with communication due to the constraints of the technologies and teaching at a distance, as illustrated in the following response:

> They [Students] want to just give the answers form [sic] the reading and be done. The whole concept of doing labs and writing lab reports that engage thinking is hard to do with limited contact with the student. This is the same problem that science teachers have in face-to-face teaching but without the interaction with the students. (#32)

Discussion

The type and frequency of laboratory activities reported by this group of online secondary science teachers are consistent with the tradition of face-to-face instruction (Lunnetta et al. 2007). In particular, they indicated using hands-on and simulated experiments as the laboratory component to their online science teaching. The instructional time allotted for science is consistent with a course meeting every day (~1 h per course per day). Using the weekly average computed over a 36-week academic calendar year, 194-hours per year is above the teacher reported value for the U. S. 8th grade on the 2003 TIMMS (Martin et al. 2004). However, the percentage of this time spent for laboratory instruction (28 %) is below the reported U.S. and international averages at the 8th grade for time spent conducting an experiment or investigation (Martin et al. 2004).

The use of simulation activities in lieu of traditional hands-on activities is consistent with the recent experimental research that has shown equivalent learning outcomes in a K-12 context (Klahr et al. 2007; Triona and Klahr 2003). The heavy use of hands-on activities is likely tied to the notion of experiential learning (Combs 1982). Curriculum kits (purchased or provided), combined with at-home experiments using simple materials, are effective mechanisms for providing this experience. However, these types of experiences are limited in scope by the cost and availability of materials as well as concerns for student safety.

The overestimation of the use of virtual activities and underestimation of the use of simulated activities may be tied to the ambiguity of these terms and their colloquial definitions. In our work with teachers, we have found utility in our set of definitions that build from the basis of laboratory activity as the collection and analysis of data. However, in this definition, we delineate based upon two dichotomous criteria: the setting up of equipment and the nature of the equipment. This way of describing laboratory activities is useful for thinking about the nature and extent of online science instruction and in determining whether it matches the intended goals and learning outcomes needed for a particular situation.

The example activities provided by respondents are predominantly student-centered and required the collection of data, but failed to illustrate key components of the nature of science. These components include: the use of scientific discourse, student collaboration, analysis of error, and the ambiguity of empirical work. It is important to note that the standards movement has identified these components as content knowledge, not simply skills or elements of the process of science. Therefore, students will be held responsible for understanding them on high-stakes examinations. This finding suggests that the online experience may be moving students further away from the goal of scientific literacy through practical investigative work.

Activities that engage students with appropriate reasoning to focus on the epistemic nature of scientific knowledge in authentic practices appear to be deeply needed. These components have also been missing in face-to-face instruction (McComas et al. 2002), but this issue is being addressed by a broad and concerted effort (Blanchard et al. 2010; Donovan and Bransford 2005; Sadler 2006; Simon et al. 2006). However, the degree to which this is being addressed and illustrated for teaching in solely online learning environments is unknown.

Considering the type, frequency, and nature of the activities described, the research team was left with the strong impression that the online learning environment was mostly a re-creation of what is known as traditional teaching in a face-to-face environment. If this is true, then it implies that the decisions of these online science teachers concerning the use of laboratory activities were heavily influenced by their experiences in face-to-face classrooms.

In a traditional setting, instruction is typically characterized by teacher-directed activities, didactic instruction, and limited student-to-student engagement (Martin et al. 2004). Our identification of an IRE-type discourse where the teacher initiates the interaction and provides directions, the student responds, and then the teacher evaluates, supports the previous conjecture that IRE "typifies the discourse of western schooling, from kindergarten to the university" (Hall and Walsh 2002, p. 188). The results of the current study suggest that this type of instruction may also transcend the mode of instructional delivery. Since we did not ask directly about attitudes, beliefs or to compare their pedagogical practices across these environments, the specifics of any causal relationship is unknown.

Despite this notable pattern and potential relationship, the researchers question the degree to which the online teacher limits instruction when the learning environment is so constrained by available tools and a mandated, inflexible curriculum. If information technology professionals are most likely to be responsible for decisions about course management software systems (van Rooij 2009), this suggests that an institution's technology goals drive pedagogy and that teaching and learning must adapt. Further, if we accept that the affordances and constraints of learning online are unique (Martinez and Peters Burton 2011), then we must question the nature and degree to which these elements interact to produce a teaching and learning environment, especially in light of what we know from other modes of delivery. As suggested by Corter et al. (2011), "the scaffolding around the lab may be at least as important as the lab itself" (p. 2056).

Regardless of the delivery mode, the inquiry vision of the National Science Education Standards has proven difficult to enact (Anderson 2002; Crawford 2007; Roehrig and Luft 2004). However, respondents in our study provided some insights into barriers that may prove to be unique to learning science online, student-teacher interactions, namely student engagement, and nonverbal communications. Recently, Clark et al. (2012) described the following affordances of online inquiry environments to support science education: scripting for collaboration and activity structures, access and tools for making sense of data, asynchronous and synchronous communication, optimization of group composition, co-creation and sharing of artifacts, and awareness tools. It would seem that certain affordances, such as asynchronous and synchronous communication, would address student-teacher interactions as a described barrier to implementing inquiry. The affordance of access, as well as available tools for making sense of data, coupled with the ever-increasing volume of Web-accessible data (Hilbert and Lopez 2011), suggests that authentic activities could be designed. This implies that the tools provided to teachers in the online environment could be used in ways that address potential barriers while providing an authentic experience for students.

We interpret these barriers as a call for research and development that focuses on materials and strategies for using the existing communication tools of course management systems (synchronous and asynchronous) to better align with the activity of science such that the nature of science is more clearly addressed, student work is collaborative and authentic, and the formative elements of a scientific inquiry are more accessible to all participants. This parallels a previous call for research related to online teacher professional development (Dede et al. 2009). To simply focus on producing more interactive, media-rich curriculum that leverages the visualization affordance of an online medium to represent scientific concepts is not enough. The principle activities of the discipline must also be accessible as an authentic practice of learning (Edelson and Reiser 2006). Reports of recent development projects from the international community as well as projects in the U.S. funded through the Next Generation Learning Challenge (http://nextgenlearning.org/), suggest that basic development of collaboration as a theme is being applied to the technology of virtual laboratory experiences (Jara et al. 2009).

Considering the nature of the digital tools made available to online teachers, these themes support the online environment as unique, and likely represent real barriers. However, the nature of these themes suggest that they might be overcome with instructional materials that better leverage the existing tools coupled with professional development appropriate to teaching in the online environment. Applying the concept of educative curriculum materials, resources intended to promote teacher and student learning, could potentially address both issues (Davis and Krajcik 2005; Schneider and Krajcik 2002). The perspective of the current sample of teachers reinforces the speculation of researchers regarding the uniqueness of online teaching and learning based on the affordances of the available technologies.

Conclusion

This study addresses the lack of research involving K-12 virtual schools in the United States concerning specific content areas, and in this case, secondary science. The results have important implications for the field of science education in relation to teacher preparation, materials development, and support. Due to the increase of online students, the challenge of preparing well-qualified science teachers to teach in online environments is of increasing significance. This is an issue that colleges of education will want to consider, as the overwhelming majority of programs in the United States are still concentrated on preparing future teachers solely for traditional environments (Kennedy and Archambault 2012).

The affordances and constraints of learning science online are unique and require materials and a learning environment that enact the principle activities of science as the accessible, authentic practice of learning. Further, high-quality professional development is an ever-present need. Educative materials are a concept that should be leveraged in order to improve teacher content knowledge as well as practice. As supported by this study, while the available learning environments continue to evolve, our understanding of promoting and supporting science laboratory activities and inquiry in those contexts lags. Future research centered on how to better align laboratory activities such that the nature of science is more clearly addressed, student work is collaborative and authentic, and the formative elements of a scientific inquiry are more accessible, will be essential. This is especially true, as blended and online learning become an increasingly central aspect of the 21st century educational landscape across the globe.

Appendix

Laboratory Activity—A type of scientific inquiry that requires students to setup and manipulate equipment for the purpose of data collection.

Time Spent on Laboratory Activities

1. How much time per week per course do your online students spend working on science (coursework only, not homework)? _______ hours _______ minutes

2. How much time per week per course do your online science students spend working on laboratory activities? _______ hours _______ minutes

3. In relation to question #2 above, rate the percentage of time per week (e.g., 5%, 20%) that your online science students spend working in the following laboratory activities: Virtual experiments; Hands-On, Real World Experiments; Simulated Experiments; Remote Experiments

Examples of Laboratory Activities—Curriculum

You responded previously that your online science students spend time using the following types of laboratory activities**.** For each, please provide a detailed example of what students do and the materials they use for completing these activities (either as a description and/or URL).

Teaching with Laboratory Activities—Instruction

You responded previously that your online science students spend time using the following types of laboratory activities**.** For each, Please describe how you teach with it or provide (copy/paste) a brief lesson plan. (as the teacher, what do you do?)

Rate the degree to which you consider each of the following for determining how to integrate laboratory activities in your online science instruction. (heavily considered, somewhat considered, not considered, not applicable)

#. State science education standards.
#. National science education standards.
#. The high-stakes assessments my district or state uses to measure student progress.
My own developed curriculum materials.
#. A district/school curriculum consultant/developer.
#. A university or college professor.
#. A colleague who teaches science online.
#. A colleague who doesn't teach science online.
#. What I understand about how students learn science.
#. The intended learning goals of the instructional unit or lesson.
#. The technology resources available to the students (i.e., software).
#. The physical resources available to the students (i.e., materials).
#. The technology available to me as the instructor (i.e., courseware).
#. The technology skills of the students.
#. The degree to which my students can collaborate efficiently.
#. The types of assessment strategies made available by the content provider.
#. My knowledge and comfort with using technology.
#. My knowledge and comfort with using laboratory activities.

Rate the Degree to Which Your Laboratory Activities are Connected with the Other Elements of Your Online Instruction

#. Teacher lecture
#. Curriculum materials
#. Student projects
#. Class discussion (synchronous)
#. Homework
#. In-class work

#. Online discussion board (asynchronous)
#. Briefly explain your thinking process for the ratings you gave in question IIIc above.
#. Briefly explain your decision making process for determining which types of laboratory activities to use with your online science students.

Thoughts About Online Inquiry-Based Teaching

The National Science Education Standards (NSES) define inquiry-based instruction as containing the following 5 essential features: 1) Engagement in scientifically oriented questions, 2) Priority is given to evidence in responding to questions, 3) Explanations are formulated from evidence, 4) Explanations connect to scientific knowledge, and 5)Explanations are communicated and justified.

#. As an online teacher, what unique barriers in the online world of education, have you experienced in providing this form of instruction? Please explain.

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