AC 2009-989: THE ROLE OF VIRTUAL LABORATORY TECHNOLOGIES IN TECHNOLOGY EDUCATION

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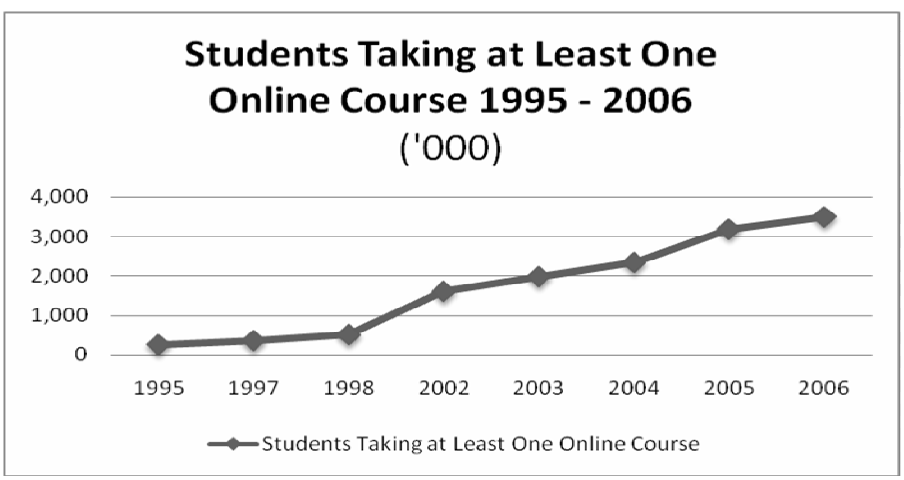
What are the effects of virtual laboratory technologies in education?

Abstract

The rapid growth of the internet and digital technology has provided educators and researchers new avenues to be explored in the Virtual world. This article examines the recent developments in Virtual Laboratories as an alternative to the traditional physical laboratories. This literature review considers the various definitions used to describe the Virtual Laboratory and how these definitions effect there implementation both in research and from a pedagogical perspective. It will also consider the various methods used to deliver VL and how these methods have evolved as these new technologies become available to educators and researchers. The article will further examine the latest technologies that have not been researched to any great extent and provide insights into the possibilities these newest technologies can provide. The review will conclude with possible avenues for future research.

Introduction

The use of distance learning (DL) as a means of educational delivery has become more and more prevalent with today's educational institutions. The increase in DL is exemplified in the reporting "that about 1.9 million students were studying online in the U.S. in the fall of 2003" [1]. It has also been reported that the increase is not restricted to the U.S. as DL is providing a more important part of educational delivery in such countries as UK, South Africa, and China. These increases have challenged educators and researchers to develop Virtual Laboratories to emulate the traditional laboratory and incorporate them into the virtual world of DL. This explosion in DL and the subsequent growth of Virtual Laboratories (VL) is "made possible by the development of the internet" [1].



[2], [3]

The incorporation of new technologies in virtual laboratories can be viewed as an intricate set of components. These sets of components are a combination of software and hardware incorporating various aspects of these technologies. The development of new technologies as they relate to computers both software and hardware have effected the growth of VL and the progress in new technologies in other mediums has affected the delivery methods available. S. Kerr noted “there is good evidence that using technology can effectively help students learn” [4]. The current research as stated by D’Angelo and Wooley “focuses on four broad areas - distance education, discipline specific studies, faculty perceptions, and specific technology tools” [5]. This article will look within these areas at the research that examines the introduction and affects of these new technologies in combination with their impact on students, teachers, researchers, and the curriculum.

Virtual Laboratories have taken on many forms and delivery methods over the years. The internet is the new medium of choice for (VL) delivery but the introduction of new technologies has provided educators many avenues to creatively develop content and teaching methods. Along with the various methods of delivery and forms, the VL has been defined in many ways. The balance of this article is divided into the following sections. The second section describes the methodology of the literature review. Section three provides a brief perspective of VL and their implementation outside academia. Section four examines case studies of the implementation and design of VL technology in education and section five details virtual laboratories and the integration into virtual worlds. The sixth section offers results and discussion on the literature review and the final section is devoted to the conclusions drawn from the review.

Research method

This study researched the impact of new technology on virtual laboratory education to determine the results of such new technologies on education. An empirical approach to the research was undertaken to examine the current research literature on the topic. The integration of new technology on VL has been growing exponentially as these new technologies have been introduced. The research was designed to help identify the issues and solutions research has investigated to make the integration as uniform as possible and to provide the best pedagogical practices to this integration into education both within the traditional classroom and DL.

One of the main focuses of this research was to generate a sound and robust reference list to establish credibility to the research. The articles were individually evaluated and subjected to a validity analysis composed of the following criteria (a) the credibility of the author(s) and institution(s) where the research was performed along with a robustness and methodology that conforms to best practices, (b) whether the publisher of the article employs the peer review process, (c) timeliness of the article, and (d) the diversity of the subject matter to current academic research was a major concern as well.

VL in Research

Virtual Laboratories have been described in many ways and their implementation have been characterized by Budhu as “Web-based laboratories, also known as virtual laboratories, or simply virtual labs, or cyberlabs, have become complementary and, in some cases, alternatives to physical labs” [6]. The VL definition to researchers is more general as “to interact with colleagues, access instrumentation, share data and computational resource, and access information in digital libraries” [7]. This allows researchers to share information and data mine these resources to further their own and others research. It also allows the sharing of resources other than data and attracts research & development funding through collaboration. These types of VL are not without restrictions, there are guidelines that each individual or organization that is participating in the VL must abide by and specific elements are identified for the enforcement of these guidelines.

The government and private industry have been heavily involved in the implementation and use of VL. The Human Genome Project (HGP) has been employing this technology since 1988 when the U.S. Congress appropriated funds to the Department of Energy (DOE) and the National Institutes of Health (NIH) thus establishing the HGP. The official start of the project was in October of 1990 and was funded with an anticipated cost of $ 3 billion. The concept behind the project as reported by Collins (1999) in his article “Medical and societal consequences of the human genome project” is for researchers

> To submit their data to free, public data bases within one day after verification, any scientist, whether based at a university, a corporation, or a government laboratory, can log on by computer and have full and rapid access to the sequence data [8].

This provided researchers and laboratories open access for data mining the central repository of the HGP thus providing the rapid expansion of the common knowledge in genome research.

The Science & Technology Collaborium is another example of the implementation of VL in research efforts. In this case the Collaborium [9] is designed to provide open source technology to communicate knowledge among research centers, private corporations, governments and universities in underdeveloped countries. This will than provide these countries with the ability to achieve a level of competitiveness economically as well as scientific development. This VL approach is designed using open source technology with the expressed desire to reach out to remote areas where internet services are sporadic, expensive or non-existent by providing many of these technologies to overcome these handicaps free of charge.

The use of VL in research has provided scientist and researchers the opportunities to reach out globally. In underdeveloped regions, the incorporation of VL helps reduce the isolation that many researchers and scientists in these areas have traditionally been accustomed to. It allows for the increase in the scale and size of research in multiple fields while providing the sharing of assets and ideas thus facilitating the ability to do research.

VL in Education

The Virtual Laboratory has gained acceptance as an "alternative to physical labs when such labs are unavailable because of lack of space or funds or equipment malfunction" [6], along with the lack of physical proximity to the physical lab. The growth of distance learning has fueled the growth in VL and research into the design and effectiveness of these VL in education. The definition of the virtual lab encompasses a full range of products and services. Couture describes this spectrum as "simple simulations of phenomena …, to network-based systems allowing remote access to data or actual set-ups and full fledged learning environments including simulated experiments, tools, and learning resources" [9]. This very dichotomy in definition has created a virtual argument on what really is a virtual lab.

The following case studies demonstrate the degree of complexity and capacities of VL and how various institutions have achieved their goals with specific implementations. The case studies proceed from the very simplistic to a full fledged learning environment. The first two VL environments were custom simulations providing varying degrees of realism and custom GUIs. The remaining case studies were designed with the objective of using commercially available

GUIs.

The "Sniffing out efficacy: Sniffy Lite, a virtual animal lab" [10] exemplifies the simplistic view of a VL and the results of its effectiveness in animal behavior education. Sandy Venneman and Laura Knowles report of the results of their research in attempting to reverse the decline in performance by their students. The lack of funding for animal research prompted the authors to "examine the possibility of using a virtual laboratory to address this performance decline" [10]. The VL of choice was the "Sniffy Lite" [11] which simulates basic conditioning processes of animals similar to that which is done with live animals. The advantages of this simple VL were the inexpensive price and that it could be installed on the students' computers.

The research involved six sections of students over two semesters. The first two sections were designated the experimental group which did the tutorials from Sniffy Lite. The next two sections did equivalent amount of extra work in terms of hours as the tutorials required for the Sniffy Lite. This involved reviewing animal schedules of reinforcement. The third group had no additional intervention added to the course work. The results were based on scores on exams for the six sections of students. The first exam was administered prior to the Sniffy Lite deployment and the second exam was given after the intervention of the VL. The students were also polled on the use of the Sniffy Lite to get their impressions of the VL. Other than the additional cost of the software, the students that expressed a positive opinion identified the real life emulation of the VL, the enjoyment in using the software, and the increased understanding of the subject matter.

The results of the research indicated that the experimental group, those that used the Sniffy Lite VL, prior to the introduction of the VL did the same as the other two groups on exam one. After the introduction of the VL software, the experimental group outperformed the other two groups by a full letter grade on the second exam. The authors concluded that the implementation of the virtual lab, in this case Sniffy Lite, was an effective learning tool. The particular learning objective of animal reinforcement was more clearly understood by the students with this implementation of a VL application.

A more complex simulated VL was described and researched by Couture in the research article "Realism in the design process and credibility of a simulation-based virtual laboratory" [09]. The design parameters of the virtual physics lab (VPLab) was for it to be enjoyable and instinctive with an interface that was interactive providing the students the ability to perform experiments as if they were in a physical laboratory. It was also important that the VPLab was not perceived to be a game but a serious learning tool. The VPLab was developed primarily for distance learning students with the knowledge that this experience might be the only opportunity to work in a laboratory environment. The graphical user interface (GUI) provides the learner a set of tools consistent with those found in a typical classroom laboratory. The tools are divided into eight generic tools which are always available and specific tools for each given experiment. The VPLab design is such that approximately twelve experiments can be performed.

The designers' of the VPLab were concerned about maintaining realism with the completed design of the VL. Couture describes the underlying principle that was followed as "formal and functional realism guided the design process of VPLab" [09]. The principle followed guidelines that encompassed some of the following elements. There was no more information available in the VPLab as would be expected in a physical lab. There must be the same or similar interactivity as would be possible in a real experiment. The VPLab help section was designed as an instruction manual which replicated what would be expected in a real lab. As with any simulation, there were unavoidable circumstances where significant variations from a physical lab had to be made, but these were kept to a minimum.

The VPLab was then launched for student to work with and a study on the perceptions of the students was conducted to determine the integrity of the project. The study was conducted using a rather small sample of size of 13 students. The data collection method involved three steps consisting of (a) a questionnaire was used to evaluate students past knowledge of simulations and computer software, (b) a sequence of assignments were carried out that were indicative of what a beginner user would perform including video taping the user, and (c) a final interview with each participant was instigated to understand the effectiveness of the VPLab. The qualitative results were then analyzed using a qualitative software program to index the results.

The overall impressions of the students were quite high with many beneficial elements mentioned. The main concerns dealt with the tools that were provided but did not belong in a real lab such as a camcorder. The VPLab for many of the students had the look and feel of a video game which was one concern of the developers from the onset. The positive impressions of the VPLab overshadowed the negative ones. The providing on demand video clips of the real experiment being performed in simulation was quite beneficial. The visual prompts of what simulation objects were supposed to do were quite helpful in performing the experiments and provide additional realism. The tools provided were considered equivalent to those that would be found in a physical lab. The students also enjoyed the freedom and control perceived within the VPLab.

The author considered the VPLab project a success with some caveats. Though one of the main design goals was to shy away from the video game feel, many of the students were distracted by the "videogame appearance of the objects in the simulation" [9]. Those students that had experience with physical lab experiments felt the simulated experiments were very different from those of the VPLab. The designers' adherence to the principle of realism was accomplished with the few observed distractions and they will continue to refine the imagery in the VPLab. The overall conclusion was to continue making refinements to the simulation and reinstitute the study. They also plan on researching other VL implementation and including larger number of students in these studies.

The article "A virtual laboratory environment for online IT education" [12] provides the experience of Drexel University's implementation of their virtual networked laboratory (VNL). The university was introducing a new BS degree in IT and their commitment to distance learning mandated that they develop a VL to accommodate these distance learning students. The question was asked "How can the IT laboratory experience best be provided to the online student" [12]. The solution that they came up with was a virtual laboratory where remote learners can carry out multiple experiments, including the actual set-up of the network connection. Their research demonstrated that course management software such as Blackboard were needed for online delivery but did not adequately support the required functionality of laboratories. Simulations and VM technologies were considered as options for the VNL but it was determined that these simulators did not provide the student the ability to work with the authentic technologies.

The system designers approach to the VNL was an open format which allowed the student not only to work within the environment but “be involved in the construction of the laboratory access itself” [12]. A closed format would not allow the students access to the construction of the network access thus not providing the full experience required in IT education. This design required the student to select the appropriate components to best construct the laboratory environment to carry out the assignment. This open construction is closely scrutinized by the instructor to limit the openness to the level of competency of the student providing a greater degree of learning. The software components were chosen based on what the students would expect to work with in the real world. Once the design was finalized the VNL was implemented and placed in service.

The VNL was deployed on a server to provide the focus of the experiments. The connectivity was provided by a client machine. The system was designed so each course instructor can set-up the components that are either closed, those elements the student does not see or work with or opened, those elements that the student will be required to manipulate. Once these components are established, the student is required to perform the experiments as prescribed by the instructor. In conjunction with Blackboard, the instructor is able to maintain course control and provide a repository for submissions by students. The designers have also incorporated DameWare, a management application system, as a means by which the instructor can log-on to the VNL systems and observe the students’ activities.

This prototype VNL system has not been evaluated with respects to the student learning outcomes. The designers are still working on better ways to integrate the VNL into the IT curriculum and are also considering the use of this system in the classrooms in addition to distance learning.

The Remote Laboratory Emulation System (RLES) developed at the Rochester Institute of Technology (RIT) is a complex multifaceted VL centered on the distance education students gaining the same capabilities as the local students receive in a real laboratory. Charles Border, one of the main designers of the RLES described the problem as “how could we deploy a system that would provide a system that would provide access to these capabilities” [13]. He describes in his research article the design, implementation and first year deployment of RLES. The article also reports on the successes and deficiencies of the project.

The design requirements of the RLES were quite different than the VPLab. The RLES would use commercially available software generating recognizable interfaces as apposed to custom designed interfaces. The RLES project was instituted to instruct IT students in the areas of programming, networking, and security. The requirements for the RLES were (a) distant learning students have access to the internet (no speed requirement), (b) all software must be compatible with Windows, Mac, and Linux operating systems, (c) most all applications reside on the server and the student desktop is as thin as possible, (d) the system must be able to expand over time, (e) multiple session capability with the students able to save work, in process, (f) as cost effective as the current physical lab at RIT, and (g) multiple functionality of configurability of the student systems. It was also important that the system would use Virtual Machines (VM) to accommodate the multiple operating systems.

The RLES had some distinct advantages over the classroom environment. The use of VM technology allowed the students to save a network or system configuration, thus making it transportable from one desktop to another. It also provided prepackaged virtual machines with operating systems that had security flaws that the students could experiment on without fear of the operating systems being upgraded. Finally, the use of virtual networks provided virtual servers and clients where viruses and malware could be introduced as a part of the course curriculum. In the past, special isolated labs had to be set up for this purpose. These advantages made the project very worthwhile in addition to the other benefits to be realized.

The system was designed to be modular, incorporating the technologies primarily supplied by Microsoft. The choice of the Microsoft family of products was due to the reliability of Active Directory and the ease and efficiency of Remote Desktop. The students' access to the system was controlled by the Remote Desktop Protocol. A specific port number was assigned to the system and Access Control Lists were created to limit access through a specific router's interface. The server deployed for RLES was determined based on a metric based on the number of VM per student and the number of hours per week each student would work in the system. This metric was quite clumsy as the number of hours per week and the number of VM required were based on unknown variables. The server storage space was also based on the number of VM required and the total number of students in all courses using the RLES.

The initial deployment of the RLES system constituted the use of two 3.4 GHz CPUS with 2 GB of Ram along with two hard drives. The 40 GB hard drive stored the server hosting system and the second 300 GB hard drive was for student storage. The deployment of the system coincided with a case study of the initial 16 students using the system. The 16 students were interviewed at the beginning of the course to understand their experience with Windows and UNIX systems. The students reported extensive experience with Windows (75%) and their experience as users with UNIX was 65%. 70% of the students reported little or no experience with server visualization. The course and thus the use of RLES constituted a series of lab exercises and textbook readings. They were required to configure a virtual network and implement network services including DNS, LDAP, and DHCP. The course ended with a practical final exam which involved meeting with the course instructor to validate their working knowledge of the course content. Of the 16 students participating in the course and study, 14 completed the assignments which demonstrated the success of the system. Overall, the students were extremely pleased and receptive to RLES, which has prompted RIT to further enhance the system. The most significant enhancement is the migrating “to a more robust and scalable blade/SAN architecture” [13]. The RLES project was considered a success and the author anticipates many additional directions for the system in the future.

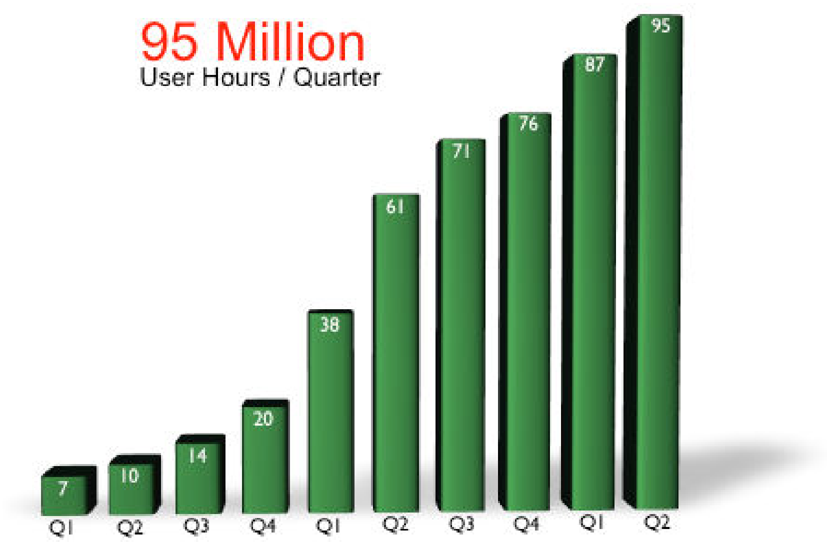
The implementation of VL has global implications as well. A recent implementation of CORBA technology in China represents one such effort to create a VL. Wang, Weini Lu, and Jia introduce a virtual lab as a foundation for experiments in digital communication. The architecture is based on the middleware software package CORBA which in conjunction with Java, C++, and the powerful numerical computing program Matlab which provides a highly scalable and re-useable VL. The VL employs an object oriented approach which as stated by the authors “the client program only needs to know the object’s name and knowhow to invoke the object’s interface” [14]. This allows the VL to simulate and model systems over multiple domains and interfaces.

The actual VL designed by the authors demonstrates the versatility of the underlying architecture, combining a number of different components to create a highly extensible approach. The interface employed for both client and server was the IDL interface CommPrinciple.idl. This implementation allowed for transparent client to server communication whether the object is on the same computer or across a network. The server utilized the Matlab engine to act as a service providing the clients with a set of functions and a compiler. The client side interface utilized Java Beans and the experimental components provided by the learner. The interface consisted of (a) menu bar, (b) attribute editor, (c) tool bar, (d) operating window, (e) equipment bar, and other miscellaneous components. This allows the learner to select the appropriate components for the experiment to be performed and an interface for accomplishing the task.

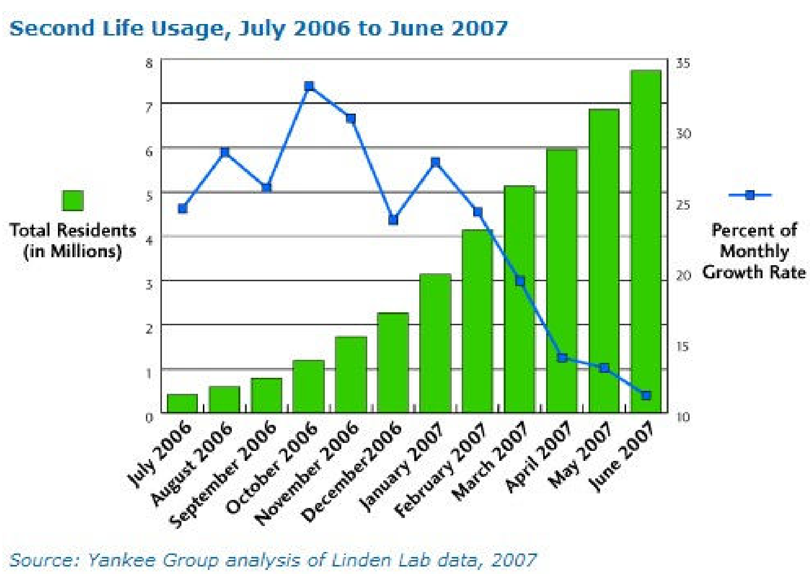
The authors [14] provided a demonstration of the effectiveness of the VL with an experiment involving the filtering of digital communication. The experiment provided insights into the versatility of the VL and how it can be successfully implemented over the internet. The authors’ conclusion is well founded in that VL will play an increasing role in distance education. The architecture developed in their article is adaptable and the underlying structure will allow designers of VL to develop custom VL and provide learners the opportunity to experiment anytime and anywhere.

Virtual Laboratories and Virtual Worlds

The virtual lab has been expanding into the virtual world (VW) as illustrated by the observation “Such graphics-rich online environments could bring a more human touch to distance education and make it easier for students to work together on virtual laboratories and other projects, say some researchers” [15]. The virtual environment has become common place with the rise of Second Life, Entropia Universe, and Cyworld becoming prime opportunities for researchers. In the article “Virtual worlds: Multi-Disciplinary research opportunities” the authors David Bray and Benn Konsynski state “Virtual world environments offer significant opportunities for research in many fields for study” [16]. These VW environments have attracted real world private business, banking and most significantly a few real world universities are offering classes on their virtual islands in these VW environments. The authors describe how the Harvard Law School has set up their CyberOne course in Second Life on Berkman Island. Emory University has also set up a combination business and political science course that is taught on their SIMsim island. It has been estimated that “eighty percent of active internet Users will have experienced at least one virtual world by the end of 2001” [16]. As the charts below demonstrate that user hours and number of residents have grown. The first chart is from 2006 through the second quarter of 2008 and the second chart is self explanatory but they reveal how the growth of Second life typifies the growth of these virtual worlds.



[17]



[18]

The VW environment has taken on an existence all their own with their own currency and rudimentary laws. These currencies have now established real world values, for example the Entropia Universe's PED is valued at 10 PED for one US dollar. Second Life has just claimed the first virtual millionaire and banks are establishing storefronts, allowing VW participants to withdrawn actual money from ATMs using their VW currency. Property can be purchased, houses built, and most importantly, avatars (the virtual character representation of the participant) can be created and sold. The US congress is taking these VW economies seriously as well, considering the ways these virtual transactions and incomes can be taxed. These VW are taking on all the components, behaviors and social interchange that one can be found in the real world.

The VW as a virtual laboratory provides many opportunities for researchers. It is suggested by Bray and Konsynski that researchers should consider "research into (1) information systems, (2) neurobiology, (3) political science, and (4) organizational governance" [16]. These research opportunities could provide validation and new theories in business information and political governance as they exist in VW. The understanding of the nature and intersection of these VW to the real world avenues should be postulated and researched.

Discussion

The development and implementation has been an ongoing process in the realm of Virtual Laboratories. The term "Virtual Laboratory" has taken on many forms and meanings. Simple VL can be delivered as demonstrated by "Sniffy Lite" via CD and installed directly on the desktop. They have also evolved into very complex implementations requiring high performance servers and network connections. The software requirements for VL can either be off the shelf programs or custom made applications simulating various laboratory environments. The recent focus of academia in distance learning has provided additional impetus in developing VL to be delivered over the internet.

These new avenues of delivery have stimulated the evolution of innovative and technologically advanced solutions to enhance the learning outcomes for learners. These innovations have advanced as new technologies both hardware and software have evolved. The research has demonstrated that the evolution of VL has provided educators excellent platforms for online experimentation in many disciplines. In conjunction with current management systems such as Blackboard, instructors are able to deliver more than just the experimental experience but also course content, assignments, and a platform for discussion and interaction.

These VL systems, though very successful, have not been realized without some issues. One of the major hurdles that have to be overcome with the development and implementation of these systems involves the recreation of the real physical laboratory. In many custom designed simulations the objects and implementations appear to have a video game appearance which detracts from the overall learning experience. There is also the concern of VL not fully representing reality as an example "Most biology professors still say that the experience of dissecting a frog while gagging on the stench of formaldehyde simply can't be replicated online" [19]. These hands on experiences are what concern many educators when considering VL as a teaching tool.

The freedom and complete control of these types of environments were considered very positive by the learners. As indicated in an article by Carnevale when discussing the use of a VL in chemistry [19]

> Learning on the computer simulations can also be fun, Ms. Ellison says. The ***Virtual*** ChemLab plays sound and visual effects as chemicals react, whether subtly or with a bang. "I really liked blowing stuff up in the ***virtual*** lab," she says. "In the ***virtual*** lab you can try anything you want, and it's OK."

This type of flexibility and in this case safety has great appeal for many disciplines in the sciences. Brigham Young University has created a VL for their advanced chemistry lab which allows students to "safely use virtual representations of toxic cations, such as mercury, and experiments that normally take weeks are finished in minutes" [19]. An advanced physics lab was virtualized to allow students to work independently online to perform physics experiments. The VL provides a virtual lab partner to assist the student in these experiments providing good as well as bad advice to aid the student in his/her discovery process.

The experiences of the RSEL and VPLab have demonstrated the positive results of VL as not only an online teaching tool but as a supplement to in class instruction. These projects have clearly demonstrated the power of these technologies to better instruct the learners. The systems use similar technologies to reproduce physical environments in a virtual laboratory. They provide the same functionality that physical hardware in the past has provided without the cost of the hardware. These VL are created in such a manner that errors in experimentation are not catastrophic and are completely portable.

Conclusion

There has been some research into the integration of VL into the educational process. The research efforts have mainly focused on the architecture and delivery of the VL technology with minimal research into the effectiveness as an educational tool. Those research studies that have investigated the outcomes of these technologies have reported good success which has fueled the further development of VL. The need of online VL for distance learning has also provided the impetus to continue development in this area. There are justifiable arguments both pros and cons to the effectiveness of these technologies though it is imperative that continued research into the merits as an educational tool be explored. The introduction of VW will also have a dramatic impact on the growth and acceptability of VL in the future. These new environments have great promise for research and as educational tools and should be explored with great vigor. There is a need for additional research on the best practices of combining these technologies and pedagogical methodologies.

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