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Online Science Lab Options: Pros, Cons, and Effectiveness

Learning science is an active process. Learning science is something that students do, not something that is done to them. In learning science students describe objects and events, ask questions, acquire knowledge, construct explanations of natural phenomena, test those explanations in many different ways, and communicate their ideas to others.

National Science Education Standards (CSMEE, 1996, p. 20)

It has been well established that most science educators believe hands-on laboratory experimentation provides students with the best way to learn science and should be a component of lab science curriculums. This requirement is easy enough to satisfy if the course is conducted on a campus with formal laboratory facilities, but it poses problems if the related course is not conducted on campus. Over the years, educators have tried, with varying degrees of success, numerous methods and techniques to provide off-campus students with valid laboratory experiences.

The Objectives of Science Laboratory Experiences

Before we examine various laboratory options, the essential functions of laboratory experimentation need to be reviewed. Educational institutions have long compiled lists of the rationales and objectives for the laboratory components that accompany science courses (Rice University, 2006). These traditionally include the following:

- Students learn by doing.
- Experimentation must teach basic laboratory techniques.
- Experimentation must demonstrate and reinforce understanding of the scientific method.
- Experimentation must teach the ability to adhere to instructions on laboratory safety, to recognize hazardous situations and to act appropriately.
- Students must learn to measure, manipulate, observe, and reason.
- Students must develop scientific manipulative skills and perform quantitative experiments.
- Experimentation should help students learn to manipulate and interpret numerical data

Students must learn to observe, recognize, and interpret patterns in laboratory activities.

Students must develop the ability to keep careful records of experimental observations and to communicate with others about these observations and the conclusions drawn from them.

Experimentation should teach the ability to work independently and to also work effectively as part of a team.

Experimentation should show the relationship between measurement and scientific theory.

Learning Objectives for Undergraduate Natural Science Laboratory Experiences

Acquire basic laboratory skills

- Learn to observe, measure, record, convert, and analyze data.
- Learn lab safety, recognize potential hazards, and act appropriately.

Acquire communication and recording skills

- Learn to keep timely, comprehensive lab notes for work replication.
- Clearly and concisely communicate research data and experimental results.
- Improve oral and written communication and presentation skills.

Gain maturity and responsibility

- Learn advanced preparation and organization skills plus the value of mistakes.
- Work independently and as a part of a team.

Understand the context of science

- Recognize the relevance of accurate data gathering and measurement.
- Learn and appreciate the processes and concepts of the scientific method.
- Relate lab results and experiences to the real world.
- Appreciate the major consequences of minor oversights.

Integrate knowledge and experience

- Appreciate and apply critical thinking skills in science and other work.
- Apply math, science, and logical processes to science and other work.
- Skeptically evaluate cause-and-effect conclusions in science and society.
- Recognize when arguments and positions do and do not make sense.

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Summarized from Rice University laboratory educators in natural sciences and engineering

Traditional Campus Labs

In higher education, science courses have traditionally been conducted on college campuses and have consisted of a live classroom-lecture component combined with an additional wet-lab component, usually performed at a separate time and in the campus's science laboratory facilities. This approach is referred to as face-to-face (F2F) learning. A fully equipped and stocked campus laboratory is assumed to provide online students with ideal opportunities to experience science in all the ways envisioned by the above rationales and objectives.

In the laboratory, undergraduate students are normally placed into groups ranging from two to four and occasionally up to six or more students. They are provided with science materials such as chemicals, specimens, microscopes, measuring and analysis equipment, personal safety items, and any other tools required to perform an assigned scientific experiment. Although these laboratories usually contain sophisticated electronic equipment, undergraduate students rarely have the opportunity to operate that equipment and usually are only told how it works or allowed to observe it being used by an instructor or aide.

The groups of students use a lab manual and are allocated a set amount of time to review an experiment's objectives, conduct the activity, observe and document results, and then analyze the data, formulate conclusions, and prepare notes for a formal lab report. By going through this hands-on, tactile process of employing the scientific method, it is expected that students will learn and understand the science concepts covered in their course and develop good critical thinking and problem-solving skills. In academic circles this traditional science laboratory experience is considered to be the gold standard of science learning.

However, science instructors are increasingly acknowledging the reality that not all students are benefiting from their traditional science laboratory experiences. This unfortunate situation is usually attributed to institutional limitations, not the facilities or instructors. Many institutions suffer from a lack of adequate science laboratory space, resources, and personnel to provide ideal laboratory experiences for undergraduate students. They primarily compensate by arranging science students into lab groups of a sufficient size to be "processed" as efficiently as possible within the space and time available. Usually one student in the group takes the lead and actually performs the experiment and manipulates the science materials. Another student may be the record keeper, but most students have little opportunity to handle the materials or perform any meaningful lab work. Typically, remaining group members engage in private conversations while feigning interest in the laboratory activities in which they cannot participate and thus are only superficially engaged.

Most educators believe campus-based laboratory experiences are effective tools for teaching science, and indeed they are, under ideal circumstances that allow each student to actively perform all experiments and utilize the full spectrum of laboratory equipment. Unfortunately, ideal circumstances are not the reality in the majority of today's over-crowded, underfunded, and understaffed campus laboratories. Even if laboratories contain highly sophisticated laboratory equipment, rarely are undergraduate students allowed to operate it. This reality is forcing instructors to question the true value of traditional campus-based laboratory experiences for the average undergraduate student.

Simulations and Virtual Labs

Science simulations usually take the form of computer-based, graphic virtual representations and interactive enactments of laboratory experiments or exercises. Professional simulations play relevant and important reinforcing and training roles in education and industry. For example, the military and NASA train pilots in sophisticated simulators before allowing them to fly real fighter jets and space shuttles. Before cutting into a cadaver, much less an actual patient, Harvard medical students explore all the layers and organs of the human body in minute detail via cutting-edge simulations created from painstakingly compiled images of micromillimeter slices of cadavers. Professionals training for advanced careers in disaster preparedness and management interact with a variety of simulated scenarios that put them and their staffs through their paces before they are faced with real-world catastrophes.

High-level computer simulations can undoubtedly play a vital complementary role in educational experiences and help students better learn processes and understand complex principles and relationships from the safety of a virtual environment. Unfortunately, simulations of such extraordinary sophistication that genuinely reflect reality cost hundreds of millions of dollars to develop. Where they do exist, such computer simulations are rarely available to undergraduate science students. This situation is unlikely to change until higher education and community colleges have access to the type of economic resources available to NASA, the military, and private industry.

In the early years of online education, as a response to limited laboratory facilities, science instructors hoped that computer simulations would be the panacea to provide students with a valid substitute for laboratory experiences. As computer technology has become more sophisticated, laboratory simulations have continuously improved and are successfully utilized to complement numerous science course curriculums. These virtual labs include multimedia elements, high-resolution visuals, audio instructions, interactive tutorials, and other elements to enhance learning and retention. Table 4.1 delineated pros and cons of computer simulations.

Table 4.1. Computer Simulations as Substitutes for Traditional Lab Experiences	

Pros:
• Students like them because
  ○ they are easy and
  ○ they are like computer games.
• They are relatively cheap because
  ○ they can be found online and
  ○ they are free from many publishers.
• They meet some lab learning objectives.
• They are useful as pre-labs and for reinforcing important concepts.
• There are no liability issues or facilities costs.
	Cons:
	▪ They meet few lab learning objectives.
	▪ They are inadequate for major-level work.
	▪ Students miss tactile experiences.
	▪ They are too passive for deep learning.
	▪ They may not be adequately challenging.
	▪ Professional science organizations consider them inadequate lab substitutes..
	▪ Students are seeing science instead of doing science.
	▪ They may not be accepted for transferable course credits.
	▪ Good ones are very expensive to create.

Undoubtedly, simulations can play a useful complementary role in certain types of educational experiences. Different types of high-level simulations allow students to interface and essentially interact with relevant learning materials in a safe virtual environment. Health fields, engineering, environmental and physical sciences, computer sciences, and numerous other important fields of study frequently use high-tech simulations to explain processes, complex principles, and relationships. Many respected colleges and universities including MIT, Stanford University, and Brigham Young University have developed and employ virtual laboratory simulations. However, these institutions utilize their excellent simulations as pre-labs or a supplements to the content of their courses rather than a substitute for real world, hands-on laboratory experiences, which they separately provide their students.

Despite their valid roles in supporting and reinforcing science education, simulated computer laboratory experiences continue to be judged by educators and major science education organizations as ineffective substitutes for traditional, tactile laboratory experiences. The National Science Teachers Association (2009) states, “For science to be taught properly and effectively, [wet] labs must be an integral part of the science curriculum.” In light of decades of declining science literacy and the evidence that laboratory experimentation is vital to understanding science and the science learning process, students undoubtedly need greater exposure to lab science courses that provide genuine hands-on lab experiences. The American Chemical Society (2009) has taken an unequivocal position that simulations are not a valid substitute for tactile labs. These influential voices have combined to insist that national education standards require tactile, wet-lab experiences for accredited and transferable credits.

Simulations are occasionally quite useful, especially in replacing extremely dangerous or hazardous experiments. Yet, simulations cannot begin to replace true laboratory experience because they are ill-suited for delivering a realistic environment to conduct experiments, to measure results, to determine error, and to appreciate lab safety considerations. Simulations tend to be basically passive like computer games; to not fully engage students in relating science to themselves and the real world; to restrict students to a narrow investigative path; and to offer no opportunity to explore their errors or the implications of them. Most simulations are physically unconvincing and never provide the ambiguous results that normally occur with real instruments and promote critical questioning of cause-and-effect evaluations. For these reasons, increasing numbers of institutions are refusing to accept transferred science credits if a course's laboratory component was performed solely or primarily via computer simulations.

Remote Access Labs

Modern remote access technology allows scientists to schedule time on the Hubble Telescope and to fully operate it from nearly anywhere in the world at almost any time of their choosing. Similarly an Air Force pilot based in New Mexico can remotely operate a drone airplane flying across the mountains of Afghanistan and instruct it take photos and drop bombs as it flies across hostile locations that are too dangerous for human pilots. Renowned cardiovascular surgeons in New York City can remotely access a surgical robot in France and actually use it to perform heart surgery on patients who are thousands of miles away.

This same type of technology allows remote access to some of the world's most technologically advanced science laboratory instrumentation. Academic remote access labs (RALs) are often lumped into the computer simulation category because RALs are accessed via science students' computers. However, unlike simulations that try to replicate real-world experiences, RALs actually are real-world experiences because they provide access to fully functioning advanced scientific instrumentation that is actually used daily in genuine, real-world science applications and investigations.

RALs allow students working from a home or campus computer to conduct genuine experimentation on remote laboratory instruments. Students can thus analyze data via highly sophisticated instrumentation that in the past was available only to high-level professionals. Because RALs can be accessed 24/7, students have the opportunity to utilize this state-of-the-art technology at almost anytime and from almost anywhere. These possibilities are leading to the development of new teaching strategies and exciting new collaborative opportunities for undergraduate science students.

Today a student can perform an experiment using a commercially produced lab kit to manually perform an experiment and gain a basic understanding of the conceptual components of a particular scientific process. The student can then use additional lab kit materials to acquire and prepare sample materials that are sent to the Integrated Laboratory Network (ILN), a remote laboratory facility sponsored by Western Washington State University. The ILN houses extremely complex scientific instrumentation that is beyond the economic capabilities of most institutions to acquire.

At a prescheduled time, an ILN technician and the student interact via computer. The technician inputs the student's samples into various sophisticated instrumentation including a mass spectrometer, a flame atomic absorption unit, and a gas chromatograph. The student receives instructions and is allowed to operate this equipment from his or her computer, fully test the previously prepared samples, and immediately receive a complete report on the test results, which can then be compared to the tactile experiment previously performed. This is a genuine real-world experience because the instrumentation used by the student is the same instrumentation that is used by research scientists, crime lab investigators, and technical medical specialists.

Remote access can add rich and genuine science laboratory experiences for students who lack access to such advanced scientific instrumentation in their own communities. The increasing availability of this type of access is already changing some of the methodology for teaching instrument-based science. Table 4.2 sums up the pros and cons of remote access labs.

Table 4.2. Remote Access Labs as Substitutes for Traditional Lab Sessions

Pros:	**Cons:**
▪ Enrich and reinforce tactile labs	▪ Are not yet readily available
▪ Provide real-world technology experience	▪ Require pre-planning and scheduling
▪ Perform advanced and dangerous labs	▪ Can be costly
▪ Meet most lab learning objectives	▪ Do not meet all lab learning objectives

Hybrid Labs

When a science course is listed as a hybrid, that usually implies the lecture and content portions of the course are taught online, but students are required to attend scheduled laboratory sessions on campus. Hybrid courses are offered by institutions and instructors who believe students must have hands-on laboratory experiences and that the only way to effectively provide them is to bring students to the campus's formal laboratory facilities.

Hybrid labs certainly fulfill the vital and traditional wet-lab objectives and experiences required for science learning and allow students to acquire fully accredited and transferable lab science credits. Because students taking hybrid science courses often live at a considerable distance from the campus and/or are also working adults, the hybrid lab sessions are usually offered via full day session over several weekends during the semester.

There are two basic drawbacks to this form of hybrid lab science course. The first deals with the timing of the labs. Normally labs are spread out through a term, and the experiments to be performed each week correspond to the learning objectives then being studied. Because hybrid labs are usually held less frequently and in all-day sessions, there is the potential for a substantial disconnect between the lab experiences and the course content materials being studied at that time. Also, students often become fatigued by marathon lab sessions and their learning tends to be impaired as they strive to complete day-long and possibly mind-numbing sessions of back-to-back science experiments.

The second drawback of hybrid labs is that they require students to come to campus, which for most students completely defeats their purpose in taking an online course. Students usually take online courses to specifically achieve needed flexibility in scheduling their studies around work, family, and other commitments. If they are unable to achieve that goal with one institution's online lab science courses, there is a high probability that they will take those lab science courses from a different institution that offers them fully online. Plus, they may then decide to take their other courses from that institution too. Table 4.3 summarizes the advantages and disadvantages of hybrid labs.

Table 4.3. Hybrid Lab Sessions as Substitutes for Traditional Lab Sessions

Pros:	**Cons:**
▪ Exactly replicate traditional labs ▪ Provide hands-on science activities ▪ Provide access to formal lab materials ▪ Fulfill all laboratory learning objectives ▪ Provide transferable course credits	▪ Require students to come to campus ▪ Defeat the objectives of online courses ▪ Limit course's enrollment to students within commuting distance ▪ Increase institution's facilities expenses for personnel, insurance, and materials costs ▪ When conducted in a few intensive full-day or weekend sessions during the term, o experiments may not be performed when the concepts are being taught in the course o the focus may be on the completion of experiments in lieu of relating outcomes to concepts o student fatigue often negates learning

The files of Hands-On Labs contain histories of a few small institutions that tried offering their hybrid lab students the option of commercial science lab kits instead of coming to campus to perform labs. This option provided a convenience to students who could not attend scheduled lab sessions. It also gave the instructors an opportunity to compare outcomes between the different lab options. Rather than attending campus sessions, students soon overwhelmingly selected the commercial lab kits, even though they had to purchase them separately. Because the learning outcomes were actually a bit better for the lab-kit students, within a few semesters those institutions dropped their hybrid lab sessions and now offer their courses fully online with lab kits to satisfy their course laboratory components.

Kitchen Science Labs

Science experimentation using common elements found in a typical home kitchen can provide excellent learning experiences for elementary and middle school students. However, this method is not usually considered adequate or appropriate for higher education and rarely for college-level science majors' lab courses. Despite its genuine basis in science, college students tend to not respect kitchen chemistry and to feel it is too simple for the higher levels of learning they expect. Science educators are inclined to share this view and believe higher education courses for both science majors and non-science majors should have a traditional laboratory learning component. This is especially important for science majors and community college or career college students who expect to transfer to a four-year program and need to ensure their lab science course credits will be accepted.

Despite these criticisms, a few exceptional kitchen chemistry lab courses have been developed for introductory college chemistry. Most notable of these is the "anytime anywhere chemistry experience" developed in 2001–2002 under a FIPSE grant by associate professors of chemistry Jimmy Reeves of the University of North Carolina at Wilmington and Doris Kimbrough of the University of Colorado at Denver. Analysis of comparative results found that students performing these kitchen labs at home outscored their campus peers on their lab practicum by about 10 points. This project received a Sloan-C Award for Effective Practices in 2003 and showed that students will diligently work to perform laboratory experiments at home and that kitchen chemistry experiments can enhance students' appreciation for how chemistry is relevant to their daily lives.

Lyall and Patti (2010) agree that kitchen chemistry may provide a suitable approach in introductory chemistry courses and for students who require only a basic knowledge of chemistry. However, they feel kitchen chemistry experiments are not adequate for students who intend to make a career in chemistry, biochemistry, or other disciplines that require a high degree of chemical experimentation.

On the downside, implementing kitchen chemistry experiments often requires the student to construct simple science equipment so it's easy for the science lessons to get lost in equipment-construction logistics. Another challenge with kitchen labs is that the results can vary significantly, depending on the brand of materials used. The chemical composition and purity in the typical household cleaners used in kitchen labs can vary substantially by brand names.

Kitchen labs can also be quite expensive and wasteful when they require the purchase of products students do not normally have in their homes, apartments, or dorms.

A kitchen lab can require a substantial amount of time as well as money if students have to shop at several stores to find all the items needed to perform an experiment. In addition, a student may need only a small amount of a substance, such as a few grams of Borax, but can purchase it in nothing smaller than a five-pound box for $11. If an experiment requires several such items, the kitchen lab approach can be time consuming as well as very expensive and wasteful. An internal HOL study comparing household items that could approximate the chemicals in a lab kit's ionic reaction experiment found that even if the smallest available quantities of the household items were bought to replicate each chemical, the student would pay at least four times the cost of the lab kit's experiment bag. Thus, instructors who believe kitchen chemistry labs will save their students money are possibly mistaken.

Another presumed advantage of kitchen science labs is that students can easily find the required experimentation materials at home, but this too is seldom the case. As previously discussed, required materials can be very expensive and time consuming to find, and often students simply do not want to be bothered. Table 4.4 summarizes the plusses and minuses of kitchen labs.

Table 4.4. Kitchen Labs as Substitutes for Traditional Lab Sessions

Pros:	**Cons:**
▪ Provide hands-on science activities ▪ Relate science to the real world ▪ Can fulfill most laboratory learning objectives ▪ Assumed to be cheap and easy ▪ May provide transferable course credits ▪ No facilities-related expenses	▪ Limited sophistication of experiments ▪ Illustrate primarily basic concepts ▪ Questionable adequacy for college-level work ▪ Students do not respect as serious science ▪ Quality varies from creative to inadequate ▪ Time and costs required to obtain materials and construct equipment ▪ Cost of acquiring materials can be substantial ▪ Lab results can vary by products used ▪ Potential safety and liability issues ▪ No learning advantages over campus labs

Like many instructors who care more about students' finances than the students do, Dr. Peter Jeschofnig tried the kitchen lab approach for a few semesters of his calculus-based online physics course. He prepared a list with detailed specifications for each item the students would need to acquire to perform their experiments and even included the names of several shops and online links where the items could be bought. A few students diligently acquired all materials and had no problems performing the labs. But the majority of students seemed to have at least a few procurement problems during the semester and continually complained about the hassles with obtaining their materials. Many students procrastinated in filling their supply list and were then late with assignments because some item was not available or was on backorder at Radio Shack.

Dr. Jeschofnig experienced no further complaints after switching to a commercially assembled physics lab kit in 2003. Even though students could purchase the kit's individual materials at a fraction of the commercial kit's cost, having all needed items handily packaged together apparently has greater value to them than saving money.

Despite their real world connections, the bottom line is that kitchen science labs have no learning advantage over traditional laboratory experiences. Their supposed advantages in cost and convenience are a myth. The majority of higher education's science instructors believe kitchen science labs are overly simplistic and not suitable or acceptable substitutes for accredited college level laboratory experiences.

Instructor-Assembled Labs

Several very dedicated online science educators who apparently have a lot of spare time, or who have made time for the sake of their students, have designed lab kits around their course's lab manual and then assembled lab kit supplies for their students to either buy or check out. Most of these instructor-designed kits are very good and provide great home-based science learning experiences for their students.

Unfortunately, because these instructors are educators first and not businesspeople or stock clerks, the logistics of assembling lab kits soon becomes fatiguing and frustrating. These instructors must first determine all the different materials, chemicals, specimens, equipment, beakers, pipettes, and other equipment that the students will need to perform the experiments; these can total a hundred or more individual items. Then suppliers for each item must be located so that pricing, terms, and shipping can be negotiated. The instructors must also familiarize themselves with constantly changing government regulations and ensure that any chemicals and materials they intend to provide are in compliance. When the supplies arrive, they must be unpacked, sorted, allocated, and repackaged into the students' lab kits. Then the kits must be distributed to the students or through the bookstore, and then purchase or deposit details must be settled. Table 4.5 lists the pros and cons of instructor-assembled kits.

One online science professor in Alaska stocks several dozen science items in her office and requires her students to come to campus to check them out at the beginning of the semester and to return them at the end. These commutes can be an inconvenience for many students.

Instructors usually require students to return borrowed science equipment and supplies at the end of the term, then the instructor or a lab tech must verify each inventory item to ensure it can be reused by another student the following term. Anger and irritation plus settlement charges for costs related to missing and damaged items must be negotiated. Returned items must be inventoried and counted so that replacement materials can be ordered and the process can begin again.

Table 4.5. Instructor-Assembled Kits as Substitutes for Traditional Lab Sessions	
Pros: ▪ Provide hands-on science activities ▪ Fulfill laboratory learning objectives ▪ Assumed to be cheap and easy ▪ Provide transferable course credits	**Cons:** ▪ Requires investment of time and multiple resources by instructor or institution, or both ▪ Safety concerns and liability issues ▪ Purchasing, stocking, assembly, packaging, accounting, and restocking issues ▪ Instructor relegated to stock-clerk chores ▪ Inevitable disputes regarding returns ▪ Potential conflict of interest and distractions from teaching responsibilities

Within a few terms, most instructors who try this approach abandon it. After they begin to calculate the uncompensated time they and their lab assistants spend on this enterprise and to consider the hassles and headaches it creates, they soon decide their time would be better allocated to teaching and having meaningful interactions with students instead of worrying about lab kit supplies. These instructors also begin to recognize the potential liability risks of such an endeavor. Most of them finally conclude that although providing science lab kits to students is a good thing on one level, on another level it can be an exceptionally inefficient use of their professional time as an educator.

Commercially Assembled Lab Kits

It is reasonable to expect that laboratory experiences that accompany online science courses should achieve levels of outcome similar to campus-based laboratory experiences. No lesser standards should be acceptable in considering substitute laboratory experiences for online science courses (Jeschofnig, 2009). Thus, the same standards applied to on-campus labs must be applied to any commercially assembled lab kits that are used with online science courses.

Commercially designed and assembled lab kits for higher education tend to be sophisticated, academically aligned boxed collections of appropriate science materials. Such kits have been designed, produced, and distributed by Hands-On Labs (HOL; www.LabPaq.com) since 1994 and are available in all science disciplines for undergraduate college and high school students. These include introductory, science major, and non-major course kits for biology, human anatomy and physiology, microbiology, nutrition, chemistry, physics, physical sciences, geology and earth sciences, environmental sciences, and forensics. (Note: The authors of this book are the owners of HOL, which they founded specifically to produce the academically aligned science lab kits they have developed in conjunction with experienced online laboratory science educators.)

Other science kit suppliers include eScience Labs (http://esciencelabs.com), which has been producing a limited but increasing number of commercially assembled kits since 2008. These are primarily designed for the middle and high school markets, but they also produce some kits for college level courses. Quality Science Labs (www.qualitysciencelabs.com) is a small, home-based company that also produces lab kits for the middle and high school markets. With the growth in online education and the evidence of effectiveness demonstrated by HOL over the past decade, it is reasonable to expect additional commercial lab kit suppliers to soon appear.

Table 4.6. Commercially Assembled Lab Kits as Substitutes for Traditional Lab Sessions

Pros:	Cons:
▪ Replicate traditional wet campus labs	▪ Additional cost for students
▪ Aligned to match course content	▪ May require adoption contracts by manufacturers for production purposes
▪ Meet all laboratory learning objectives	▪ No immediate instructor assistance or peer communications
▪ Provide transferable course credits	▪ More challenging and time consuming for students
▪ Include lab manual & required materials	
▪ Convenient and easy to use	
▪ No time, place, or scheduling limitations	
▪ Safe, fully insured, and shipped direct	

Commercially assembled science lab kits have the potential to address all the needs and issues thus far discussed regarding science laboratory experiences for online students. A well-designed and well-equipped lab kit that is academically aligned to specific course objectives will mirror the types of experiments that students normally perform in campus labs. The price of commercial lab kits can run into the hundreds of dollars, but they normally contain a related lab manual as well as needed science equipment and supplies. Kit costs are usually offset by convenience, commuting-related savings, and savings from not having to purchase a separate lab manual.

All the traditional requirements and objectives expected of a laboratory science learning experience can usually be met by commercially assembled lab kits. Students have valid interaction with science equipment and materials, engage in measurement and quantitative activities, experience learning from manipulation and observation, have the opportunity to make and mature from mistakes, and integrate their math and language skills by computing and communicating experimental results. They also learn to logically and pragmatically approach problem solving as they physically perform steps of the scientific method and develop the critical thinking skills required for analysis of results from their scientific experimentation activities. Table 4.6 summarizes the strengths and weaknesses of commercially assembled kits.

Unlike computer simulations, commercial lab kits physically engage students in active learning. Unlike the marathon lab sessions of hybrid labs, commercial lab kits allow students to perform and learn from experiments in rhythm with the flow of course content. Unlike the simpleness of kitchen science labs, commercial lab kits provide students with genuine science equipment, chemicals, and specimens to work with. Unlike the inconvenience of student-supplied labs, commercial lab kits conveniently provide consistency in materials as well as the necessary science supplies, which can be stored in the kit box. Unlike instructor-assembled labs, commercial lab kits contain nothing that needs to be returned and are fully insured to protect the user, the user's institution, and the user's instructor.

We have worked in distance science education for over two decades and have personally tried and tested every conceivable substitute for traditional laboratory experiences available, including all of those previously discussed. None ever came close to the levels of convenience, personal satisfaction, and educational opportunities for both students and instructors that are provided by commercially assembled science lab kits. Other instructors may prefer other ways of providing substitute laboratory experiences. However, we and scores of online lab science instructors we know who have traveled similar paths find our students' learning experiences with commercially designed and assembled science lab kits are equivalent to or better than those of our F2F campus students. Further, we believe commercially assembled lab kits are the most practical and effective way to provide engaging and valid laboratory opportunities for online students while freeing instructors from laboratory management duties and providing more valuable time for interacting with students.

Evidence Supporting the Effectiveness of Commercial Science Lab Kits

Several comparisons have been made of F2F campus vs. online student assessments where the course content plus lab assignments and assessments were equivalent and the only difference was that F2F labs were conducted on campus and online labs were conducted with commercial lab kits.*

CCC-OnLine, Denver, CO, a survey of online student satisfaction asking students' lab preference (Vorndam, 2007).

* 25.2 % of respondents preferred campus labs over home lab kits
* 9.9% were indifferent
* 64.8 % of respondents exclusively preferred lab kits

Ocean County College, NY, a comparison of Human Anatomy and Physiology Society national exam scores (Jeschofnig and Spencer, 2008

* F2F range 26–74, mean of 45.09
* Online range 28–80, mean of 45.73

Herkimer County Community College (SUNY), NY, a comparison of students using the Science Major's Biology Kit (Herzog, 2008). Online students substantially outperformed F2F:

* 62% of online students scored an A or B (average grade = 87.5)
* 43% of F2F students scored an A or B (average grade = 75.8)

Colorado Mountain College, CO, first- and second-semester chemistry, a comparison of equivalent scores on pre- and post-course American Chemical Society proctored exams (Jeschofnig, 2009). Online students outperformed F2F students by 5% in lab grades and 1% in overall grades.

CCC-OnLine, Denver, CO (Lormand, K., biology professor, personal communication with L. Jeschofnig, November 4, 2009):

Introductory College Biology: 93% of online students made a C or better during the spring 2008 semester versus 77% of F2F students

General Biology: Since the fall of 2004, online students have outscored F2F students by an average of 6.3% on their mean final exam scores. Spring 2008 mean final exam scores were 83% for online students and 72% for F2F students

Anatomy & Physiology I: Since the fall of 2004, online students have outscored F2F students by an average of 7.5% on their mean final exam scores. Spring 2008 mean final exam scores were 78% for online students and 71% for F2F students

Hands-On Labs, Inc., survey of fall 2008 LabPaq users conducted via constant contact (HOL, 2009). Over 87% of responding online students using LabPaq kits achieved an A (65%) or B (22%) in their lab science course, and 80% were very satisfied with their experience.

**Comments and data are based upon the use of Hand-On Lab's LabPaq kits.*