Teaching Science Online

Promise and Challenges

(β) basis policy research

Florida Virtual School
CELEBRATING 15 YEARS of INNOVATIVE EDUCATION

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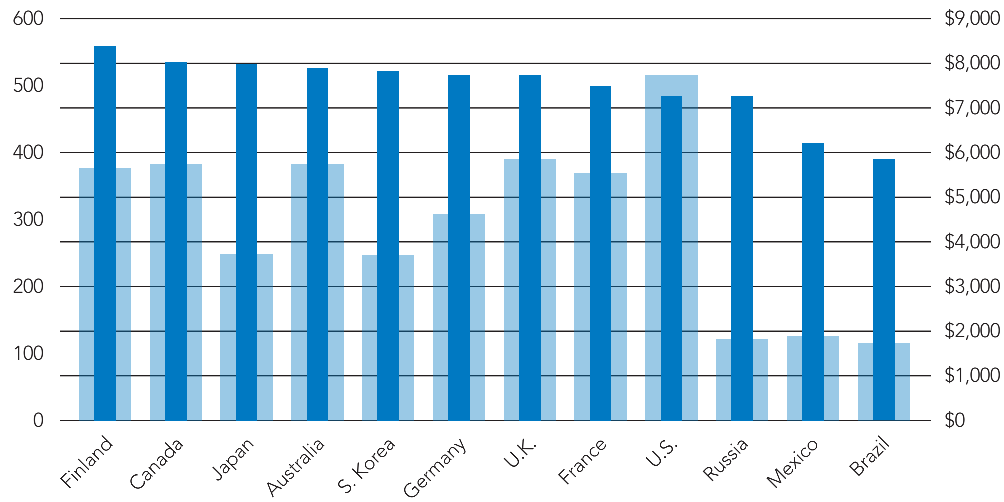
Introduction

The poor state of primary and secondary science education in the United States has left educators searching for better options for today's students. Though science scores on the 2011 National Assessment of Educational Progress (NAEP) saw an increase from 2009 results, the 2011 NAEP revealed that only a third of U.S. 8th graders scored at or above proficient in science (NCES, 2012). Similarly, the 2009 Program for International Student Assessment (PISA) and 2007 Trends in International Mathematics and Science Study (TIMSS) assessments found disappointing science achievement in America relative to other countries. Notably, in the 2007 TIMSS, the U.S. trailed Singapore, Chinese Taipei, Hong Kong, and Japan in 4th grade average science achievement. Moreover, the average score of participating American students was statistically similar to that of Latvia, Hungary, and Kazakhstan (TIMSS, 2007).

Figure 1: 2009 PISA Science Scores and Average Per-Pupil Spending



("U.S. education spending...". 2011)

These less-than-impressive science results can be traced back to a lack of quality instruction in the classroom. In a 2006 report, the National Research Council (NRC) identified several troubling facts on U.S. science education. Not only did NRC cast the overall state of laboratory (or "lab") education as poor, they also found significant disparities in the lab experience among schools. Even when proper materials were provided, students who participated in lab experiences had no better grasp of scientific concepts than students who received only classroom instruction. This discrepancy is attributable to a failure to connect lab experiences with content learning (Singer et al., 2006).

To compound matters, the U.S. is spending more on education than ever before. With elevated levels of spending has come intense scrutiny of educational outcomes (Peng & Guthrie, 2010). Between school years 1995-96 and 2005-06, the nation's average per-pupil expenditures rose by 25 percent (US DOE, 2011b). During this same span, scores on the NAEP rose by a mere 3 percent.

Against this backdrop of disappointing academic achievement, substandard instructional methods, and heavily-scrutinized educational spending, educators continue to feel intense pressure to develop strategies for advancing science education that are both academically and fiscally effective. Online education is one such strategy, and its recent surge is emblematic of both the gravity of these concerns and the field's promise. From this perspective, online education is about extending resources to control costs and reach areas that lack educational necessities for instruction (Nation's Report Card, "National trends").

As online education continues to proliferate, an emphasis should be placed on researching policies and practices that promote its effectiveness. To that end, this report identifies some of the more prominent benefits of teaching science online and explores various hurdles that need to be cleared to realize those benefits. This report ends with a series of guideposts on potential best practices for online science instruction that emerged from this research.

Teaching Science Online

Definitions and Key Concepts

Online learning is defined broadly as a form of distance learning that leverages a range of computer and web-based technologies to deliver instruction and curricular content (Means et al., 2010). Courses can be delivered and overseen entirely online, or combine aspects of both online and face-to-face learning (popularly called blended or hybrid learning) (Watson, 2008). Students can take online courses to supplement those at a physical school or as part of a virtual school where courses are delivered and overseen primarily, or even exclusively, through the internet (Means et al., 2010).

Components of an Online Science Curriculum

Much like the traditional classroom, teaching science online consists of activities which require passive consumption from students (e.g. instruction through lecture, textbook, audio, or video) along with lab experience (Anderson, 2010). Consistent with the National Research Council's *America's Lab Report*, this report considers lab experiences to include:

1. Physical manipulations of substances or systems under investigation;
2. Simulations that represent physical models;
3. Interactions with data drawn from the real world; and
4. Remote access to scientific instruments or observations (Singer et al., 2006).

For online science courses, the delivery of "passive instruction" to students shares many common practices and concerns with online courses in other subjects (e.g., mathematics and language arts). Accordingly, many observations regarding "passive instruction" are general to online education as a whole.

However, the challenge of offering a strong lab experience is largely unique to the teaching of science online. Although hands-on activities are used in a variety of subjects, few play as central a role as the lab experience in science courses (Kennephol and Shaw, 2010). Much of this report is dedicated to discussing the particulars of offering an effective lab experience to students who participate in online secondary science courses.

Beyond Replication

Within online education, there exists an impulse to merely replicate the activities of traditional classrooms. However, this practice of imitation assumes that the traditional practices of brick-and-mortar schools are the most effective and neglects online education's potential for innovation (Jona & Adsit, 2010). Science courses can tap into the online environment's unique resources in order to meet diverse student needs while maintaining a rigorous academic core. Consequently, the effectiveness of online science courses should be measured by how well student-centered goals and academic standards are met.

Knowlton (2000) characterizes student-centered teaching as a style of instruction that gives students control over their learning (Figure 2). Classroom objects, such as lab materials, become tools for self-guided learning. Rather than serving as lecturers, teachers take on more active roles as mentors and facilitators of learning. Student-centered teaching also requires that students collaborate with one another and their instructor as they move through the process of learning.

Figure 2: Teacher-Centered vs. Student-Centered Classrooms

	Teacher-Centered Classroom	Student-Centered Classroom
Pedigogical Orientation	Positivism	Constructivism
"Things"	Professor introduces "things" and suggests the implications of those things.	Both instructor and students introduce "things,"and both offer interpretations and implications.
People	Roles of instructor and student are regimented: The instructor disseminates knowledge, and the student reflects that information.	Roles of instructor and student are dynamic: The instructor and students are a community of learners. The instructor serves as coach and mentor; the students become active participants in learning
Process	The instructor lectures while the student takes notes	Instructor serves as facilitator while studetnts collaborate with each other and the instructor to develop personal understanding of content.

(Knowlton, 2000)

Online courses offer the flexibility requisite of student-centered teaching. As the field of online education grows, students are presented with increasingly greater opportunities to determine how and when they would like to learn. In addition, online students have the advantage of being able to email or message fellow students and instructors at any time with questions or ideas. Accordingly, educators designing and delivering online science courses should move beyond fidelity to existing brick-and-mortar practices, and instead focus on student-centered pedagogy by leveraging resources unique to the online learning environment.

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Promise

In the face of stagnant achievement and rising costs, online education promises compelling options for today's primary and secondary students.

In disadvantaged communities, local schools may not possess the on-site resources to offer more than a basic curriculum. As a result, schools often turn to online providers as a cost-effective way to offer more specialized courses to their students. According to the National Center for Education Statistics (NCES), the majority (or 62 percent) of public school online course offerings are credit recovery programs (Queen & Lewis, 2011). These online credit recovery programs enable students to earn credit for courses they previously failed while permitting them to maintain their regular course schedules.

For students looking toward college preparation, online courses provide advanced courses that may not be available at local schools. Currently, online dual placement courses are offered at 47 percent of public schools that have online options. Twenty-nine percent of these schools also offer online Advanced Placement®[1] (AP) courses (NCES) (Queen & Lewis, 2011). Given that only one-third of traditional school districts offer AP or International Baccalaureate (IB) courses, online providers of college preparatory courses present a cost-effective channel to reach interested students in disadvantaged communities (iNACOL, "Fast facts"). In 2009, for example, approximately 17 percent of traditional public high schools that offered AP courses did so online (Davis, 2009).

Much of the research concerning the relative effectiveness of online and face-to-face education emphasizes the "no significant difference" phenomenon, which finds that students of online education courses perform no differently from students who take their face-to-face counterparts (Cavanaugh, 2001). Means et al. (2010) define a successful online course as one in which there is no significant difference in student outcomes between the traditional face-to-face course and the online equivalent. For many school leaders, the allure of conserving scarce funds drives their interest in online education. In comparing costs between brick-and-mortar and full-time virtual schools, Anderson et al. (2006) find that the operating costs are largely the same, but that facility and transportation costs would likely raise the benefit/cost ratio of online schools. If student outcomes are equivalent, then, the online course remains more cost-effective, particularly in remote or otherwise disadvantaged areas without enough students to warrant an on-site teacher with credentials in advanced content areas (Means et al., 2010).

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[1]AP and Advanced Placement Program are registered trademarks of the College Board, which was not involved in the production of and does not endorse this product.

Challenges

Laboratory Experience

Given the centrality of the lab experience to science education, a school's ability to offer students engaging scientific experiments is paramount to quality science instruction. This prerequisite presents a profound challenge for online science education because students enrolled in online courses work at a distance and often at inconsistent times. Online schools that aim to offer hands-on experiments tend to use home experimentation kits. These hands-on experiments, however, can run into a series of cost and quality issues, including an inability to perform multiple trials and the inevitability of design flaws in experiments conducted away from a monitored lab setting (Kuhn et al., 1995).

Access to Computer/Broadband

One of the great promises of online education is its potential to expand education to disadvantaged communities. The major hurdle facing these communities is limited access to broadband. In 2010, nearly 100 million Americans did not have broadband in their homes (FCC, 2010). Moreover, the 2010 Census reports that nearly a quarter of American households do not own a computer (U.S. Census Bureau, 2010). While small, local virtual schools may be able to supply their students with computers for course-related use, larger virtual schools, particularly those operating at the state, national, and even international levels, will confront the major challenge of providing an equitable online education (Anderson et al., 2006).

Standards and Research

As with most emerging technologies, online learning currently outstrips research on its effective development and implementation. Typically, literature on online education is limited to the field's potential benefits and intuition rather than measured effects. Standards and best practices in pedagogy and implementation are still very much in development (Freedman et al., 2002; Reeves, 2003; Greenberg, 2009).

Much of the extant research on distance learning focuses on adult and post-secondary education, with fewer studies on online learning design, deployment, and effectiveness in the Kindergarten through Grade 12 context (Cavanaugh, 2001). Cavanaugh et al. (2009) suggests that the same traits associated with successful online learners (e.g. high intrinsic motivation, strong management) are those typically associated with adult learners. Because adult learners may have a natural inclination toward online due to higher levels of academic and social maturity, the research and best practices regarding adult and postsecondary online learning cannot be automatically applied to elementary and secondary online learning (Cavanaugh, 2001).

Opportunity

The hands-on development, application, and refinement of online science instruction has evolved more rapidly than its research base in regard to formal standards and best practices, much like collaborative learning, credit recovery programs, and other critical areas in the broader field of online education. However, a review of extant research did reveal a number of important guideposts. Specifically, the following five observations for educators emerged from the review.

1. The laboratory experience is an essential part of a rich science curriculum (Nersessian, 1991). Though this observation may seem axiomatic, it is imperative that educators constantly seek out innovative, engaging, and effective ways to integrate the lab experience into online education.

2. Simulated lab experiences are as effective as hands-on lab experiences across a range of learning measures. Unlike hands-on labs, where students conduct experiments by directly manipulating physical materials, simulated labs are computer-based imitations of real experiments (Ma & Nickerson, 2006). A review of the research strongly suggests that the learning outcomes of students

conducting hands-on experiments and those conducting simulated experiments are largely similar (Strangman & Hall, 2003; Klahr et al., 2007; Finkelstein et al., 2006). Simulated labs allow students to "step back" from their work to better understand underlying concepts and processes (Ma & Nickerson, 2006; Eberbach & Crowley, 2005). Furthermore, these labs cut down on operational errors (e.g., incorrect measurements), rough transitions between class and lab time, and extra time used for setting and cleaning up (Carmichael et al., 2010; Singer et al., 2006; Jona & Adsit, 2010). In addition to those advantages, simulated labs also help online schools skirt their major challenge of resource limitations and provide their students with quality laboratory experiences (Jona & Adsit, 2010).

3. While holding much promise for online education, simulated labs have several potential drawbacks. Because labs are simulated, students do not automatically gain knowledge on experiment design or technical laboratory skills (e.g., pipetting substances, properly cleaning lab equipment); however, online schools may enrich the simulated lab experience by incorporating these lessons into their curriculum. In addition, proponents of hands-on labs maintain that addressing lab error and troubleshooting experiments are constructive elements of the lab process that more accurately reflect the nature of scientific research (Ma & Nickerson, 2006).While online labs must be more deliberate in teaching students how to handle error and troubleshooting, online schools are developing hybrid labs that allow for students to handle large amounts of data and error. Both researchers and practitioners agree that online schools should consider using hybrid labs that combine different approaches, affording students experiences that are as comprehensive, if not more so, than traditional labs. When evaluating the effectiveness of hybrid course designs for undergraduate students, both Riffell & Sibley (2004) and Tuckman (2002) found blended designs to be more effective than other "pure" methods. Provided that resources are available for both types, a combination of these approaches seems to be the most effective means of promoting student learning (Jona & Adsit, 2010).

4. Remote labs are becoming increasingly popular and can be a viable option for distance learners to perform real experiments (Gustavsson, 2003). Remote labs create a "mediated reality", where students physically manipulate material through controlling equipment (i.e. robotic arms) from afar. Though more widespread among university settings, the use of remote labs is becoming more commonplace within elementary and secondary education through initiatives such as Northwestern University's Project ACCESS. Project ACCESS partners with iLabsCentral, a remote lab provider, to offer scalable remote lab solutions for low-income schools (OSEP, "About us"). Remote labs hold the potential to combine the cost-effectiveness of simulation labs and the ability to generate real data that comes with hands-on experimentation (Kennepohl & Shaw, 2010).

5. Online science activities should be modeled around achieving specific student goals, not necessarily replicating the traditional classroom experience. Rather than viewing online schools as a mirror image of traditional schools, educators should begin developing pedagogy for the unique needs of the online student. When properly designed and implemented, online science activities have the potential to be both cheaper and more effective than analogous activities in a traditional classroom (Jona & Adsit, 2010).

The Florida Virtual School Approach

This section explores the extent to which the policies and practices of Florida Virtual School® (FLVS®) correspond to those identified in research.

1. FLVS recognizes the importance of the lab experience for students taking science courses. The majority of online science courses provided through FLVS reserve 20 percent of class time for labs. In an effort to provide its students a well-rounded and exemplary science education, FLVS is constantly seeking out innovative ways for students to actively participate in science from their own homes. The challenges of delivering a quality online science education have inspired and shaped how FLVS

develops innovative labs which leverage students' home environments, foster collaboration between instructors and students, and emphasize an understanding of science as it relates to students' own worlds. To that end, FLVS curriculum specialists scan the horizon for emergent practices and ideas, field test the most promising, and then identify opportunities to integrate and monitor the most productive in actual course work.

2. FLVS incorporates simulated experiments in many of its science courses. For example, students taking space science courses are able to access a computer program that shows them the day and night sky so that they may familiarize themselves with celestial movements, constellations, and related phenomena. Students are also able to conduct basic biology and chemistry labs from their home or school computers. FLVS stands by the belief that simulated labs can be just as – and perhaps more – effective than traditional, hands-on labs. Simulated labs allow students to repeat experiments until they completely understand the process, as well as pause and return to experiments in the midst of their busy schedules. These labs also hold potential for eliminating unhelpful errors that divert students from the experiments' educational purposes.

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3. Many FLVS science labs can be classified as hybrid labs, or labs that give students two or more avenues through which they can design and complete experiments. Specifically, FLVS curriculum specialists identify six unique types of labs: hands-on, simulation, video, remote, live lesson, and real world. In order to broaden students' exposure, as well as ensure that all students can complete experiments in ways that are both convenient and affordable, FLVS encourages teachers to develop labs that incorporate a variety of these six lab types. *Hands-on labs* refer to traditional labs. In the case of FLVS, hands-on labs are often conducted at students' homes and consequently involve the use of basic household items (e.g., glasses, foods, cleaning products). *Simulated labs* are experiments that are conducted solely through the computer and are designed to mimic hands-on labs. *Video labs* are performed by others, recorded on video, and frequently presented as an option to students who cannot or wish not to perform hands-on experiments. *Remote labs* are conducted through computers, but involve students physically completing experiments from a distance (e.g., students control a mechanical arm while dissecting an insect). *Live lessons* typically involve an instructor and his/her students conducting a lab simultaneously via webcam or related technologies. Select science teachers at FLVS conduct Family Science Nights, where instructors and parents perform labs alongside students. Live labs also give students the opportunity to analyze and correct large amounts of data from their fellow classmates at one time. *Real world labs* require students to use their surrounding environment in order to develop and conduct an experiment. In partnership with the Crystal Springs Preserve, FLVS offers students access to real-world data regarding wildlife, water levels, and other natural phenomena for use in their labs. Hybrid courses, which combine any number of these types of labs, enable students to conduct experiments in diverse and engaging ways. For example, students using the space science computer program can complete the same lab by physically going outside and mapping stars. This flexibility not only affords students multiple opportunities to complete the lab, but also gives them the advantage of conducting experiments in two complementary ways.

4. Mirroring the growing body of research that points to the positive potential of remote labs, FLVS is taking steps forward in incorporating remote labs into their science courses. Physics courses already use remote labs; FLVS plans to continue to monitor developments in the availability and efficacy of remote lab opportunities, as well as seek innovative ways to integrate the most promising and productive of these opportunities into the curriculum.

5. Practitioners at FLVS are faced with the serious challenge of transforming brick-and-mortar pedagogies into teaching techniques that work for online students. While online educators insist that online education holds an equal or greater educational potential relative to traditional schools, many hurdles to the realization of that potential persist. By way of example, collaboration, one of the most prominent concerns for both online educators and parents, is inspiring innovative efforts at FLVS. While collaboration is being addressed by all online educators, science teachers are particularly ahead of the curve and are beginning to incorporate collaborative labs in their online courses. FLVS encourages science teachers to create assignments that require two or more students to work together in developing and conducting lab experiments. In addition to collaboration, online schools face the challenge of catering to specific student needs. Since online courses tend to accrue more diverse groups of students than traditional schools, online educators are under immense pressure to develop student-specific lesson plans. Educators at FLVS have begun to tap online schooling's promise to bring together and educate diverse groups of students. By way of example, FLVS is now looking at non-linear science courses that allow students to complete lessons in the order and at the pace that best suit their learning needs.

While many online students are limited to video and simulated lab experiences, FLVS students, in contrast, are able to take part in real-world, live lesson, hands-on, and remote labs that make science a reality.

Conclusion

Emerging research indicates that online science courses hold the potential to provide students from all backgrounds and learning levels with a comprehensive science education. While many of the teaching techniques used in traditional science classrooms can be transferred to the online environment, the development of genuine, online lab experiences requires great creativity on the part of educators. FLVS is an influential actor in the new movement among online schools to create collaborative labs that inspire and teach students to become science practitioners in the real world. While many online students are limited to video and simulated lab experiences, FLVS students, in contrast, are able to take part in real-world, live lesson, hands-on, and remote labs that make science a reality. Despite the challenges facing these courses, FLVS is committed to providing all students with a top-notch science education that fits individual needs and delivers both meaningful and accessible lessons.

About Basis

Basis Policy Research (Basis) is an independent research firm specializing in K-12 education. Basis provides both qualitative and quantitative research services to school districts, state departments of education, foundations, and other education-related organizations. We have offices in Grand Rapids, Michigan and North Carolina's Research Triangle, and serve clients throughout the United States. Basis was founded in 2009 with the vision of making rigorous analytics and research services accessible to those on the ground floor of education reform. With a primary focus on helping students, we provide education leaders, practitioners, and policymakers with timely and accurate information that leads to smarter policies and better practices.

About FLVS

Florida Virtual School (FLVS) is an established leader in developing and providing virtual Kindergarten through Grade 12 education solutions to students nationwide. A **nationally recognized e-Learning model**, FLVS, founded in 1997, was the country's first state-wide Internet-based public high school. In 2000, the Florida Legislature established FLVS as an independent educational entity with a gubernatorial appointed board. FLVS is the only public school with funding tied directly to student performance. Access the school at **www.FLVS.net**.

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