CURRENT CAPABILITIES AND LIMITATIONS OF WEB-BASED LABORATORIES

Report Submitted to:

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December 12, 2002

Professor Ronald Biederman, Advisor

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Dr. Lee L. Zia, Program Director
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Dear Dr. Zia and Mr. Simoneau,

Enclosed is our report entitled Current Capabilities and Limitations of Web-Based Laboratories. It was written at the National Science Foundation in the Division of Undergraduate Education during the period of October 21 through December 12, 2002. Preceding our arrival in Washington D.C., preliminary work was completed in Worcester, Massachusetts. Copies of this report are being submitted simultaneously to Professor David DiBiasio, as well as Professors Ronald Biederman and Susan Vernon-Gerstenfeld for evaluation. Upon faculty review, the original copy of this report will be catalogued in the Gordon Library at Worcester Polytechnic Institute. We are very grateful for the time that you both have devoted to us.

Sincerely,

David Dunlop

Julie Martin

Matthew Morency

Stephanie Morin

ABSTRACT

This project provided the National Science Foundation (NSF) with a report on the current capabilities and limitations of web-based laboratories in undergraduate education. The purpose of this investigation was to assist the NSF in understanding future trends of web-based laboratories. Through contact with Principle Investigators, detailed data was obtained on how the laboratories have been used and tested in class curricula. Recommendations were made for future research and development using the data we obtained.

AUTHORSHIP PAGE

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  - Teaching Methods – David Dunlop
  - Laboratories – Stephanie Morin
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National Science Foundation

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EXECUTIVE SUMMARY

The National Science Foundation (NSF) initiated our project in an effort to discern what advancements have been made with web-based laboratories in recent years. They also hoped to determine to what extent these laboratories can be used and how they have supported existing curricula for the classes that they are supplementing. In order to accomplish these goals, we provided the NSF with a report on the current capabilities and limitations of web-based laboratories.

We contacted Principle Investigators (PIs) of web-based laboratories through email and telephone interviews to collect data on their current laboratories. Once our interviews were complete, we divided the data we received into two groups: qualitative and quantitative data. The qualitative data was presented in the form of three particular issues: the cost of web-based laboratories, replacement of hands-on laboratories, and problems with computer proficiency. The quantitative data provided us with indications of web-based laboratory uses, flexibility, versatility, and effectiveness.

Once we analyzed our results, we were able to draw some conclusions about the capabilities and limitations of the current web-based laboratories. Our quantitative results demonstrated four capabilities of web-based laboratories: (1) Web-based laboratories can be integrated by teachers into class curricula in multiple ways, (2) Web-based laboratories are flexible and can appeal to multiple grade levels, (3) Web-based laboratories are versatile and allow students to determine the pace and depth of their laboratory experience, (4) Web-based laboratories are able to assist students in learning the class material.

From our qualitative results, we concluded that there are three limitations of web-based laboratories: (1) Web-based laboratories require a large start-up cost, (2) At this time web-based laboratories cannot replicate the sensory aspects of experiments, so they are unable to replace many hands-on laboratories, (3) Students must have a basic proficiency with computers in order to use web-based laboratories.

There are three social implications that are involved in our conclusions about web-based laboratories: (1) Change in equipment training for career preparation, (2) Change in social interactions between teachers and students, (3) Change in role and possible replacement of teachers.

From our conclusions and social implications, we formulated six recommendations for the NSF to further study web-based laboratories: (1) Web-based laboratories should be developed for higher level education classes, (2) Research on the design aspects of web-based laboratories should be conducted, (3) A study of the costs of web-based laboratories as compared to the costs of hands-on laboratories should be performed, (4) Studies on measurable students outcomes from web-based laboratory use should be encouraged by the NSF, (5) Research on the effects of web-based laboratories on different learning styles, genders, and ethnicities should be completed, (6) Annual database updates must be done to enable monitoring of the changes in the field of web-based laboratories.

We believe web-based laboratories have the potential to become useful tools in education. However, there are many aspects of these laboratories that still need to be studied and developed before their role in education can be determined. Once more studies have been conducted on web-based laboratories and there is a better understanding of their abilities, it will be clear whether they can function as replacements of hands-on laboratories.

CHAPTER 1. INTRODUCTION

With the creation of the personal computer, use of the Internet has become an important part of the current culture. As a result, the World Wide Web has also become a part of learning at all levels of education. Students are now learning how to perform classroom exercises on computers in elementary school and developing the ability to do a majority of their work on computers and the World Wide Web in high school and college. The schoolwork can come in a number of forms, including research projects conducted on the World Wide Web and web-based laboratories. Web-based laboratories are intended to enhance a classroom learning environment or to function as an independent educational tool.

Non-interactive and interactive teaching methods are two main concepts in education. A non-interactive teaching method is one that allows students to passively learn information. Students do not have the ability to affect or modify the learning experience according to personal deficiencies in information. For example, instructional television is a non-interactive teaching method because students do not have the ability to participate in the action on the television program; students only have the ability to observe. An interactive method of teaching allows students to participate in the educational experience and relate to the material they are learning. Students also have the ability to modify the educational experience to suit their personal needs (Bransford, Brown, & Cocking, 1999). One example of an interactive learning environment is a laboratory experiment.

Laboratory experiments are commonly considered an excellent way to interactively reinforce material that is learned in class. Students have the ability to modify an experiment to address any deficiency in knowledge, allowing for the possibility of a greater understanding of class material. Although there are benefits to having laboratories accompany a lecture, the cost may inhibit the optimal implementation. Cost can come in a number of forms, but for laboratories, it mainly arises in terms of equipment. Availability issues arise as well, in terms of space and faculty. As a result, students may not be able to acquire the complete learning experience they need, simply because the laboratory equipment, space, and instructors are not available (Andelin & Naismith, 1986).

As a possible alternative to hands-on laboratories, researchers have been developing web-based laboratories. These laboratories have the potential to provide another learning environment for students to study material that they are learning in class. Web-based laboratories also have the ability to provide students with a hands-on laboratory simulation. This allows students to learn the laboratory procedure outside of the hands-on laboratory so that the time they can spend in the hands-on laboratory is efficiently used (Bennett, 1999).

Similar to hands-on laboratories, web-based laboratories have disadvantages as well as advantages. There is the possibility that some students are not as proficient with computers as they may need to be to perform the web-based laboratory successfully. Students also may not have access to a computer where they could perform the laboratory. If students cannot use a computer efficiently, or they do not have access to one, web-based laboratories may not be viable educational tools (Bennett, 1999).

Since its creation in 1950, the National Science Foundation (NSF) has taken on the responsibility of using scientific research to make advancements in technology.

Today the organization has grown, and not only supports research, but also attempts to promote a more comprehensive learning experience for students at all levels of education, including the undergraduate level. One way the NSF does this is by funding innovations in materials development to support new approaches to teaching and learning in undergraduate Science, Technology, Engineering, and Math (STEM) areas (NSF, 2002). These include investigations into web-based laboratories, which are designed for students who may not be able to receive enough hands-on experience in a laboratory class, or may be looking for a way to study the material on their own time.

The NSF would like to discover what advancements have been made with web-based laboratories in recent years. They also hope to understand to what extent these laboratories can be used, and how they have supported existing curricula for the classes that they are supplementing. This study was started one year ago by a group of students from Worcester Polytechnic Institute of Worcester, Massachusetts to investigate the availability of web-based laboratories on the World Wide Web. A list of one hundred web-based laboratories was compiled using two Internet search engines, Google and Yahoo!, as well as searching for pertinent proposals in the Project Information Resource System at the NSF Division of Undergraduate Education facility. The web-based laboratories that this project group found were then identified by discipline and evaluated using the Visual, Aural, Read/Write, Kinesthetic (VARK) classification system, a structure of learning styles. The information they identified from the discipline separation and VARK classification, as well as individual laboratory information, was then compiled into an Access database to be used by the NSF for future research (Amigud, Archer, Smith, & Szymanski, 2001).

The NSF initiated our project in order to continue the research completed in the previous study. We used the web-based laboratories listed in the database as a sample in a study to determine the current capabilities and limitations of web-based laboratories. To accomplish this, we contacted the Principle Investigators (PIs) of each laboratory in the database in an effort to investigate the advancements of the web-based laboratories in recent years. Once we collected these data, we used them to discern the positive and negative trends of web-based laboratories. We were able to use this information to draw conclusions about the capabilities and limitations of web-based laboratories, which we used to formulate future research possibilities and areas in the field that need to be developed. The NSF will be able to use this information to understand the current status of web-based laboratories and initiate additional research projects.

CHAPTER 2. LITERATURE REVIEW

In order for us to look at the capabilities and limitations of web-based laboratories, we must first examine previous work in educational methods. This begins by investigating non-interactive and interactive teaching methods. Laboratories are an interactive teaching method and have traditionally been found in schools as a supplement to classroom learning. Now they have started to appear on the World Wide Web. Much like hands-on laboratories, web-based laboratories also provide supplemental interactive learning experiences for material being taught in class.

TEACHING METHODS

Non-interactive and interactive teaching methods differ in the way that class material is presented to students. In a non-interactive environment, students do not actively participate; they listen to and watch what is presented. However, in an interactive environment, students are required to actively participate in the learning experience and apply their knowledge to educational activities. This teaching method accommodates inquiry-based and student-centered instruction.

A non-interactive method of teaching is one in which students passively acquire information. For example, video taped lectures are non-interactive educational tools; they are viewed without any interaction between the viewer and what is happening on the screen. This method of teaching declined in popularity due to lack of student interest since its introduction in the 1960s (Neil, 1998). This type of environment is ineffective in creating a situation where students can explore the topics that they are learning (Bransford, Brown, & Cocking, 1999).

In an interactive environment, the students are involved in their learning experience. While it is possible to describe ideas or to watch actions being preformed, it is completely different for students to perform the tasks themselves. An example of interactive teaching is laboratory experiments where students are able to explore while learning. Students are able to learn at their own pace and also have the ability to revisit sections of the material that they would like to look at in more detail (Bransford et al., 1999).

LABORATORIES

Laboratories are involved in multiple educational programs and have been for many years. They provide students with a supplemental way of learning the material being taught in class. There are numerous advantages to laboratories, but there are also some disadvantages.

History of Laboratories

Laboratories have been used for educational purposes for over 125 years. One example of this is Worcester Polytechnic Institute (WPI), an undergraduate college in Worcester, Massachusetts, which was built in 1865. The college was founded to provide young men with a different style of education than was available at other institutions. Instead of the standard classroom education that other colleges provided, WPI was developed to instruct students in the use of tools and machinery along with providing the theories of science. The founders wanted to be able to show the practical application of these theories and give their students the greatest advantage when faced with similar issues (Tymeson, 1965).

This was accomplished by creating two main buildings for education. The first building consisted mainly of classrooms to provide the standard theories of science in a lecture environment. The second building was designed as a manufacturing shop, which provided a hands-on experience for students so that they could learn the practical applications of the topics discussed in lectures (Tymeson, 1965). As WPI has grown from these two original buildings, the unique theory of learning has remained the same. The college continues with the idea of including laboratories and hands-on experiences to the majority of the courses offered. This is just one example of how laboratory work was first introduced into the undergraduate learning experience.

Advantages of Laboratories

Laboratories are supplemental activities to classroom learning. Most undergraduate colleges and high schools accompany their courses with laboratories for additional exposure to the concepts addressed in class. Laboratories provide hands-on experience for students, which allow the students to "do science" rather than simply listen or read about it (Poole & Kidder, 1996). Many students have commented that laboratories help them obtain a larger picture of the topics discussed in class by allowing them to perform the physical simulations or experiments (Poole & Kidder, 1996). Laboratories present the actual uses of these topics, which help students relate the concepts to real life.

Karl A. Smith, a professor at the University of Minnesota and author of *Inquiry and Cooperative Learning in the Laboratory*, states in his speech at the Accreditation Board for Engineering and Technology and American Society for Engineering Education (ABET-ASEE) Colloquy that students are able to learn more efficiently and effectively when "inquiry-based learning" is available (Feisel & Peterson, 2002). Inquiry implies that students are involved with the learning. Instead of a lecture environment where physical participation in the learning process is not available to the students, inquiry-based learning allows students to actively partake in a variety of different exercises that enhance their learning. Laboratories do just that; they allow the students to be involved and let them learn by doing.

Laboratories also introduce students to cooperative learning. Experiments are usually performed in pairs or groups of students, so they are able to experience inquiry-based learning along with cooperative learning, which incorporates the individual skills of each student. Cooperative learning also involves peer interaction. The students work together and combine their knowledge to solve the problems presented in each experiment (Hart, Mulhall, Berry, Loughran, & Gunstone, 2000). This interaction makes learning more enjoyable because students are able to work with their friends and actively learn by performing a variety of different experiments (Strain & Pearce, 2001).

For engineering colleges in particular, experiments are a major portion of the curriculum. Grayson (1977) explains that in 1977, as much as ninety percent of the space available in engineering college buildings was used for laboratories and faculty offices. These are required to prepare the engineering students for the type of work they will be performing after graduation. Students can receive the hands-on training they need and become familiar with equipment in the workplace while still in school, which saves time and makes them more attractive to employers.

Along with providing experience, laboratories also provide students with the opportunity to practice the necessary writing skills for professional reports. These reports accompany each laboratory to demonstrate to the professor that the students understood the material presented to them. They usually follow the scientific method, which includes the purpose, hypothesis, materials, results, and conclusions (Poole & Kidder, 1996). This develops thinking and processing skills for students, as well as the ability to draw conclusions based on the data collected. The laboratory report shows that the students completely understand the concepts. They have to be able to apply what they have learned to develop a hypothesis and explain the results.

Disadvantages of Laboratories

Although laboratories have many advantages, there are also some disadvantages. One disadvantage of laboratories is the cost of the equipment needed to run many of the experiments. These costs sometimes cause universities or high schools to purchase used laboratory equipment since new equipment can range up into the hundreds of thousands of dollars. A university may choose to buy two pieces of used equipment rather than one piece of new equipment in hopes that students will have more time to use them. One problem with used pieces of equipment is that some may have defects, such as calibration problems, resulting in impractical results. Also, older equipment may not have all of the options needed to specify the exact parameters of the experiment. The other option that a university or high school may choose is to purchase one piece of the higher technology equipment (Andelin & Naismith, 1986). This creates problems with availability when the classes become too large in size. Students are required to use the equipment individually, which forces them to wait until it is available.

A potential solution to this problem is to split the classes into several smaller laboratory sections. As a result, a smaller number of students are in the laboratory at once, creating more time for each student to use the higher technology equipment. This solution can work for certain universities, but there are limitations. If there are too many sections of students, the availability of the laboratory can become an issue since numerous classes need to use the same facility. The availability of the faculty members can become an issue as well. Since a faculty member must be present in the laboratory whenever students are using the equipment, the availability of faculty members can be another limiting factor. A class can only be divided into as many sections as there are faculty members available.

As a result of these limiting factors for laboratories, another way of learning and performing laboratories is being developed. This is by using the World Wide Web to provide students with a laboratory experience. If laboratory equipment were accessible on the Internet, the equipment would be available at any time of the day and students would be able to use it at their convenience. Students would not have to wait for a faculty member to be available or for other students to finish using the equipment they need to use.

WEB-BASED LEARNING

The potential impact of the World Wide Web on our educational system is considered limitless by some researchers, whereas the limitations of traditional classroom instruction are fairly well known (Lowther, Jones, & Plants, 2000). Web-based learning is the next logical step in education because it provides students with better learning experiences, puts the focus on students, and prepares students more effectively to utilize their knowledge in the future (Khan, 1997; Relan & Gilliani, 1997).

Web-based learning is a form of education that uses the World Wide Web as the medium of delivery. There are two forms of web-based learning: web-based instruction and web-based laboratories. Web-based instruction is the use of technologies and resources of the World Wide Web as a means for delivering education (Khan, 1997). Web-based laboratories are laboratories that are performed on the World Wide Web.

Web-based learning is student-centered, which means that the student is in control, makes decisions about pacing, and focuses on the material that the student feels is important (Relan & Gilliani, 1997). This allows the student to better assimilate and reflect upon material, which results in a greater level of comprehension (Williams & Peters, 1997; Taylor & Eustis, 1999). Web-based learning is also capable of delivering assessments and providing immediate feedback, which reinforces learning and helps to identify deficiencies in knowledge (Brown, 1999).

WEB-BASED LABORATORIES

Web-based laboratories are one form of web-based learning. They can be classified into four different categories based on the way they represent information. Although web-based laboratories have advantages, they also have disadvantages.

Types of Web-Based Laboratories

The term web-based laboratory encompasses a wide variety of web-accessible educational resources including, but not limited to, images, animations, interactive simulations, and remote manipulations of laboratory equipment (Zia, personal communication, October 23, 2002). Each type of laboratory presents information to the student in a different way, allowing them to be used for multiple educational approaches.

Images are static representations of laboratory experiences that do not provide an interactive experience for the student. Image-based laboratories include photographs, diagrams, and charts as the method of information representation. These are most useful as a visual complement to a hands-on laboratory. For example, a student can view online images of specimens as would be seen under a microscope in order to identify a similar image on a real slide (Zia, personal communication, October 23, 2002).

Animations are non-static representations of laboratory experiences that do not provide an interactive experience. Animation laboratories are movies and laboratory simulations that the student can view, but the parameters cannot be altered in order to obtain a different outcome. These are most useful to show a change or progression of an experiment over time. For example, animations can be used to illustrate the growth cycle of a tadpole to a frog. The changes are shown in a movie format as a continuous process rather than an image format, which has the ability to show individual steps, not the entire evolution (Zia, personal communication, October 23, 2002).

Simulations are interactive laboratories, which allow the student to control the experiment. These laboratories can come in the form of applets and interactive movies, but the movies are different from the animations because the student has the ability to adjust the parameters to obtain different outcomes. The student is able to attempt the experiment multiple times, gaining immediate results and a greater possibility of learning. In a physics applet, for example, the student must designate parameters for velocity and trajectory angle in order to shoot a projectile and hit a target a certain distance away (Zia, personal communication, October 23, 2002).

Remote manipulation of laboratory equipment is another form of an interactive laboratory. These laboratories give the student access to run equipment at a distant laboratory using parameters the student designates. This request gets submitted to a server, the experiment is run in a short period of time, and the results are sent to the student when they are complete. The results can come in many forms, but for some, they come in the form of graphs and a live video of the experiment actually taking place on the machinery (Zia, personal communication, October 23, 2002).

Advantages of Web-Based Laboratories

Similar to hands-on laboratories, web-based laboratories have the ability to give students added exposure to the material they are learning in class. Web-based laboratories allow students to create physical simulations as well as experiments similar to a hands-on laboratory.

A web-based laboratory that was designed for an introductory engineering laboratory class, conducted by Professor Michael Karweit of John Hopkins University, has proven very useful. The class contains six web-based laboratory experiences which provide an environment that allows students more freedom to experiment than was previously possible (Karweit, 2000). The students are able to use the material that they learned in class to complete the laboratory experiences, which provides them with another representation of the material they are learning.

Web-based laboratories have some additional advantages to traditional laboratories. One advantage is that web-based laboratories have the ability to prepare students for a hands-on laboratory by providing them with the preliminary information that they will need to know before performing the laboratory. They can do this by showing students what materials and equipment they will be using in the hands-on laboratory and allowing them to practice the procedure without using the real equipment. This method has many advantages to it. It allows the students to prepare themselves on their own time so that the hands-on laboratory time will be used most efficiently. Since laboratory space is becoming a concern, this alleviates some time constraints on laboratory availability. It also allows the students to learn about what materials and equipment they will be working with so that safety concerns can be mitigated. Some laboratories have safety concerns because of chemicals or certain equipment used, and by learning how to properly manipulate this equipment prior to the hands-on laboratory, accidents could be reduced (Hair, 2000).

One example is ChemLab at Dartmouth College. ChemLab is utilized in Dartmouth's general chemistry laboratory class before performing hands-on laboratories to give students practice with laboratory techniques. The practice comes from a web-based simulation of the hands-on laboratory, which allows students to repeat the necessary techniques until they feel comfortable with them. It would be difficult to do this in a hands-on laboratory due to financial and material constraints. Professors have found that students perform at a higher level in the hands-on laboratory and have a more in-depth understanding of the underlying principles of the laboratory experiences when the web-based laboratory component is performed first (Hair, 2000).

Another advantage to web-based laboratories, similar to other types of technology assisted learning, is that the laboratories have the ability to provide the amount of information that the student is looking for and can cater to individual needs. Students have the ability to obtain the information that they require for personal purposes (Bennett, 1999). Almost all the information about the subject can be presented in the web-based laboratory, so it is possible for students to study what information they feel they need. This ability comes without having to perform a hands-on laboratory each time, which is too costly for most institutions.

For an introductory biology class at Whitman College, Professor Earl Fleck created a virtual fetal pig dissection laboratory. While this web-based laboratory was originally intended for those who would not dissect a real pig for moral or ethical reasons, the majority of students in the class now use it. This laboratory allows all students to dissect multiple pigs without incurring additional costs to the institution. This has lead to greater understanding of the material covered than the hands-on laboratory experience had provided, and has allowed students interested in the material to perform the laboratory without infringing upon their moral and ethical beliefs (Fleck, 2000).

Disadvantages of Web-Based Laboratories

Although there are many advantages to involving web-based laboratories in class curricula, there are some disadvantages as well. These disadvantages come mainly in the form of student access to computer equipment and insufficient computer abilities of some students. Not all students have access to a computer when they want to study the material or use the web-based laboratories. Also, since computers are fairly new in recent years, many students may not be as competent in the use of computers as some other students, which could have an impact on the effectiveness of a web-based laboratory as compared to a hands-on laboratory.

Many students have begun to buy a personal computer for college use. It is becoming necessary for most schoolwork since many professors expect reports and projects to be submitted in computer format. Some students do not have the ability to buy a computer because they are still fairly expensive, and this leads to inaccessibility of the web-based laboratories (http://www.computerlearning.org/TECHED.HTM). If students do not have a computer to work on, it will not be possible to perform a web-based laboratory on their own time. Colleges are trying to alleviate this problem by providing computer laboratories throughout their campuses so that students have the access that they need to a computer. In this way colleges have identified this problem and they are making an effort to come to a solution.

Since computers are a fairly new piece of technology in recent years, not all students have developed sufficient skill in the operation of a computer. If students do not have the ability to work on a computer, it is not possible for them to perform laboratories that are on the computer either. This could slow down the learning process and may affect the results of their web-based laboratory use. If students are unable to perform the actions on the computer, they could be unable to finish the laboratory, not because they do not understand the material presented, but due to inadequate computer proficiency (Bennett, 1999).

Now that there is a comprehensive understanding of the previous beliefs of web-based laboratories and their abilities, we can investigate the current capabilities and limitations of laboratories offered on the World Wide Web.

CHAPTER 3. METHODOLOGY

Our project has provided the National Science Foundation (NSF) with a report on the current capabilities and limitations of web-based laboratories. We began by using the database that was created for the NSF a year ago as our initial sample group. We updated the entries in the database and contacted the Principle Investigators (PIs) of each site to receive specific information about the use of their laboratory. This information was then analyzed in order to discern the emerging trends in the implementation of web-based laboratories.

SORTING THE DATABASE

We began our research by becoming familiar with the existing database. We accomplished this by dividing the one hundred laboratories into four groups by discipline so that the workload was balanced between the group members. The discipline groups consisted of biology, engineering, mathematics and physics, and chemistry and other subjects. We then checked the availability of these laboratories and classified them as either "available" or "unavailable." Available laboratories were located at the web address given in the database or easily located at another web address. Unavailable laboratories could not be located or were no longer active.

SAMPLING TECHNIQUE

Once these groups were identified, we classified the web-based laboratories as either non-interactive or interactive. Non-interactive web-based laboratories include images and animations. These types of laboratories allow the user to view the experiment without the ability to modify the parameters. Interactive web-based laboratories include simulations and remote manipulations. These types of laboratories allow the user to run the experiment and modify the parameters as needed. Non-interactive laboratories are designed specifically to show a concept, while interactive laboratories are designed for the user to discover the concept at a personalized pace. Due to the inherent differences between non-interactive and interactive laboratories, comparison between the two would be complex.

We decided to investigate only the interactive web-based laboratories for our research purposes. The previous study recommended this approach for a number of reasons. Interactive laboratories provide students with an experience that more closely resembles a hands-on laboratory than non-interactive laboratories. These laboratories allow students to actively participate in and regulate their own laboratory experience. Also, ninety percent of the web-based laboratories found in the database are interactive laboratories, leaving a large sample size. The interactive laboratories provided us with a sample of ninety web-based laboratories out of the original one hundred found in the database. This is an example of purposive sampling since these laboratories were specifically chosen as the sample, rather than being chosen at random (Nachmias & Nachmias, 1987). Only the interactive laboratories contained the particular characteristics we were hoping to research, such as interactive learning, which is why we purposely chose them as our sample.

INTERVIEWING

Once our sample was defined, we checked the validity of the contact information for the PIs of each laboratory that was provided in the database, and updated it as necessary. We then sent out a preliminary email to the PI of each laboratory. We created two different emails, one for the available laboratories and one for the unavailable laboratories. In the available laboratory email we requested assistance with our research and asked a few initial questions focusing on the experiences they had encountered while using these laboratories, assessment or evaluation studies they had conducted, or other evidence of effects on student learning (see Appendix C). The unavailable laboratory email requested similar information, as well as questioning the current status of the laboratory website. This could include a new web address or information regarding the reason for its discontinuation (see Appendix D).

As we received responses, we contacted the PIs to set up telephone interviews. From these interviews, we obtained more detailed information on the purposes and uses of the laboratories. This included information on how the laboratories are incorporated into classroom curricula, original design decisions, and evidence of measurable student outcomes when available. We also received recommendations to visit other web-based laboratories and include them in our research (see Appendix E).

DATA EVALUATION

While we conducted the interview process, we updated the current database with our findings. The data that we obtained from the interview process was organized into two categories: qualitative and quantitative data. The qualitative data included results of student evaluations and faculty comments. From this data, we were able to find recurring issues with web-based laboratories. The quantitative data included information from the PIs about the uses of their web-based laboratories, as well as formal studies that had been conducted. We used the quantitative data from multiple PIs to construct four different graphs. We analyzed the graphs for patterns, which led us to our conclusions about web-based laboratories. These conclusions were divided into capabilities and limitations, and were used to develop recommendations for further research. Our conclusions and recommendations were presented to the NSF in a report for their future use in the development and advancement of web-based laboratories.

CHAPTER 4. RESULTS AND ANALYSIS

The data that we obtained for this project came from many different sources. The majority of our data was obtained from the personal interviews that we conducted with the available PIs of the different web-based laboratories, while the rest was received in emails from the PIs and documents sent to us about research conducted on different laboratories. We combined all of this data to find recurring trends among the web-based laboratories. Some of the trends were established from qualitative data, while others were based on quantitative data. The trends that could not be quantified were issues of the cost of web-based laboratories, the replacement of hands-on laboratories with web-based laboratories, and computer proficiency. The trends we were able to determine based on quantitative data included web-based laboratory use, flexibility, versatility, and effectiveness.

QUALITATIVE DATA

Many different opinions and ideas were collected from our contact with the PIs of each web-based laboratory. Some of these ideas could not be quantified since they were simply personal opinions or findings. Three issues in particular were discussed in many of the interviews. These were the cost of a web-based laboratory, the replacement of hands-on laboratories with web-based laboratories, and potential problems with computer proficiency.

Cost of Web-Based Laboratories

One idea that was discussed in many of the personal interviews was the cost of web-based laboratories. L. Van Warren, the developer of the Virtual Sickle Cell Lab, was one PI who had particularly significant problems with the cost of developing his web-based laboratory. The first cost problem occurred two years ago when this laboratory was originally developed for a professor at the University of Arkansas for Medical Studies (UAMS). Warren had hoped to create a remote manipulation laboratory so that scientific personnel and students could run an electrophoresis gel apparatus over the World Wide Web. However, he was unable to acquire funding for this idea, so he settled for creating a simulation laboratory that allowed students to set the parameters and watch a simulation of the gel on the computer. Once completed, the simulation Virtual Sickle Cell Lab was used for one year at UAMS, but was then taken off of the website. This was not because it was an unsuccessful laboratory, but because the university did not have the funding or infrastructure to keep it online. Warren encountered his second cost problem when he could not find funding to maintain and update his web-based laboratory. The lack of funding caused the web-based laboratory to be taken off of the university's website. This laboratory is currently unavailable for student use until new funding can be found (L. Warren, personal communication, November 1, 2002).

A second example of cost problems when developing a web-based laboratory came from an interview with Jim Rusconi, the designer of The Virtual Cell Tour. Rusconi had originally hoped to create an interactive game for students to play that would explore the components of an animal cell. He had based this idea on a video game, and had hoped to provide the students with different pathways they could follow to learn about the parts of an animal cell. Rusconi had a problem finding funding for his laboratory idea, just as Warren had. He received a grant for ten thousand dollars, but this was less than he needed to create his interactive game. As a result, Rusconi developed The Virtual Cell Tour, which is a simulation with which students interact, rather than an interactive game as he had originally hoped. Since its development in 1996, Rusconi has not encountered any costs problems while updating and maintaining The Virtual Cell Tour. It was only the initial creation cost of the web-based laboratory that limited Rusconi's development. The laboratory has been successfully integrated into class curricula for the past five years (J. Rusconi, personal communication, October 31, 2002).

Although there are some PIs that encounter cost problems when originally developing web-based laboratories, some others have no problems finding the funding that they need. One example of this is the Physics Interactive Video Tutor (PIVoT) developed by Richard Larson. Larson was awarded two million dollars to fund his project, which was the amount that he needed to create the simulation laboratory as he originally planned. This is a very successful laboratory that has been used for the past six years in physics classes at Massachusetts Institute of Technology. During this time, Larson has not encountered any funding problems while maintaining and updating the PIVoT web-based laboratory (R. Larson, personal communication, November 5, 2002).

One other laboratory that did not have any problems with funding was the Calculus On the Web (COW) laboratory developed by Gerardo Mendoza. Since he was awarded the full four hundred thousand dollars that he had requested for his original start-up and maintenance costs, this laboratory was developed exactly as Mendoza had planned. Just like the PIVoT laboratory, the COW laboratory has been in use for the past six years, and has been updated and modified as needed without any problems (G. Mendoza, personal communication, November 5, 2002).

These four web-based laboratory examples show that there are usually very large start-up costs when designing a web-based laboratory. The start-up cost of a laboratory can fall into a large range of values. Some simple simulations, like The Virtual Cell Tour can cost around ten thousand dollars, while some more intricate simulations, like the PIVoT laboratory can cost around two million dollars to design. These start-up costs usually consist of computer hardware, computer software, and designer costs, but vary depending on the design of the laboratory (DUE 9950380). If funds cannot be found by PIs to compensate for these costs, an original web-based laboratory idea is usually modified to reduce the cost or it is not developed at all. This is considered a limiting factor to the growth of web-based laboratories.

If PIs are able to find the funding to develop a web-based laboratory, the maintenance costs are usually very low. Many of the PIs are able to make adjustments to the laboratories as needed, without any additional costs or assistance. As seen by three of the web-based laboratory examples, after the start-up costs, they did not have to worry about funding for the maintenance. Warren was the only PI that encountered maintenance problems after start-up, but these problems were mainly a result of UAMS's network infrastructure, rather than Warren's funding problems.

After analyzing the information that we received on the costs of web-based laboratories, we noticed that there has not been any cost analysis research done in this area. One original hypothesis that we had about web-based laboratories was that they would be more cost efficient than hands-on laboratories. However, with the data we have obtained, we cannot come to any conclusion about this issue. We feel that this is an area where future research can be done to compare the cost effectiveness of web-based laboratories to hands-on laboratories in order to determine which is more efficient. This information would not only assist the NSF in future research, but also many professors who have already integrated or are considering integrating web-based laboratories into their teaching.

Issues with Replacing Hands-On Laboratories

A second trend that we determined based on the qualitative data was the issue of replacing hands-on laboratories with web-based laboratories. Each person who works with web-based laboratories has an individual view on whether web-based laboratories will be able to completely replace hands-on laboratories. Two of the PIs interviewed have particularly strong and opposing views on this topic. Warren believes that it will never be possible to completely replace hands-on laboratories, while James Henry, the designer of the Control and Process Dynamics laboratory, feels that it already is possible to replace some hands-on laboratories with web-based laboratories (L. Warren, personal communication, November 1, 2002; J. Henry, personal communication, October 25, 2002).

Warren believes that students need to be able to use their senses when completing laboratories. He used a chemistry laboratory as an example, where students use their senses of smell and touch to determine particular characteristics of a substance or information about its identity. If students tried to perform these experiments on the World Wide Web, they would not be able to experience the scents of different substances or their different consistencies. This limits what the students are able to learn about the experiments. He feels that web-based laboratories are good teaching guides for students, but that they cannot completely replace the hands-on experience (L. Warren, personal communication, November 1, 2002).

Henry has the opposite view on this issue. He developed the Control and Process Dynamics laboratory to completely replicate a controls and processes laboratory. This web-based laboratory is used as a preliminary experience for some students before they complete the hands-on laboratory, but for others, it is their only exposure to the experiment. Some schools and universities, such as The University of Sydney, Australia, that are not able to purchase the equipment needed to run this experiment in a hands-on laboratory, use the web-based laboratory as a replacement. Henry feels that this material can be demonstrated just as well on the World Wide Web as in a hands-on laboratory so the students are not disadvantaged by using the web-based version (J. Henry, personal communication, October 25, 2002).

These two cases show that the issue of web-based laboratories replacing hands-on laboratories does not have a simple answer. It seems that in some cases web-based laboratories are able to replace the hands-on versions, like with the Control and Process Dynamics laboratory. However, in the case of a chemistry laboratory, this does not seem possible since the sensory aspects of the laboratory are essential to understanding the concepts presented in the experiment. Currently, technologies that allow students to experience all of the sensory aspects of a laboratory on the World Wide Web have not been developed yet. This is something that may be researched and designed in the future to expand the capabilities of web-based laboratories. However, at this time, the lack of sensory aspects available in web-based laboratories is a limitation for particular experiments.

Issue of Computer Proficiency

A third issue that was addressed in the interviews with three of the PIs was computer proficiency. Anne Spalter, the designer of The Exploratory Project discussed the issue of students with computer phobia. She was concerned that in general many web-based laboratories do not cater to the needs of students unfamiliar with computers. They are designed for students who know the basic uses of computers, which limits students that either have never used a computer or have a computer phobia (A. Spalter, personal communication, October 30, 2002). Mendoza and Larson also addressed this concern in their interviews. They were worried that students that are not proficient with computers will be left behind when web-based laboratories are used in classes (G. Mendoza, personal communication, November 5, 2002; R. Larson, personal communication, November 5, 2002). These comments introduced another limitation of web-based laboratories. They must be designed for students of all levels of computer understanding. If educational tools are going to be on the World Wide Web, teachers and designers need to be sure they are still usable by all students.

We feel this is an issue that research could be conducted on. Some of the web-based laboratories we looked at were very clear about their direction and were extremely user friendly. Others were complicated and it was difficult to understand the direction of the experiment. When future web-based laboratories are designed, we feel that this issue should be included in their research. It is important to make sure that classroom activities or assignment do not limit the number of students who will be able to perform them.

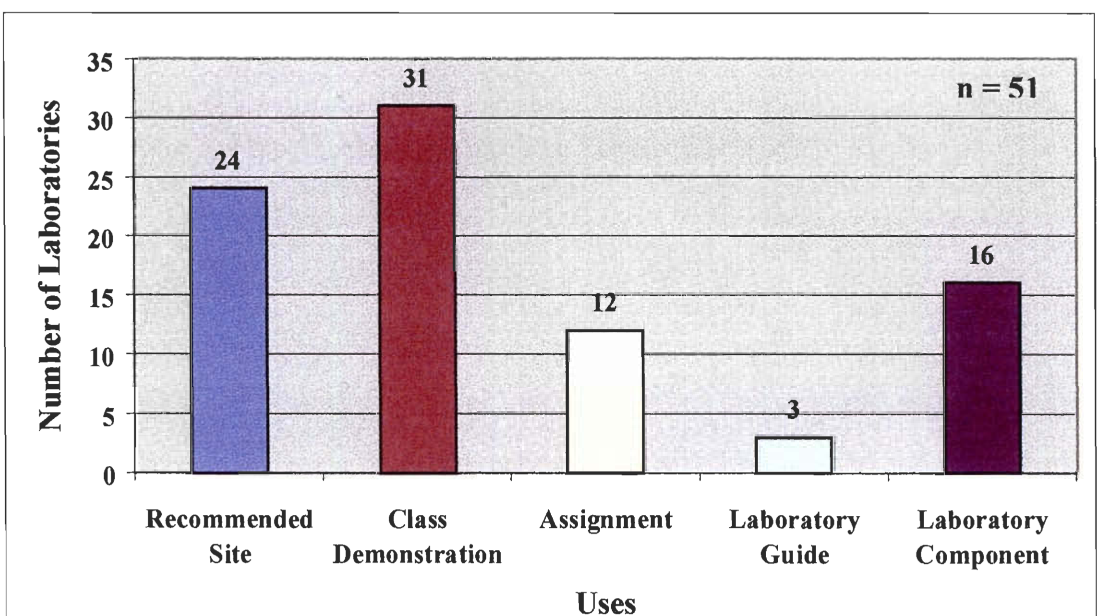
QUANTITATIVE DATA

Many questions that were asked in the personal interviews with the PIs had answers that were comparable between interviews. This made the data we received easy to quantify and analyze for common trends. The trends that we noticed with our quantitative data were web-based laboratory use, flexibility, versatility, and effectiveness. These trends all had data that could be displayed graphically and then analyzed to determine these common trends of web-based laboratories.

Web-Based Laboratory Uses

We have found that web-based laboratories can be implemented into classroom curricula in at least five different ways. Information about the ways fifty-one of the web-based laboratories have been used by teachers was gathered from individual interviews and email contact with the PIs of each of the laboratories. The data that we collected is shown in Figure 4.1.

Figure 4.1: Uses of Web-Based Laboratories



The five different uses of web-based laboratories that we found were as a recommended site, a class demonstration, an assignment, a laboratory guide, and a full laboratory component. The use of web-based laboratories with the least amount of integration into class curricula is as recommended sites. Twenty-four of the fifty-one web-based laboratories we researched have been recommended to students who are looking for additional information on a particular topic. This means that the laboratories are not specifically included in the class curriculum, but that the teachers supply these laboratories as additional resources for students. The teachers never go through the web-based laboratory in class with the students or assign it for homework; these laboratories are simply recommended for students that are looking for an alternative explanation of the concepts being taught in class.

The second use of web-based laboratories is to integrate the laboratory as a classroom demonstration. As shown in Figure 4.1, this is the most common way that web-based laboratories are used. Thirty-one of the fifty-one web-based laboratories we researched have at one time been used as a classroom demonstration. This implies that teachers have performed this laboratory in front of a class to show and explain the concepts being taught. They can also be used in teachers' offices during office hours to help demonstrate the material to the students who want extra help (R. Pfaff, personal communication, November 5, 2002).

The third use of web-based laboratories that we determined from our interviews and emails was as assignments. Some teachers had their students complete these web-based laboratories as a component to homework or as a classroom assignment. The laboratories were used as complements to assigned questions or problems that students had to research. They would complete the experiment in order to obtain a better understanding of the material presented in the problems. Unlike a recommended site or a classroom demonstration, web-based laboratories that are used as assignments require that students complete them.

Only three of the web-based laboratories shown in Figure 4.1 have been used as laboratory guides. Laboratory guides refer to web-based laboratories that complement a hands-on laboratory. They are usually performed prior to a hands-on laboratory, but occasionally the two experiments are done simultaneously when a computer is available in the hands-on laboratory. A guide illustrates what the students hope to see during the laboratory or the results they expect to obtain. For example, students perform the CMS Histology web-based laboratory while they perform the hands-on laboratory during their histology class at Finch University of Health Sciences/The Chicago Medical School. The web-based laboratory serves as a "roadmap" to the hands-on laboratory, giving specific examples and descriptions of each step of the experiment (C. Brandon, personal communication, October 25, 2002).

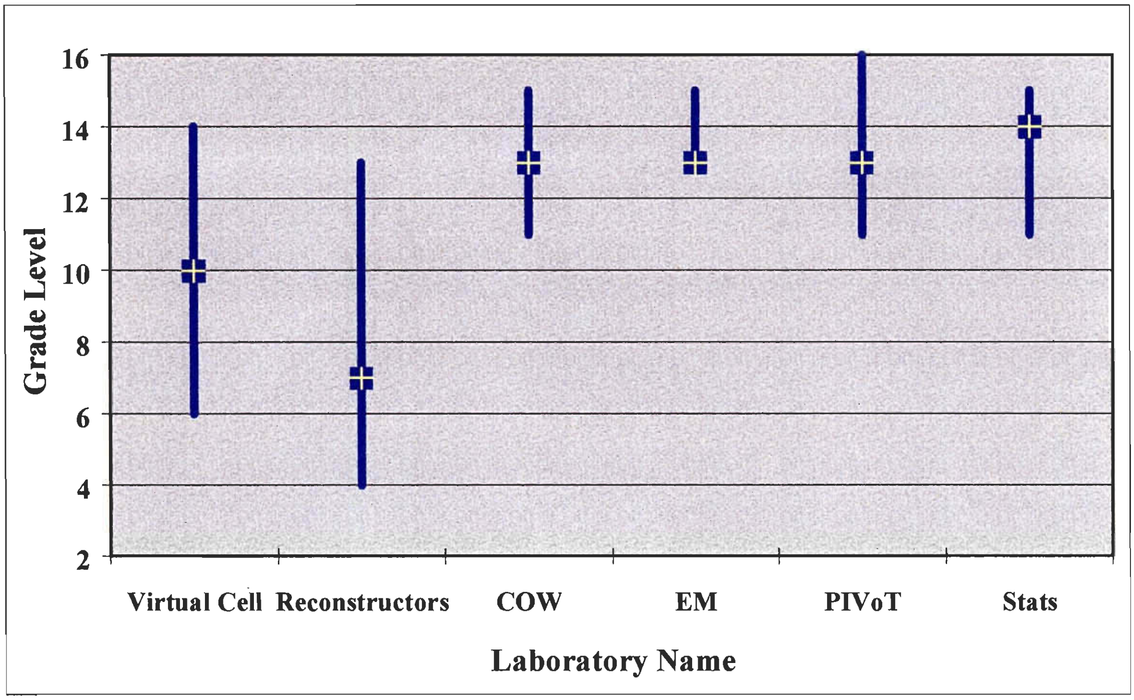
The final use of web-based laboratories that we identified is as a full laboratory component. As shown in Figure 4.1, sixteen of the laboratories we researched have been used in this manner. These laboratories were able to supply the students with the entire laboratory experience on the World Wide Web. Some of these laboratories were completed in classroom settings, while students completed others individually or in groups on their own time. An example of a web-based laboratory that is used as the primary laboratory component is the Control and Process Dynamics laboratory. The University of Sydney, Australia uses this web-based laboratory since they do not have access to the equipment needed to complete the hands-on version of the experiment (J. Henry, personal communication, October 25, 2002).

Many of the fifty-one laboratories researched have been used in more than one of these ways. Different teachers implement these laboratories into their curricula in different ways. Some teachers rely on them more heavily to provide a full laboratory experience for students, while others simply use them to complement their classes. These choices are up to the individual teachers since many of the laboratories are designed to be flexible and fit into class curricula in multiple ways.

Web-Based Laboratory Flexibility

We have found that many web-based laboratories can be used by students in a wide range of grade levels. The data that supports this finding was obtained from six of the different web-based laboratories we researched. The PIs of each of these laboratories informed us of the grade level that the web-based laboratory had been originally designed for, as well as the range of grade levels that actually used these laboratories. This data is shown in Figure 4.2.

Figure 4.2: Grade Range Flexibility Graph



The web-based laboratories that had information about grade range are shown along the x-axis of the graph with the grade levels on the y-axis. The grade level that each laboratory was originally developed for, the target grade level, is displayed in Figure 4.2 as a box with a cross in the middle of it. The bars extending from the boxes illustrate the range of grade levels that included these laboratories in their curricula.

For example, as shown in Figure 4.2, The Virtual Cell Tour was originally designed for tenth grade students. The grade levels that actually implemented this laboratory ranged from sixth grade to fourteenth grade, sophomores in college. This data shows that this laboratory was much more flexible than the designer originally thought it would be. Middle school students were able to utilize this laboratory as well as college level students, even though they may not have used it in exactly the same ways. The material in this laboratory was still helpful to all the different students involved.

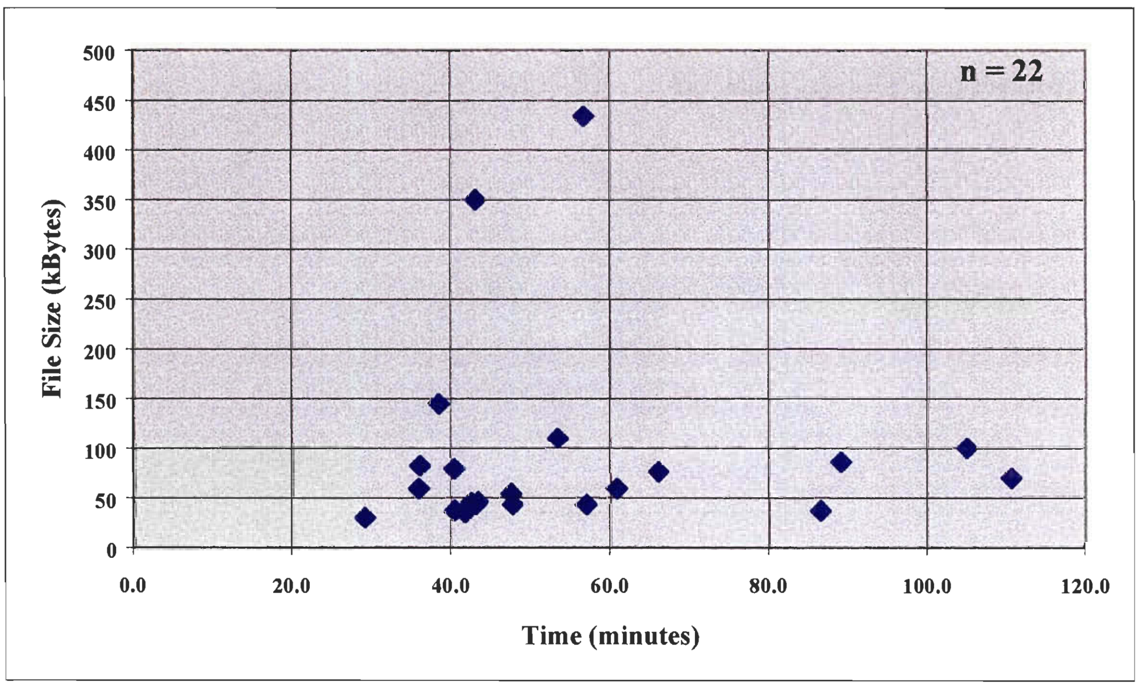
All six of the laboratories presented in this graph were used by a range of grade levels, rather than just the originally targeted grade level. Using Animation in Teaching Electromagnetism is the only laboratory that is being used by higher grade levels than the target, but not by lower grade levels. This is due to the fact that higher level studies, such as electromagnetism, are usually only introduced in college level classes. Since this laboratory was designed for freshmen in college, it can be used mainly by higher grade levels and not by lower grade levels. The other five laboratories range up and down with the grade levels that use them, allowing many different teachers to use this material in their classes. This shows that web-based laboratories are flexible in their use. They are not limited to being implemented into the curriculum of one grade level; a wide range of grade levels can use them. The flexibility allows some laboratories to be used by middle school students, as well as high school and college students.

One problem that we have noticed from this data is that there are not many web-based laboratories specifically designed for more mature classes. As seen in Figure 4.2, college students are using some laboratories originally designed for middle school and high school students. Students at the higher grade levels would benefit more from a laboratory that is designed specifically for the material that they are studying in their current class, rather than one that is designed for a lower level class. This problem seems to be most prevalent in the discipline of biology, as with The Virtual Cell Tour and The Reconstructors. Since the basic ideas of biology are introduced in elementary and middle school, but studied throughout college, it seems that more advanced laboratories on this information have been overlooked. This is an area of research that could be completed in the future to hopefully fill the gaps of higher level biology web-based laboratories.

Web-Based Laboratory Versatility

We were also able to determine that web-based laboratories are versatile. This conclusion is primarily based on data we received from a study conducted on the Virtual Geotechnical Laboratory by its researcher Timothy Wyatt. Wyatt observed the duration of time students spent performing the laboratory as well as the size of their log files when finished. This data is shown in Figure 4.3.

Figure 4.3: Student Log Files for the Virtual Geotechnical Laboratory Graph



Source: Wyatt, 2000

The duration of time that students spent performing the laboratory is shown along the x-axis of the graph, measured in minutes. This shows that some students spent around thirty to fifty minutes performing the laboratory while others spent over one hundred minutes. The size of the student's log file when finished with the laboratory is shown along the y-axis of the graph, measured in kilobytes. The file size is a measure of student activity. The larger the file size, the more material the student explored while performing the laboratory. Figure 4.3 shows that there is a wide range of the amount of material that students explored while performing this laboratory. The majority of students had log files within the range of thirty to eighty kilobytes, but there were two students with log files over three hundred kilobytes. It would seem that these larger log files must have taken a long time to obtain, but this is not true. These students were online for less than an hour, but were still able to obtain these large log files. This shows that there is little correlation between file size and the time spent performing a laboratory. Figure 4.3 shows that this laboratory was versatile to the student's desires. They could spend as much time and explore as far as they needed to understand the materials in this laboratory (Wyatt, 2000).

Although the Virtual Geotechnical Laboratory was the only web-based laboratory that studied this type of data, a few other PIs, such as Larson and Mendoza, provided us with anecdotal information that was very similar. They described the flexibility the students had in the amount of time they spent performing the laboratory, as well as the different ways students could complete the laboratory. Many web-based laboratories are designed with multiple pathways of completion, to cater to the interests of the students. These anecdotal references helped strengthen our data on laboratory versatility (R. Larson, personal communication, November 5, 2002; G. Mendoza, personal communication, November 5, 2002).

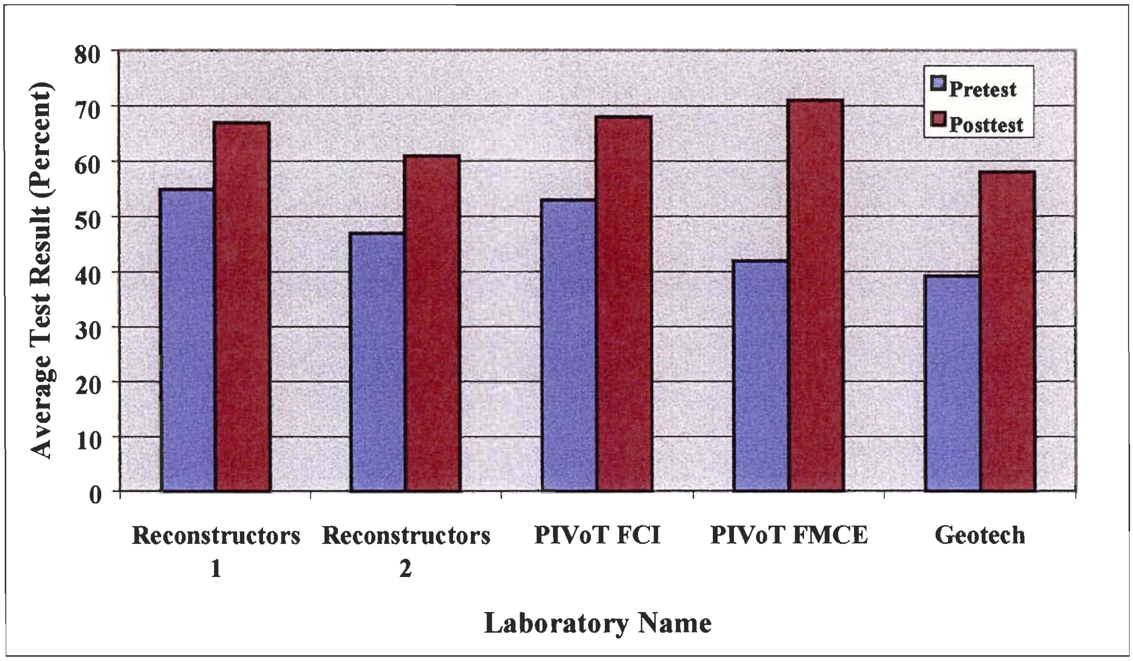
Web-based laboratories provide students with the opportunity to determine the pace and depth of learning that they prefer. Many of the laboratories consist of multiple pathways to complete the experiments. This allows the students to choose the way they feel will be most helpful to them and does not limit them to one procedure. The versatility of web-based laboratories allows them to accommodate different types of learning styles and personalities.

In depth studies on the effects of web-based laboratories on different learning styles, genders, and ethnicities should be conducted. These studies would be beneficial in order to determine how these variables affect students' abilities to learn from web-based laboratories. If these issues are not addressed, it is possible that certain student populations may be overlooked during web-based laboratory development.

Web-Based Laboratory Effectiveness

A final trend that we were able to depict from our data is that web-based laboratories are effective educational tools. This trend is based on three of the laboratories we researched that had conducted pretest and posttest studies. The results we obtained from these laboratories showed the average test scores achieved by students on the pretest and the posttest that accompanied the web-based laboratories. These scores are displayed in Figure 4.4.

Figure 4.4: Laboratory Effectiveness: Pretest versus Posttest Graph



Source: Miller, Schweingruber, Oliver, Mayes, and Smith, 2002; Lipson, 2001; Wyatt, 2000

The graph represents the average test result of the pretests by purple bars. These are tests that teachers administer to the students before they perform the laboratory. The questions pertain to the information discussed in the laboratory to test the students on their previous knowledge of this area of study. After completing the pretest, the students would perform the laboratory. Once the laboratory is complete, the teachers would administer the posttest, which tests the students on the same information that was tested in the pretest. The posttest is administered to determine whether the students were able to learn the material on the test by completing the laboratory. The average test results of the posttests are represented by maroon bars in Figure 4.4. By comparing the pretest scores to the posttest scores for each laboratory, we can see that all of the posttest scores were higher than the pretest scores for the corresponding laboratory. This shows that the students understood the material on the test better after they had completed the laboratory.

The researchers of one of the web-based laboratories, The Reconstructors, conducted their study to see if the students were able to retain the knowledge for an extended period of time. They tested this knowledge by administering the pretest at least two days prior to the performance of the laboratory and then administering the posttest at least two days after the completion of the laboratory (Miller et al., 2002). By doing this, the students could not simply remember the questions from the pretest and look specifically for the answers in the laboratory to complete the posttest right afterward. The results showed that the students were able to retain the information presented in the laboratory for at least two days following completion of the laboratory.

These three web-based laboratories are the only ones we could find that have conducted this form of measurable student outcomes. We feel that these types of studies are very important for PIs to conduct so that they can prove the credibility of their laboratories. Since anyone can establish a website on the World Wide Web, it is sometimes difficult to determine which are reliable sources. If a PI can prove that a particular laboratory is an effective educational tool by conducting these studies, other teachers will be more likely to trust this laboratory and use it in their classes.

Along with just verifying the credibility of web-based laboratories, it is also important to determine whether these laboratories are more or less effective than comparable hands-on laboratories. In order to show this, tests on measurable student outcomes must be completed for both types of laboratories and then compared to determine their relative effectiveness.

The t-Test Verification

Since we used data from outside sources for the Laboratory Effectiveness: Pretest versus Posttest Graph, the validity of this data is an important concern. In order to establish validity, the certainty of the data from these studies must to be high. Table 4.1 shows values for the certainty of the data for some of the studies we used.

Table 4.1: Percentage of Uncertainty for Pretests and Posttests

Laboratory Name	t	n	p**-value**
Reconstructors I	8.33	148	<0.001
Reconstructors II	8.69	148	<0.001
PIVoT FCI Experimental Group	N/A	82	<0.01
PIVoT FCI Control Group	N/A	129	<0.01
PIVoT FMCE Experimental Group	N/A	82	<0.05
PIVoT FMCE Control Croup	N/A	129	<0.05
Rice Laboratory in Statistics	N/A	107	<0.001

Sources: Miller et al., 2002; Lipson, 2001; Lane & Tang, 2002

In Table 4.1, t represents the t-test value of the data from the study group, n represents the number of students in the study group that the data was obtained from, and the p-value is the measure of certainty of the data that was obtained from the study group. A t-test value is used to describe differences between a hypothesized average value and the average value of the data. The number of data values, n, along with the value of the t-test is used to find the p-value from a t-distribution probability table. The lower the p-value for the data, the greater the certainty of results. A percentage value for certainty can be obtained by subtracting the p-value from one and multiplying the result by one hundred (Mendenhall, Beaver, & Beaver, 2003; Upton & Cook, 2002; Griffiths & Downes, 1969).

The *t*-test values were provided for each Reconstructors pretest and posttest study. The *t*-test values were not provided for either the PIVoT studies or The Rice Laboratory in Statisics pretest, posttest, control group study. The *n* values and *p*-values were provided from all seven studies. The percentage certainty of each study is high; the lowest percentage certainty is for both PIVoT FMCE studies, which have at least ninety-five percent certainty. The percentage certainty is the probability that the results did not occur by chance and are representative of the entire population. The studies that did provide information on the validity of their data showed consistently high percentage certainties, which indicate that the data that we are using from these studies is valid and are representative of the entire population of web-based laboratories. For more information on these statistical measurements, see Appendix H.

Although there are some capabilities of web-based laboratories, there are also some major limitations to their abilities. The limitations, if not properly studied, could lead to undesired changes in education and society.

CHAPTER 5. SOCIAL IMPLICATIONS

We believe that web-based laboratories have the potential to become a major factor in future educational techniques. Currently, web-based laboratories are not widely used in class curricula, but this will likely change in the near future. The use of web-based laboratories in education could change the way that students learn and teachers educate. Web-based laboratories can represent information learned in a class, but currently they do not allow students to experience the sensory and social aspects that are present in a hands-on laboratory. In most hands-on laboratories, students are able to interact with laboratory equipment, as well as other students. If the sensory and social issues with web-based laboratories are resolved, web-based laboratories could be integrated into class curricula to the point of replacing teachers.

Not all of the sensory aspects of a hands-on laboratory are represented in a web-based laboratory, which has an impact on the learning experience of students. Web-based laboratories do not provide the tactile aspects of a hands-on laboratory. Students are able to see and run the equipment on the computer, but they do not have the ability to operate the physical equipment. If students use only web-based laboratories, they will not have the prerequisite equipment experience that employers may expect. Since there must be training on physical equipment, web-based laboratories should not be the only form of laboratory experience that students receive.

Along with the lack of sensory aspects, web-based laboratories also lack social aspects that are present in hands-on laboratories. There are two kinds of social interactions that exist in hands-on laboratories: student-to-student and teacher-to-student.

The student-to-student component of hands-on laboratories gives students exposure to group work. Unlike hands-on laboratories, many web-based laboratories can be completed individually. This independence limits the amount of group-oriented work that students are exposed to, so they could have a difficult time learning to work cooperatively in other aspects of their lives.

In terms of teacher-to-student interaction, the use of web-based laboratories could eventually diminish interpersonal relationships. Since students will be more likely to perform web-based laboratories on personal time, they might choose to email a question to a professor rather than go to find the professor in person. Although this creates an impersonal relationship between teachers and students, it could result in greater student independence and better problem solving skills. If students are working on their own time individually, teachers and other students will not be available to provide immediate assistance with a problem. As a result, students may be inclined to put more effort into resolving the problem on their own.

With the gained independence of students, the need for teachers and classrooms diminishes. If web-based laboratories are modified to address the sensory and social aspects, they could be used exclusively in undergraduate education. The role of a teacher will be filled by educational computer programs and interactive web-based laboratories.

Web-based laboratories have the potential to have an impact on the future of education in both sensory and social aspects. If web-based laboratories are to become a primary form of education, these issues need to be addressed in order to assure proper use of web-based laboratories.

CHAPTER 6. CONCLUSIONS

The results and social implications that we obtained from our personal interviews and email contacts led us to develop seven conclusions about web-based laboratories. We divided these into current capabilities and limitations of web-based laboratories.

The quantitative results demonstrated the four current capabilities of web-based laboratories:

1. Web-based laboratories can be used by teachers in multiple ways.
2. Web-based laboratories are flexible and can appeal to multiple grade levels.
3. Web-based laboratories are versatile and allow students to determine the pace and depth of their laboratory experience.
4. Web-based laboratories are able to assist students in learning the class material.

Our qualitative results informed us of three current limitations of web-based laboratories:

1. Web-based laboratories require a large start-up cost.
2. At this time, web-based laboratories cannot replace the sensory aspects of experiments, so they are unable to replace many hands-on laboratories.
3. Web-based laboratories require that students have a basic proficiency with computers.

CHAPTER 7. RECOMMENDATIONS

We were able to develop six main recommendations to the National Science Foundation from our results and conclusions:

1. Web-based laboratories should be developed for higher level education classes.
2. Research should be conducted on the design aspects and usability of web-based laboratories.
3. A cost analysis study should be performed comparing web-based laboratories and hands-on laboratories.
4. The NSF should encourage studies on measurable students outcomes from web-based laboratory use.
5. A study should be completed on the effects of web-based laboratories with respect to different learning styles, genders, and ethnicities.
6. The NSF should update the database of web-based laboratories on an annual basis.

Our final recommendation was developed from our experience with this project on web-based laboratories. Since the field of web-based laboratories is continually growing, it is necessary to insert new entries as they appear on the World Wide Web. This will be useful to the NSF because they will know what types of laboratories are already available when they are assessing proposals for new laboratories. The NSF should also list the laboratories from the database on their website to make this information more readily available to interested people, either within the NSF or outside the organization. It would be beneficial to make this information available for a number of reasons. Students and teachers would be able to find and use web-based laboratories that are appropriate for their classes, and PIs would be able to use this information when designing new web-based laboratories.

We believe web-based laboratories have the potential to become useful tools in education. However, there are many aspects of these laboratories that still need to be studied and developed before their role in education can be determined. Once more studies have been conducted on web-based laboratories and there is a better understanding of their abilities, it will be clear whether they can function as replacements of hands-on laboratories.

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APPENDICES

APPENDIX A. HISTORY OF THE NATIONAL SCIENCE FOUNDATION

In the 1930s and 1940s, the United States went through a major growth period, which included The Great Depression and World War II. The war had a significant impact on scientific development, and once the need for this research was over, ideas were formulated to support scientific development for everyday life. Harley Kilgore, a senator from West Virginia, first proposed the idea of the National Science Foundation (NSF) in 1945 (Mazuzan, 1994). He hoped to create an organization that was supported by grants and had the ability to contract both basic and applied research. After five years of deliberation in Congress, Kilgore's proposal was modified to meet the satisfaction of the parties involved. As a result, the National Science Foundation Act of 1950 established the NSF to promote the progress of science; to advance national health, prosperity, and welfare; and to secure the national defense, as declared in the organization's mission statement (NSF, 2002).

The NSF is directed by the National Science Board (NSB). The board is comprised of twenty-four part-time members who are appointed by the President of the United States and confirmed by the Senate. The NSB has dual responsibility as the national science policy advisor to the President and Congress, as well as the governing body for NSF (NSF, 2002).

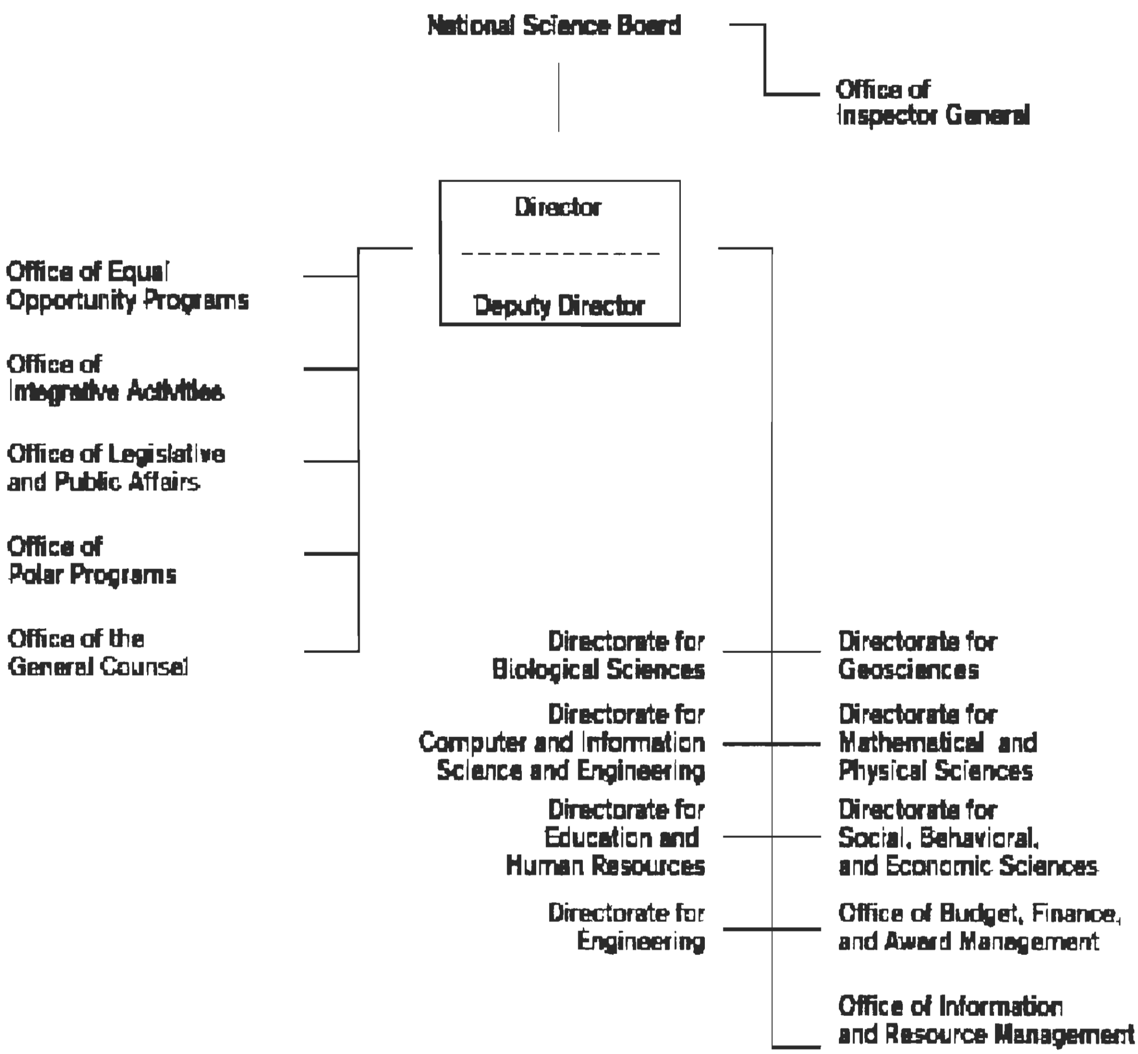
Today, after much growth, the NSF holds the responsibility to "initiate support, through grants and contracts, scientific and engineering research and programs to strengthen scientific and research potential" (NSF, 2002). The organization funds research in all fields having to do with the advancement of science to encourage discoveries in mathematics, science and engineering. Currently, the NSF funds about 1,600 colleges, universities, primary and secondary schools, academic consortia, small businesses, non-profit institutions, and other research institutions in all parts of the United States. Every year, the NSF receives about 30,000 proposals for projects related to research and education, and about one-third of these proposals are funded (NSF, 2002).

The NSF also enables the interchange of scientific information among scientists and engineers in the United States as well as foreign countries. The NSF maintains a current register of scientific and technical personnel in the United States as a "central cleaning house" for the collection and analysis of scientific and technical data for the use of other government agencies.

In 1950, President Truman approved a $225,000 budget for the NSF. Today the NSF budget is approximately $4 billion, which is about 3.8 percent of the annual federal spending for research. In 1999, the organization devoted $2.8 billion in research and $614.7 million in educational activities. Since only about 4 percent of its total budget is devoted to the organization's internal operations, 96 percent can be committed to research, making it one of the most cost-effective government agencies (NSF, 2002).

The NSF is broken up into eight groups called directorates, and these directorates are divided into smaller groups called divisions (refer to Figure A.1). Our project is sponsored by the Division of Undergraduate Education (DUE), which is a division of the Directorate for Education and Human Resources (EHR). The DUE "serves as a focal point for the NSF's efforts in undergraduate education. Whether preparing students to participate as citizens in a technological society, to enter the workforce with two or four year degrees, to continue their formal education in graduate school, or to further their education in response to new career goals or workplace expectations, undergraduate education provides the critical link between the nation's secondary schools and a society increasingly dependent on science and technology" (NSF, 2002).

Figure A.1: Organizational Chart of NSF



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APPENDIX B. THE INTERACTIVE QUALIFYING PROJECT

At Worcester Polytechnic Institute (WPI) of Worcester, Massachusetts, students are encouraged to excel in the fields of science and technology through group oriented projects. Two formal projects are conducted by all students enrolled at WPI: the Interactive Qualifying Project (IQP) and the Major Qualifying Project (MQP). The IQP is intended to give students the opportunity to extend science and technology to society by assisting an organization or corporation with a project. The MQP allows students to perform a project with a corporation within his or her area of study.

Our project, Current Capabilities and Limitations of Web-Based Laboratories, qualifies as an IQP because it allows us to work with the National Science Foundation (NSF) to advance the study of laboratory experiments on the World Wide Web. We have been given the opportunity to assist the NSF in conducting a research project that will help the advancement of science and technology. We have also been given the opportunity to use our personal skills in a group effort toward a common goal.

APPENDIX C. EMAIL SENT TO PIs OF AVAILABLE WEB-BASED LABORATORIES

Dear (contact name),

My name is (your name) and I am working with the National Science Foundation (NSF) on a study of web-based laboratories. We are using the term web-based laboratories to emcompass a wide variety of web-accessible educational resources including, but not limited to, animations, interactive simulations, and remote manipulations of laboratory equipment. The NSF is hoping to obtain a greater understanding of the educational opportunities made available to students through these web-based laboratories.

One year ago a list was compiled of one hundred existing sites that offer access to web-based laboratories and your site, (their site), was among them. The NSF is now interested in the experiences you have had with utilizing this website as an educational tool, particularly with respect to student learning outcomes. I was wondering if you could provide me with any information you may have obtained in regards to this resource. This information could be in the form of surveys filled out by students, assessment or evaluation studies that you have undertaken, comments or questions sent to you by users of the site, or other evidence of effects on student learning.

If possible, I would be interested in talking with you about the design and implementation of your laboratory as well. If you have any of the requested information and/or are available to speak with me, please reply to this email at your earliest convenience. Thank you for your time.

(your name)
(your email address)

APPENDIX D. EMAIL SENT TO PIs OF UNAVAILABLE WEB-BASED LABORATORIES

Dear (contact name),

My name is (your name) and I am working with the National Science Foundation (NSF) on a study of web-based laboratories. We are using the term web-based laboratories to emcompass a wide variety of web-accessible educational resources including, but not limited to, animations, interactive simulations, and remote manipulations of laboratory equipment. The NSF is hoping to obtain a greater understanding of the educational opportunities made available to students through these web-based laboratories.

One year ago a list was compiled of one hundred existing sites that offer access to web-based laboratories and your site, (their site), was among them. The NSF is now interested in the experiences you have had with utilizing this website as an educational tool, particularly with respect to student learning outcomes. I was unable to locate your site at the original address listed and was wondering whether the site was moved or is no longer operational. If the site is still available could you please provide me with its current address. If it is not, I would be interested to know why it is no longer used.

I was wondering if you could provide me with any information you may have obtained in regards to this resource. This information could be in the form of surveys filled out by students, assessment or evaluation studies that you have undertaken, comments or questions sent to you by users of the site, or other evidence of effects on student learning.

If possible, I would be interested in talking with you about the design and implementation of your laboratory as well. If you have any of the requested information and/or are available to speak with me, please reply to this email at your earliest convenience. Thank you for your time.

(your name)
(your email address)

APPENDIX E. TELEPHONE INTERVIEW QUESTIONS

-How is the website incorporated into a classroom curriculum?
    (replacement of hands on labs, compliment/supplement to hands on labs)

-How long have they been using the site?
    Has their been changes over time? And why?

-How did you originally come up with the design decisions?
    Why did you choose these ideas?
        (direction, assessments in lab, etc)

-Have you done any studies on the cost per student?
    Do you think the money, time, and effort put in are worth it?

-How is it working in class?
    What level of class is this used in?
        (beginner level, advanced, etc)
    What level of class was it designed for?
        (beginner level, advanced, etc)
    How many students are usually in each class?

-What measurable students outcomes did you hope to attain?
    What assessment methodologies have you set up?
        (student evaluations, faculty opinions, etc)
    Have you obtained any results?
    Do you have any data on student attrition? Before or after you implemented this?
    Are these better than outcomes before this lab was used?

APPENDIX F. LABORATORY REFERENCES

Laboratory Name	**Principle Investigator**	**Website Address**	**Brief Description**
CMS Histology	Christopher Brandon	www.finchcms.edu/cms/anatomy/histohome	A simulation guide to supplement histology hands-on laboratory
The Virtual Cell Tour	Jim Rusconi	http://personal.tmlp.com/Jimr57/	A simulation of the components of an animal cell
The Reconstructors	Leslie Miller	http://reconstructors.rice.edu/	An interactive game involving health and biology issues
The Exploratory Project	Anne Morgan Spalter	http://www.cs.brown.edu/exploratory/	A collection of applets that can help students in learning about computer graphics
Virtual Sickle Cell Lab	L. Van Warren	http://k14education.uams.edu/SickleCell/virtualLab/pages/Picture01.htm	An interactive simulation on sickle cells
Virtual Geotechnical Laboratory	Jose Emir Macari	http://chem.engr.utc.edu/	An interactive simulation for an earthquake engineering class
Control and Process Dynamics	Jim Henry	http://gozer.cs.wright.edu/classes/ceg499/ceg499.html	An interactive simulation that illustrates simple mechanical processes
Microelectronics Weblab	Jesus del Alamo	http://weblab.mit.edu	A remote manipulation of electronic systems
Physics Interactive Video Tutor	Richard Larson	https://curricula2.mit.edu/	An interactive simulation of introductory physics material
Calculus On the Web	Gerardo Mendoza	http://www.math.temple.edu/~cow	An interactive simulation of calculus materials
Using Animation in Teaching Electromagnetism	John Belcher	http://web.mit.edu/jbelcher/www/anim.html	An interactive simulation of electromagnetic phenomena that illustrates the field lines

APPENDIX G. INTERVIEW REFERENCES

Christopher Brandon

October 25, 2002

Christopher Brandon developed the CMS Histology website, which is currently only available with a password through the Chicago Medical School. This is due to the fact that the entire course is online and there are copyright permission issues. The website is used as a laboratory guide for students when they are completing the hands-on histology laboratory.

James Henry

October 25, 2002

James Henry designed the Control and Process Dynamics Laboratory. He developed this laboratory to completely resemble a controls and processing laboratory. This web-based laboratory is used as a preliminary experience for some students before they complete the hands-on laboratory, but for others, it is their only exposure to the experiment. Schools and universities that were not able to purchase the equipment needed to run this experiment in a hands-on laboratory used the web-based laboratory as a replacement. He felt that this material can be demonstrated just as well on the World Wide Web as in a hands-on laboratory.

Richard Larson

November 5, 2002

Professor Richard Larson of the Massachusetts Institute of Technology developed the Physics Interactive Video Tutor (PIVoT). Larson had no problems obtaining the two million dollars of funding that he desired in order to cover the start-up and maintenance costs for his laboratory. Many institutions over the past six years, including Massachusetts Institute of Technology, Rensselaer Polytechnic Institute, and Wellesley College, have used PIVoT. Larson has not encountered any serious problems with PIVoT. Larson thought he might have a problem with students who lack computer proficiency, however he has not to date encounter any instances of this problem.

Gerardo Mendoza

November 5, 2002

Professor Gerardo Mendoza of Temple University developed Calculus on the Web (COW). In creating this web-based laboratory Mendoza used a modular design in order to have flexibility for modification and to follow the traditional flow of the material. Mendoza had no problems obtaining the approximately four hundred thousand dollars of funding that he desired for start-up and maintenance costs. COW has been used for six years and has not encountered any serious issues. Mendoza encountered a few students early on with lacked proficiency with computers. .

Raman Pfaff

November 5, 2002

Raman Pfaff developed Mouse Genetics as well as many physics web-based laboratories. He uses these in his classes as classroom demonstrations, but also uses them in his office during office hours to help the students understand the concepts more clearly.

James Rusconi

October 31, 2002

Jim Rusconi is the designer of the simulation The Virtual Cell Tour. He had originally hoped to create an interactive game for students to play that would explore the components of an animal cell, but due to the lack of funding, he only received ten thousand dollars, he had to create a this simulation web-based laboratory instead. Since its development in 1996, Rusconi has not encountered any costs problems while updating and maintaining The Virtual Cell Tour. It was only the initial start-up cost of the web-based laboratory that limited Rusconi's development. This laboratory has been used as assignments and class demonstrations.

Anne Spalter

October 30, 2002

Anne Spalter of Brown University is one of the people working on The Exploratory Project. The web-based laboratories that she was commenting on were useful for introductory computer graphics courses. They had been used by a variety of different collages as well as her own. She personally had experience integrating their use into classes. One problem that she had run into was Java not working the same way on every computer or even working the same on one computer. She also said that web-based laboratories would have a hard time dealing with students with computer phobias.

L. Van Warren

November 1, 2002

L. Van Warren is the developer of the Virtual Sickle Cell Laboratory. He originally wanted to make a remote laboratory so that students could run their own gel apparatus and use this as a scientific tool for scientists. However, the necessary funding was not available, so he made a simulation where students type in the information and the experiment is run instead. Unfortunately, due to infrastructure and funding problems at University of Arkansas for Medical Studies the site is no longer available. Warren believes that web-based laboratories cannot replicate the sensory aspects of hands-on laboratories. He feels that web-based laboratories cannot replace hands-on laboratories, but they are good learning guides.

APPENDIX H. STATISTICAL MEASUREMENTS

T-test values were important in establishing the validity of the data in our report. Two statistical measurements are used to determine a *t*-test value. These are the mean and the variance.

A mean gives the value for the center of distribution for a sample (Mendenhall, Beaver, & Beaver, 2003). This is obtained by dividing the sum of the values by the total number of values (Upton & Cook, 2002). There are two types of means that are used in the calculation of a *t*-test value, a sample mean, X_{sample}, and a population mean, X_{pop} (Upton & Cook, 2002; Griffiths & Downes, 1969).

A variance is defined as a measure of variability of a set of data. Variance indicates the dispersion from the mean. The lower the value of the variance, the closer the data tends to be to the mean (Mendenhall, Beaver, & Beaver, 2003). There are two types of variances that are used in the calculation of a *t*-test value, a sample variance, S^2, and a population variance, σ^2 (Upton & Cook, 2002, Griffiths & Downes, 1969).

A *t*-test is a value used to describe the differences between the mean value of a sample and the hypothesized mean value for the population (Upton & Cook, 2002, Mendenhall, Beaver, & Beaver, 2003).

Table H.1: Statistical Formulas

Statistical Measure	**Formula**
Mean	$X = (\Sigma\ x_i)/n$
Variance	$S^2 = (\Sigma\ (X - x_i)^2)/(n - 1)$
t-test	$t = (X_{hyp} - X_{sample})/(\sqrt{((\sigma^2/N) + (S^2/n))})$

Sources: Griffiths & Downes, 1969; Mendenhall et al., 2003; Upton & Cook, 2002

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CURRENT CAPABILITIES AND LIMITATIONS OF WEB-BASED LABORATORIES
And Recommendations for Development

Completed on December 11, 2002

By
David Dunlop
Julie Martin
Matt Morency
Stephanie Morin

CAPABILITIES OF WEB-BASED LABORATORIES

1. **Web-based laboratories can be used by teachers in multiple ways**. Through PI contact, it has been discovered that web-based laboratories can be used in five different ways: recommended site, classroom demonstration, homework or classroom assignment, laboratory guide, and laboratory component.

2. **Web-based laboratories are flexible and can appeal to multiple grade levels**. PIs have found that their web-based laboratories have been used by students of grade levels other than the target grade level that the laboratories were designed for. This means that web-based laboratories are not limited to one audience but are flexible to accommodate students of many ages and learning abilities.

3. **Web-based laboratories are versatile and allow students to determine the pace and depth of their laboratory experience**. Many web-based laboratories have multiple pathways of completion. These pathways give students the ability to choose the direction and depth of their learning experience.

4. **Web-based laboratories are able to assist students in learning the class material**. Studies on measurable student outcomes have shown that students improve their performance on assessments after completing web-based laboratories.

LIMITATIONS OF WEB-BASED LABORATORIES

1. **Web-based laboratories require a large start-up cost**. There is a potentially high initial cost involved in the creation of web-based laboratories. This cost has been seen to sometimes limit the possibilities in their design.

2. **At this time, web-based laboratories are unable to replace many hands-on laboratories**. Many hands-on laboratories rely on the use of the experimenters' senses. Since web-based laboratories cannot address all of the sensory aspects, many hands-on laboratories cannot be effectively replicated on the World Wide Web.

3. **Web-based laboratories require that students have a basic proficiency with computers**. Since web-based laboratories are completed on computers, students must be computer literate in order to perform web-based laboratories efficiently.

RECOMMENDATIONS

1. **Web-based laboratories should be developed for higher level education classes.** For some disciplines, few web-based laboratories are available for undergraduate level classes. More web-based laboratories should be developed for these classes to provide students with an experience that more closely resembles material they are learning in class.

2. **Research should be conducted on the design aspects and usability of web-based laboratories.** Some web-based laboratories assume a certain level of proficiency on computers, but not all students are at the same level. Web-based laboratories should be designed so that the majority of students can use the laboratories, regardless of computer proficiency.

3. **A cost analysis study should be performed comparing web-based laboratories and hands-on laboratories.** Some web-based laboratories have a large start-up cost but a low maintenance cost. It would be beneficial to discern whether the cost of hands-on laboratories over time is greater than the costs of web-based laboratories.

4. **The NSF should encourage studies on measurable students outcomes from web-based laboratory use.** Although the evaluations on measurable student outcomes show that web-based laboratories are effective, there is not much of this

data available. PIs should conduct these evaluations and compare their results to tests of similar hands-on laboratories in order to assess which laboratory is more effective.

5. **A study should be completed on the effects of web-based laboratories with respect to different learning styles, genders, and ethnicities**. Since not all students have the ability to learn in the same way, it would be beneficial to find out whether these variables have an effect on the students' ability to learn from the web-based laboratory.

6. **The database should be updated annually**. An annual update would be beneficial for two reasons. First, the field of web-based laboratories is continually growing, so it is important to be aware of the changes that occur. Second, a list of the web-based laboratories in the database should be available on the NSF website. This would make web-based laboratories more accessible to interested people, within the NSF and outside the organization.

APPENDIX J. THE WEB-BASED LABORATORY TABLE

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
1	Adding Sine Waves	http://www.purchon.com/physics/waves.htm	Mathematics	Nigel D Purchon	Data
2	Applet: Induction	http://lectureonline.cl.msu.edu/~mmp/applist/induct/faraday.htm	Physics	Wolfgang Bauer	Data
3	Calculus On the Web (COW)	http://www.math.temple.edu/~cow	Mathematics	Gerardo Mendoza	Data
4	Cardio Vascular Engineering(CV) Laboratory	http://www.cs.ndsu.nodak.edu/~rvetter/ATM/html/lab_application.html	Engineering	William Perrizo	Data
5	CardioLab	http://biologylab.awlonline.com/protected/CardioLab/index.php	Biology	Robert Desharnais	Data
6	Cells Alive	http://www.cellsalive.com	Biology	James A. Sullivan	Data
7	Chaos Demonstrations	http://www.cmp.caltech.edu/~mcc/chaos_new/Chaos_demos.html	Physics	Michael Cross	Data
8	Chemical Charge Applet	http://www.chipr.sunysb.edu/eserc/ProjectJava/ChemicalChargeApplet/ChemicalChargeApplet.html	Chemistry	Janet L. Kaczmarek	Data
9	CMS Histology	http://www.finchcms.edu/cms/anatomy/histohome	Biology	Christopher Brandon	Data
10	Control, Process Dynamics	http://chem.engr.utc.edu/	Engineering	Jim Henry	Data
11	CyclePad	http://www.qrg.nwu.edu/projects/NSF/Cyclepad/cyclepad.htm	Engineering	Kenneth D. Forbus	Data
12	Delaunay triangulation	http://cage.rug.ac.be/~dc/alhtml/Delaunay.html	Mathematics	Denis Constales	Data
13	DemographyLab	http://biologylab.awlonline.com/protected/DemographyLab/index.php	Biology	Robert Desharnais	Data
14	Derivative Definition	http://www.csulb.edu/~wziemer/TangentLine/TangentLine.html	Mathematics	Bill Ziemer	Data

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
15	Device Simulation Laboratory	http://jas2.eng.buffalo.edu/	Engineering	C.R. Wie	Data
16	Energy and Environment	http://www.jersey.uoregon.edu/vlab/index.html	Other	Greg Bothun	Data
17	EnzymeLab	http://biologylab.awlonline.com/protected/EnzymeLab/index.php	Biology	Robert Desharnais	Data
18	EvolutionLab	http://biologylab.awlonline.com/protected/EvolutionLab/index.php	Biology	Robert Desharnais	Data
19	FlyLab	http://biologylab.awlonline.com/protected/FlyLab/index.php	Biology	Robert Desharnais	Data
20	GeoAstro Applet Collection	http://www.jgiesen.de/GeoAstro/GeoAstro.htm	Other	Juergen Giesen	Data
21	Geology Explorer	http://oit.cs.ndsu.nodak.edu/menu/home.ns.htm	Other	Dr. Brian M. Slator	Data
22	Haynes-Shockley Experiment	http://www.acsu.buffalo.edu/~wie/applet/diffusion/diffusion.html	Physics	C.R. Wie	Data
23	Haystack Observatory	http://fourier.haystack.mit.edu/urei/index.html	Other	Preethi Pratap	Data
24	HemoglobinLab	http://biologylab.awlonline.com/protected/HemoglobinLab/index.php	Biology	Robert Desharnais	Data
25	Ideal Flow Machine	http://www.aoe.vt.edu/aoe5104/ifm/ifm.html	Physics	William J. Devenport	Data
26	Intermol 3D-Molecular water simulation	http://cps-www.bu.edu/vmdl/Software/index.html	Chemistry	H. Eugene Stanley	Data
27	Internet Psychology Lab	http://kahuna.psych.uiuc.edu/ipl/	Other	Gary Bradshaw	Data
28	Java Applets on Astronomy	http://home.a-city.de/walter.fendt/ae/ae.htm	Physics	Walter Fendt	Data
29	Java Applets on Mathematics	http://home.a-city.de/walter.fendt/me/me.htm	Mathematics	Walter Fendt	Data
30	Java Applets on	http://home.a-city.de/walter.fendt/phe/phe.htm	Physics	Walter	Data

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
	Physics			Fendt	
31	LeafLab	http://biologylab.awlonline.com/protected/LeafLab/index.php	Biology	Robert Desharnais	Data
32	Lines: A Game of Strategy	http://www.chipr.sunysb.edu/eserc/ProjectJava/Lines/index.html	Mathematics	Glenn A. Richard	Data
33	Math, Science, Technology Education	http://www.mste.uiuc.edu/java/	Other	Barney Dalton	Data
34	Mathematics and Art Applets	http://phoenix.liunet.edu/~aburns/webpage/aburns.htm	Other	Anne M. Burns	Data
35	Mathematics Applets	http://thorin.adnc.com/~topquark/math/mathapplets.html	Mathematics	Mark Sutherland	Data
36	Microelectronics Weblab	http://weblab.mit.edu	Engineering	Jesus A. del Alamo	Data
37	MicroScape Virtual Microscope Laboratory	http://www.msa.microscopy.com/MicroScape/MicroScapeVL.html	Biology	Nestor Zaluzec	Data
38	MitochondriaLab	http://biologylab.awlonline.com/protected/MitochondriaLab/index.php	Biology	Robert Desharnais	Data
39	Molecular Structure Center	http://www.iumsc.indiana.edu/	Chemistry	John C. Huffman	Data
40	Moon Phases	http://www.astro.wisc.edu/~dolan/java/MoonPhase.html	Other	Chris Dolan	Data
41	Mouse Genetics	http://webphysics.ph.msstate.edu/javamirror/explrsci/dswmedia/mouse.htm	Biology	Raman Pfaff	Data
42	NTNU Virtual Physics Laboratory	http://www.phy.ntnu.edu.tw/java/index.html	Physics	Fu-Kwun Hwang	Data
43	Online Experiments in Bio, Chem, and Psych	http://escience.bethelks.edu	Biology	Dwight Krehbiel	Data
44	Painless-Pain Management Simulation	http://www.cdl.edu/Painless	Other	Mary Jo Gorney-Moreno	Data
45	Pea Experiment	http://www.sonic.net/%7Enbs/projects/anthro201/exper/	Biology	Bill Kendrick	Data
46	PedigreeLab	http://biologylab.awlonline.com/protected/PedigreeLab/index.php	Biology	Robert	Data

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
				Desharnais	
47	Physics Applets	http://www.jersey.uoregon.edu/vlab/index.html	Physics	Greg Bothun	Data
48	PIVOT	https://curricula2.mit.edu/	Physics	Richard Larson	Data
49	Pollutant in a Pond System	http://www.chipr.sunysb.edu/eserc/ProjectJava/Lake/index.html	Engineering	Glenn A. Richard	Data
50	PopulationGeneticsLab	http://biologylab.awlonline.com/protected/PopGenLab/index.php	Biology	Robert Desharnais	Data
51	Process Dynamics and Controls	http://www.eng.ua.edu/~checlass/Controls/	Engineering	Duane Johnson	Data
52	Project Links	http://links.math.rpi.edu/	Mathematics	Mark Holmes	Data
53	Reaction time and car accident	http://www.phy.ntnu.edu.tw/~hwang/indexPopup.html	Physics	Fu-Kwun Hwang	Data
54	Real-Time Mechatronics/Process Control Laboratory	http://mechanical.poly.edu/faculty/vkapila/ControlLab.htm	Engineering	Anthony Tzes	Data
55	Reinmann Sum	http://www.csulb.edu/~wziemer/Riemann/Riemann.html	Mathematics	Bill Ziemer	Data
56	Remote Dynamical Systems Laboratory	http://dynamics.soe.stevens-tech.edu/	Engineering	Sven K Esche	Data
57	Rice Virtual Lab in Statistics	http://www.ruf.rice.edu/~lane/rvls.html	Mathematics	David Lane	Data
58	Saturn's Rings	http://www.astrophysik.uni-kiel.de/pershome/supas086/body/SaturnRing.html	Other	J Koppen	Data
59	Science, Tobacco & You	http://scienceu.fsu.edu/content/virtuallab/index.html	Other	Patricia Dixon	Data
60	Simple Molecular Dynamics (SMD)	http://cps-www.bu.edu/vmdl/Software/index.html	Chemistry	H. Eugene Stanley	Data
61	Soil Water Budget	http://www.chipr.sunysb.edu/eserc/ProjectJava/SoilMoisture/index.html	Chemistry	Glenn A. Richard	Data

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
62	Solar System	http://www.humnet.ucla.edu/humnet/french/faculty/gans/java/SolarApplet.html	Other	Eric Gans	Data
63	Solubility	http://michele.usc.edu/classpages/chem105b/resources/aqueous_equilibria/solub.html	Chemistry	Bruno Herreros	Data
64	Telerobot	http://telerobot.mech.uwa.edu.au	Engineering	Barney Dalton	Data
65	The Exploratory Project	http://www.cs.brown.edu/exploratory/	Other	Anne Morgan Spalter	Data
66	The Gene Machine	http://www.sonic.net/%7Enbs/projects/bio115l/	Biology	Bill Kendrick	Data
67	The Grid Blaster Game	http://www.chipr.sunysb.edu/eserc/ProjectJava/GridBlaster/index.html	Other	Glenn A. Richard	Data
68	The IrYdium Project--Virtual Chemistry Laboratory	http://ir.chem.cmu.edu/irproject/applets/virtuallab	Chemistry	David Yaron	Data
69	The Java Virtual Wind Tunnel	http://raphael.mit.edu/Java/	Physics	David Oh	Data
70	The Michigan Aero Instructional Software Project	http://www.engin.umich.edu/dept/aero/java/PotFlow/	Engineering	Kenneth Powell	Data
71	The Pendulum Lab	http://monet.physik.unibas.ch/~elmer/pendulum/spend.htm	Physics	Franz-Josef Elmer	Data
72	The Reconstructors	http://reconstructors.rice.edu/	Biology	Leslie Miller	Data
73	The Virtual Biochemistry Laboratory	http://www.nobel.se/chemistry/educational/vbl/index.html	Other	Nils Ringertz	Data
74	The Virtual Cell Tour	http://personal.tmlp.com/Jimr57/	Biology	Jim Rusconi	Data
75	The Virtual Lab: Engineering the Future	http://www.ece.cmu.edu/~stancil/virtual-lab/virtual-lab.html	Engineering	Daniel D. Stancil	Data
76	The Virtual Microscope	http://www.purchon.com/biology/palisade.htm	Biology	Nigel D Purchon	Data

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
77	TranslationLab	http://biologylab.awlonline.com/protected/TranslationLab/index.php	Biology	Robert Desharnais	Data
78	Universal Molecular Dynamics	http://cps-www.bu.edu/vmdl/Software/index.html	Chemistry	H. Eugene Stanley	Data
79	Useful Applets for Introductory Astronomy	http://astronomy.colgate.edu/astronomy/instructional/applets.html	Other	Thomas Balonek	Data
80	Using Animation in Teaching Electromagnetism	http://web.mit.edu/jbelcher/www/anim.html	Physics	John Belcher	Data
81	Virtual Chemistry	http://www.chem.ox.ac.uk/vrchemistry/labintro/newdefault.html	Chemistry	Karl Harrison	Data
82	Virtual Dating	http://vcourseware5.calstatela.edu/VirtualDating/	Engineering	Gary A. Novak	Data
83	Virtual Dissection	http://www-itg.lbl.gov/cgi-bin/tutor_script	Biology	David Robertson	Data
84	Virtual Earthquake	http://vcourseware5.calstatela.edu/VirtualEarthquake/VQuakeIntro.html	Engineering	Gary A. Novak	Data
85	Virtual Experiments	http://www.uni-konstanz.de/FuF/Physik/FP/vlab.htm	Physics	Martin Stachel	Data
86	Virtual Frog Dissection Kit	http://www-itg.lbl.gov/vfrog	Biology	David Robertson	Data
87	Virtual Geotechnical Laboratory	http://www.ce.lsu.edu/~macari/virtual.html	Engineering	Emir Jose Macari	Data
88	Cardiovascular and Autonomic Pharmacology	http://courses.washington.edu/chat543/cvans/	Biology	Frank Vincenzi	Data
89	Virtual Laboratories in Probability and Statistics	http://www.math.uah.edu/stat/	Mathematics	Kyle Siegrist	Data
90	Virtual Laboratory	http://www.jhu.edu/~virtlab/virtlab.html	Engineering	Michael Karweit	Data

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
91	Virtual Laboratory	http://www.jhu.edu/~virtlab/virtlab.html	Engineering	Michael Karweit	Data
92	Virtual Laboratory for Earthquake Engineering	http://www.nd.edu/~quake/java/	Engineering	Prof. B.F. Spencer, Jr.	Data
93	Virtual Laboratory for the Study of Mechanics	http://www.ae.msstate.edu/vlsm/	Engineering	Masoud Rais-Rohani	Data
94	Virtual laboratory:Starch test	http://www.purchon.com/biology/food.htm	Biology	Nigel D Purchon	Data
95	Virtual River	http://vcourseware5.calstatela.edu/VirtualRiver/index.html	Other	Gary A. Novak	Data
96	Virtual Sickle Cell Lab	http://k14education.uams.edu/SickleCell/virtualLab/pages/Picture01.htm	Biology	L. Van Warren	Data
97	Visible Human Viewer	http://www.dhpc.adelaide.edu.au/projects/vishuman2/	Biology	Paul Coddington	Data
98	Visible Human Project	http://www.nlm.nih.gov/research/visible/visible_human.html	Biology	Rick Banvard	Data
99	WebShaker	http://webshaker.ucsd.edu/index.html	Engineering	Ahmed Elgamal	Data
100	WWW Autonomous Robotics	http://gozer.cs.wright.edu/classes/ceg499/ceg499.html	Engineering	John Gallagher	Data
103	Fixed Point Iteration Java Applet	http://www.csulb.edu/%7Ewziemer/FixedPoint/FixedPoint.html	Mathematics	Bill Ziemer	Data
104	Surface Plotter	http://zzzthai.fedu.uec.ac.jp/%7Eyanto/java/surface/	Mathematics	Yanto Suryono	Data
105	Webwork	http://www.csulb.edu/~wziemer/	Mathematics	Bill Ziemer	Data
106	Java Applets for Engineering Education	http://www.engapplets.vt.edu/	Engineering	William J. Devenport	Data
107	ExploreScience	http://www.explorescience.com/	Physics	Explore Learning	Data

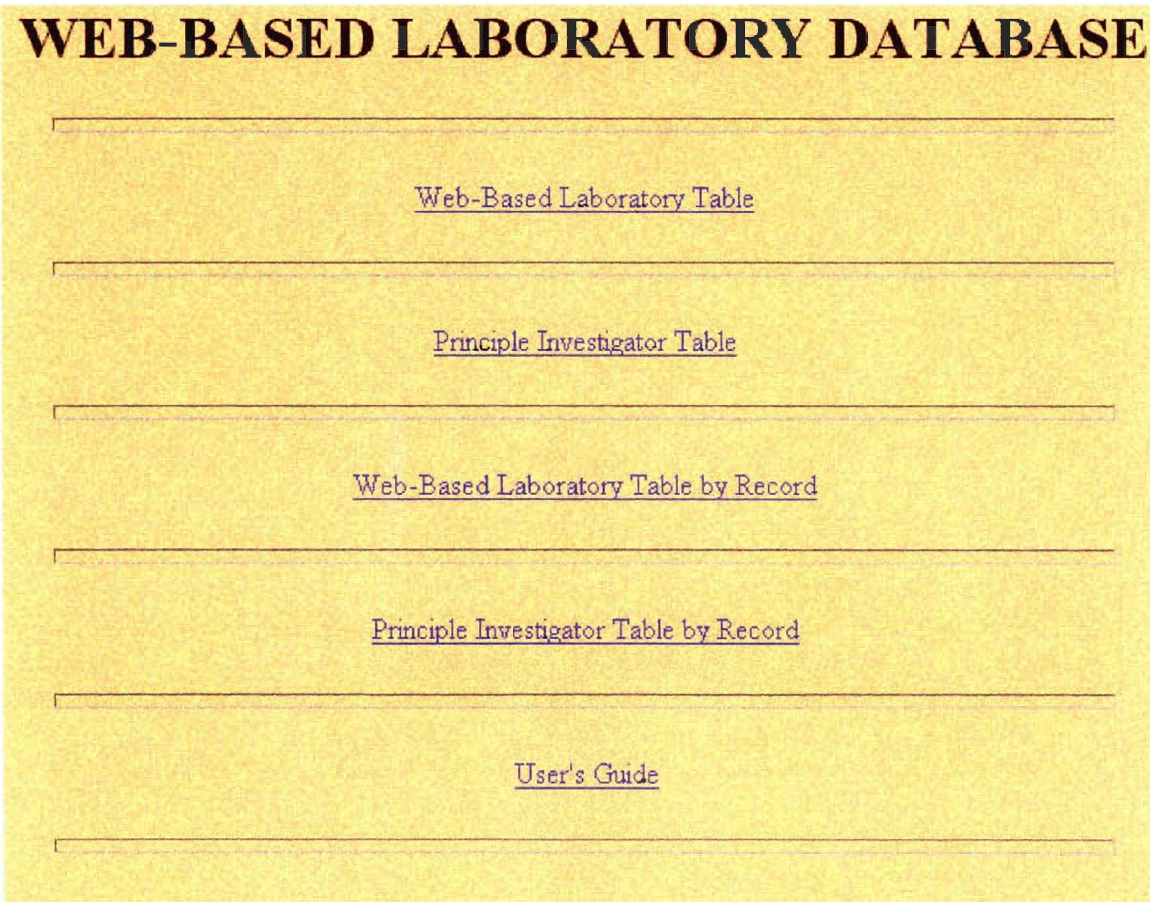
ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
				Staff	
108	ExploreMath	http://www.exploremath.com/	Mathematics	Explore Learning Staff	Data
109	Easy Java Simulation	http://fem.um.es/Ejs/	Physics	Francisco Esquembre	Data
110	Physlets	http://webphysics.davidson.edu/Applets/Applets.html	Physics	Wolfgang Christian	Data
111	Virtual Physics Demos	http://ablation.magnet.fsu.edu/stampe/links2048.htm	Physics	Patricia Stampe	Data
112	Delights of Chemistry	http://www.chem.leeds.ac.uk/delights/	Chemistry	Mike Hoyland	Data
113	Virtual Pig Dissection	http://www.whitman.edu/biology/vpd/main.html	Biology	Earl W. Fleck	Data
114	Animation Tutor for Math	http://www.sci.sdsu.edu/mathtutor/	Mathematics	Steve Reed	Data
115	WELCOME	http://www.math.metrostate.edu/welcome/	Mathematics	James White	Data
116	ChemLab	http://www.dartmouth.edu/~chemlab/index.html	Chemistry	Sally Hair	Data
117	Ms. Lindquist	http://www.algebratutor.org/	Mathematics	Neil Heffernan	Data
118	Internet Psychology Lab	http://www.ipsych.com/	Other	Gary Bradshaw	Data

APPENDIX K. USER'S GUIDE

User's Guide for the Web Interface for the Web-based Laboratory Database

The following is a user's guide for the web interface for the web-based laboratory database. The web interface allows users to view and modify the database using a web browser on their personal computer.

FRONT PAGE



This is the front page to the web interface for the web-based laboratory database. This page provides links to the five components of the web interface, which are from top to bottom: Web-Based Laboratory Table, Principle Investigator Table, Web-Based Laboratory Table by Record, Principle Investigator Table by Record, and User's Guide.

WEB-BASED LABORATORY TABLE

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
1	Adding Sine Waves	http://www.purchon.com/physics/waves.htm	Mathematics	Nigel D Purchon	Data
2	Applet: Induction	http://lectureonline.cl.msu.edu/~mmp/applist/induct/faraday.htm	Physics	Wolfgang Bauer	Data
3	Calculus On the Web (COW)	http://www.math.temple.edu/~cow	Mathematics	Gerardo Mendoza	Data
4	Cardio Vascular Engineering(CV) Laboratory	http://www.cs.ndsu.nodak.edu/~rvetter/ATM/html/lab_application.html	Engineering	William Perrizo	Data
5	CardioLab	http://biologylab.awlonline.com/protected/CardioLab/index.php	Biology	Robert Desharnais	Data
6	Cells Alive	http://www.cellsalive.com	Biology	James A. Sullivan	Data
7	Chaos Demonstrations	http://www.cmp.caltech.edu/~mcc/chaos_new/Chaos_demos.html	Physics	Michael Cross	Data
8	Chemical Charge Applet	http://www.chipr.sunysb.edu/eserc/ProjectJava/ChemicalChargeApplet/ChemicalChargeApplet.html	Chemistry	Janet L. Kaczmarek	Data
9	CMS Histology	http://www.finchcms.edu/cms/anatomy/histohome	Biology	Christopher Brandon	Data
10	Control, Process Dynamics	http://chem.engr.utc.edu/	Engineering	Jim Henry	Data
11	CyclePad	http://www.qrg.nwu.edu/projects/NSF/Cyclepad/cyclepad.htm	Engineering	Kenneth D. Forbus	Data
12	Delaunay triangulation	http://cage.rug.ac.be/~dc/alhtml/Delaunay.html	Mathematics	Denis Constales	Data
13	DemographyLab	http://biologylab.awlonline.com/protected/DemographyLab/index.php	Biology	Robert Desharnais	Data
14	Derivative Definition	http://www.csulb.edu/~wziemer/TangentLine/TangentLine.html	Mathematics	Bill Ziemer	Data
15	Device Simulation Laboratory	http://jas2.eng.buffalo.edu/	Engineering	C.R. Wie	Data
16	Energy and Environment	http://www.jersey.uoregon.edu/vlab/index.html	Other	Greg Bothun	Data
17	EnzymeLab	http://biologylab.awlonline.com/protected/EnzymeLab/index.php	Biology	Robert Desharnais	Data
18	EvolutionLab	http://biologylab.awlonline.com/protected/EvolutionLab/index.php	Biology	Robert Desharnais	Data
19	FlyLab	http://biologylab.awlonline.com/protected/FlyLab/index.php	Biology	Robert Desharnais	Data
20	GeoAstro Applet Collection	http://www.jgiesen.de/GeoAstro/GeoAstro.htm	Other	Juergen Giesen	Data
21	Geology Explorer	http://oit.cs.ndsu.nodak.edu/menu/home.ns.htm	Other	Dr. Brian M. Slator	Data
22	Haynes-Shockley Experiment	http://www.acsu.buffalo.edu/~wie/applet/diffusion/diffusion.html	Physics	C.R. Wie	Data
23	Haystack Observatory	http://fourier.haystack.mit.edu/urei/index.html	Other	Preethi Pratap	Data
24	HemoglobinLab	http://biologylab.awlonline.com/protected/HemoglobinLab/index.php	Biology	Robert Desharnais	Data
25	Ideal Flow Machine	http://www.aoe.vt.edu/aoe5104/ifm/ifm.html	Physics	William J. Devenport	Data
26	Intermol 3D-Molecular water simulation	http://cps-www.bu.edu/vmdl/Software/index.html	Chemistry	H. Eugene Stanley	Data
27	Internet Psychology Lab	http://kahuna.psych.uiuc.edu/ipl/	Other	Gary Bradshaw	Data

The Web-Based Laboratory Table lists the information on each laboratory organized by ID number. Each row, also called a record, represents a web-based laboratory.

Sample Record

ID	Laboratory Name	URL	Discipline	Principle Investigator	Information
1	Adding Sine Waves	http://www.purchon.com/physics/waves.htm	Mathematics	Nigel D Purchon	Data

Each record has six fields, which are from left to right: ID, Laboratory Name, URL, Discipline, Principle Investigator, and Information. "ID" provides a unique identification number for the record, which is necessary for database integrity. "Laboratory Name" provides the name of the web-based laboratory. "URL" provides the address of the web-based laboratory. This field is also a hyperlink so it can be clicked on to go directly to the web-based laboratory. "Discipline" indicates what discipline the laboratory deals with. Each laboratory is classified by one of six disciplines: Biology, chemistry, engineering, mathematics, physics, and other. "Principle Investigator" provides the name of the principle investigator. To obtain contact information for a principle investigator go to the Principle Investigator Table. "Information" provides a hyperlink to a directory that contains all the information that has been collected on the web-based laboratory and includes a brief description.

PRINCIPLE INVESTIGATOR TABLE

Principle Investigator Name	Principle Investigator Phone	Principle Investigator E-mail
Ahmed Elgamal	(858) 822-1075	elgamal@ucsd.edu
Anne M. Burns		aburns@liu.edu
Anne Morgan Spalter	(401) 863-7615	ams@cs.brown.edu
Anthony Tzes		tzes@poly.edu
Barney Dalton		bfs@uiuc.edu
Bill Kendrick		bill@newbreedsoftware.com
Bill Ziemer	(562) 985-5399	wziemer@csulb.edu
Bruno Herreros		herreros@chem1.usc.edu
C.R. Wie		wie@acsu.buffalo.edu
Chris Dolan		dolan@astro.wisc.edu
Christopher Brandon	(847) 578-3286	brandocj@finchcms.edu
Daniel D. Stancil		stancil@gauss.ece.cmu.edu
David Lane	(713) 348-3412	lane@rice.edu
David Oh		bamf@engineer.com
David Robertson		dwrobertson@lbl.gov
David Yaron	(412) 268-1351	project@ir.chem.cmu.edu
Denis Constales		dcons@world.std.com
Dr. Brian M. Slator	(701) 231-6124	slator@cs.ndsu.edu
Duane Johnson		djohnson@coe.eng.ua.edu
Dwight Krehbiel		krehbiel@bethelks.edu

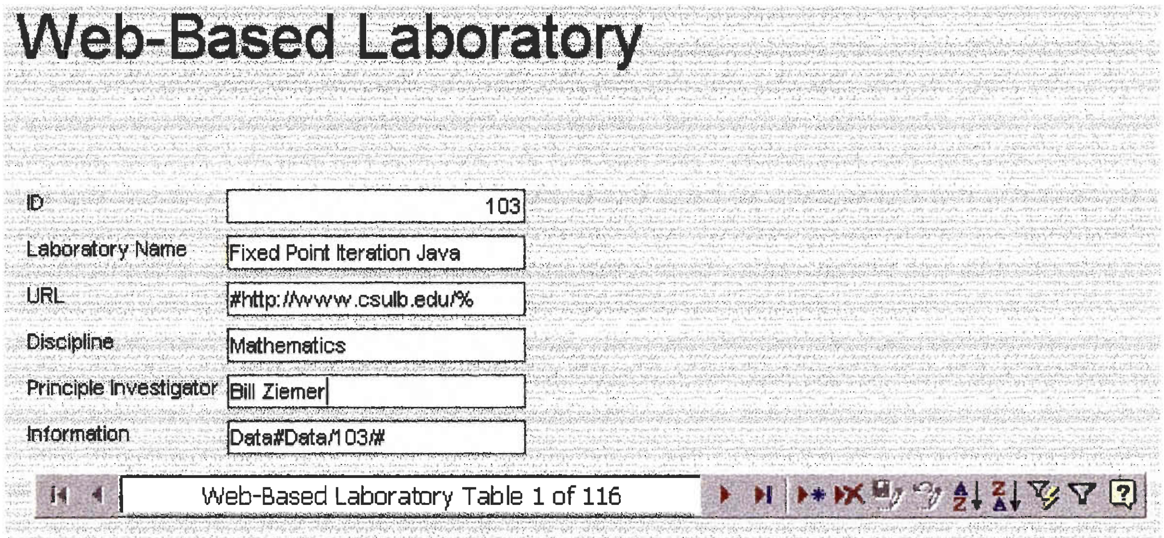
The Principle Investigator Table lists the information on the principle investigators of each web-based laboratory. Each row, also called a record, provides information on a principle investigator.

Sample Record

Principle Investigator Name	Principle Investigator Phone	Principle Investigator E-mail
Ahmed Elgamal	(858) 822-1075	elgamal@ucsd.edu

Each record provides three fields, which are from left to right: Principle Investigator Name, Principle Investigator Phone, and Principle Investigator E-mail. "Principle Investigator Name" provides the name of the principle investigator. "Principle Investigator Phone" provides the telephone number for the principle investigator. "Principle Investigator E-mail" provides the e-mail address for the principle investigator.

WEB-BASED LABORATORY TABLE BY RECORD

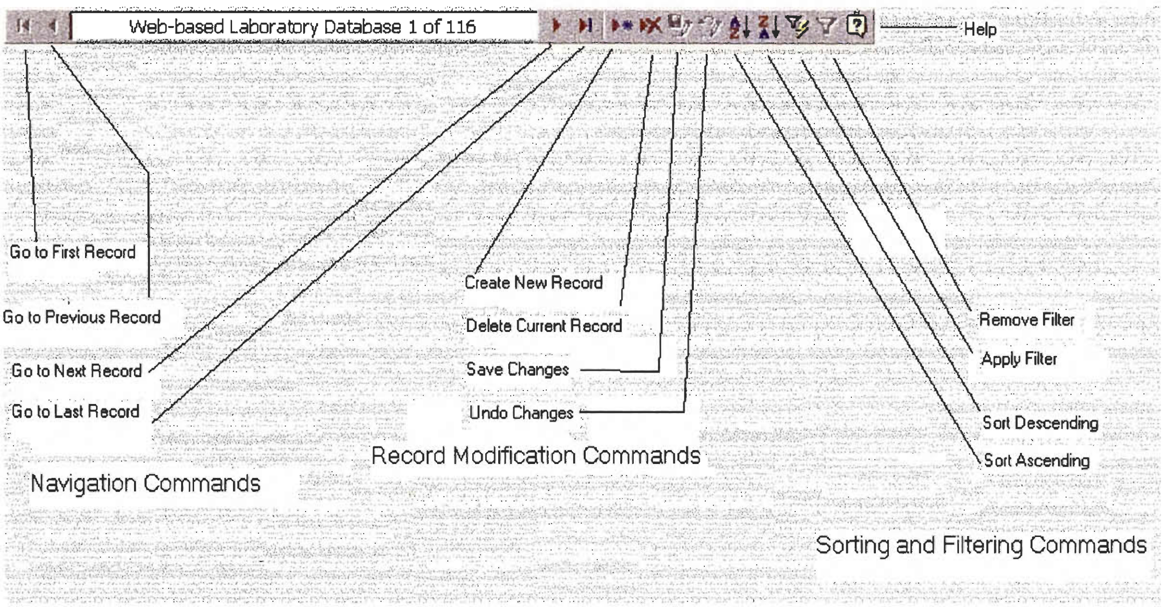


Web-Based Laboratory Table by Record provides an interface to the Web-Based Laboratory Table. This interface allows users to navigate through records, add and delete records, and filter and sort records. This interface is explained in the Control Bar section of the User's Guide.

PRINCIPLE INVESTIGATOR TABLE BY RECORD

Principle Investigator Table by Record provides an interface to the Principle Investigator Table. This interface allows users to navigate through records, add and delete records, and filter and sort records. This interface is explained in the Control Bar section of the User's Guide.

CONTROL BAR



The Control Bar is used in both the Web-Based Laboratory Table by Record and the Principle Investigator Table by Record. There are thirteen commands on the Control Bar. There are four navigation commands, which are used to navigate through the records: Go to First Record, Go to Previous Record, Go to Next Record, and Go to Last Record. There are four record modification commands, which are used to modify, delete, and create records: Create New Record, Delete Current Record, Save Changes, and Undo Changes. There are four sorting and filtering commands, which are used to sort and filter records: Sort Ascending, Sort Descending, Apply Filter, and Remove Filter. The thirteenth command is Help.

Navigation Commands:

<u>Go to First Record</u> - This command takes the user to the first record in the current order. It is grayed out and cannot be used when the current record is the first record.

<u>Go to Previous Record</u> – This command takes the user to the previous record in the current order. It is grayed out and cannot be used when the current record is the first record.

<u>Go to Next Record</u> – This command takes the user to the next record in the current order. It is grayed out and cannot be used when the current record is the last record.

<u>Go to Last Record</u> – This command takes the user to the last record in the current order. It is grayed out and cannot be used when the current record is the last record.

Record Modification Commands:

Create New Record – This command allows the user to create a new record in the database. Initially all fields in the new record that are not automatically created or have default values are blank. When a user creates a new record all required fields must be filled in, in order for the record to be saved.

Delete Current Record – This command deletes the current record from the database. Before this command is executed the user is prompted to check that they want to delete the record. When a record is deleted it cannot be recovered through the use of the Undo Changes command.

Save Changes – This command saves the changes that the user has made to the database. Changes that are made using the interface with the exception of deletion commands are not saved to the database until this command is used. When there are no unsaved changes this command is grayed out.

Undo Changes – This command undoes the most recent change, with the exception of record deletions. If no changes have been made it is grayed out.

Sorting and Filtering Commands:

Sort Ascending – This command sorts the records in ascending order based on the value in the selected field. For example, if the user is using the Web-Based Laboratory Table by Record and has "Laboratory Name" as the selected field, then the records will be sorted in ascending order by laboratory name.

Sort Descending – This command sorts the records in descending order based on the value in the selected field. For example, if the user is using the Web-Based Laboratory Table by Record and has "Laboratory Name" as the selected field, then the records will be sorted in descending order by laboratory name.

Apply Filter – This command applies a filter to the records based on the value in the selected field. The filter makes only the records that have the selected field value stay in the record order. For example, if the user is using the Web-Based Laboratory Table by Record and has "Discipline" as the selected field with the value of mathematics, then only the records that have a field value of mathematics will remain available for viewing.

Remove Filter – This command removes all filters from the records. It is grayed out if there are no filters currently applied to the records.

Other Commands:

Help – This command provides Microsoft Access Web Page Help.

USER'S GUIDE

The user's guide link provides an online version of this user's guide. However, the online version contains hyperlinks to another section when a section references it. For example, when the Web-Based Laboratory Table by Record section refers to the Control Bar, a link to the Control Bar section is provided.