USABILITY AND INSTRUCTIONAL EXPERIENCE IN A WEB-BASED REMOTE INTERNETWORKING LABORATORY ENVIRONMENT

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Keywords: Remote internetworking laboratory, usability, student instructional experience.

Abstract: A web based remote Internetworking laboratory that delivers interactive laboratory experience to geographically remote graduate students is presented in this paper. The online Internetworking (INWK) laboratory learning environment employs remote interaction with networking equipment in both individual and group setting that correlates with the constructivist and collaborative pedagogical approaches. This paper discusses the pedagogical and technical factors that influence the usability of and instructional experience in the remote laboratory environment given the constraints of the special hardware and learning outcomes of the program. A survey instrument employing a 5 point scale has been devised to measure the usability and student instructional experience in the remote access INWK laboratory. These results demonstrate the success achieved in designing and implementing the remote access Internetworking laboratory.

1 INTRODUCTION

Online student learning is made possible by advancements in network infrastructure and development of voice/multimedia protocols for seamless transport of information. However, the developer of a web based remote access laboratory faces several challenges in designing an online learning environment that ensures strong effective interaction that best replaces the onsite face-to-face interaction taking place in labs. This is exacerbated in lab environments like those employed in Internetworking (INWK) and Information Systems (IS) courses which extensively use networking hardware and computer/simulation software tools. In addition to a clear understanding of the knowledge domain requirements, the challenge is in supporting good pedagogy and learning practices given technical constraints with regard to bandwidth, quality of service, real time interactions, and multiple users (Sivakumar et al, 2005).

Remote laboratories have been successfully used in electrical engineering education to interact with spectroscopy, measurements, control systems and simulation laboratories (Linge and Parsons, 2005) (Casini et al., 2003) (Zimmerli et al., 2003) (Llamas et al., 2001) (Karampiperis and Sampson, 2005). However, none of these works addressed the specific issues pertaining to pedagogy, facilitation, scalability, usability and instructional experience within a technical framework, other than mapping the instructional content to appropriate technologies. Although these experiences cannot be directly applied to INWK laboratory, the essential elements of improved learning spaces can be adapted to develop an online learning space that is scalable, accessible, interactive, and modular. An effective e-learning laboratory design framework must employ interactive laboratories, secure real-time student interaction and incorporate effective online lab learning strategies including appropriate pedagogy, facilitation and skill building techniques to impart knowledge and meet instructional outcomes. This paper contributes to existing e-laboratory education frameworks research by demonstrating the feasibility of designing usable e-laboratory systems for strong student instructional experience with remote equipment. In this paper we describe our

Sivakumar S. and Robertson W. (2006).
USABILITY AND INSTRUCTIONAL EXPERIENCE IN A WEB-BASED REMOTE INTERNETWORKING LABORATORY ENVIRONMENT.
In *Proceedings of WEBIST 2006 - Second International Conference on Web Information Systems and Technologies - Society, e-Business and e-Government / e-Learning*, pages 172-179
DOI: 10.5220/0001253701720179

experiences in designing web-based remote internetworking laboratory (RIL) that attempts to incorporate all the qualities of an effective onsite laboratory. This paper focuses on factors that affect the usability of the RIL. In addition we also consider factors that contribute to student's instructional experience. The paper is organized as follows: Section 2 discusses the design requirements for the remote internetworking laboratory. This section outlines the reengineering of the internetworking laboratory to enable students to interact online with the remote devices in the Halifax equipment room. Section 3 discusses the factors influencing the usability and student instructional experience in the RIL environment. Section 4 discusses a typical instructional scenario in the RIL. Sections 5 and 6 present the usability and student instructional measurements in the online RIL environment. Section 7 compares the results for the onsite versus the online scenarios. Section 8 presents conclusions.

2 DESIGN ISSUES IN THE RIL

In our previous research (Sivakumar and Robertson, 2004) we have developed a remote Internetworking laboratory environment that supports text based synchronous student interaction. The Faculty of Engineering at Dalhousie University, Halifax, Canada has been offering a Master's degree program in Internetworking since 1997. The program also provides comprehensive "hands-on" laboratory experience in configuring, maintaining, troubleshooting and simulating computer networks. In the online context, the design and the implementation of an effective remote internetworking laboratory (RIL) environment is highly challenging on account of the special hardware, simulation and computing needs of the Internetworking courses. The internetworking laboratory equipment consists of personal computers (PC) and servers, networking devices including routers and switches from vendors including Cisco Systems and Nortel Networks, LAN/WAN network analyzers, and network simulation software OPNET. The networking equipment is placed on several racks with each rack having an identical set of routers, switches and hubs. The equipment consists of Ethernet, token ring, frame relay (FR) and asynchronous transfer mode (ATM) technologies. The laboratory has access to a DMS-100 telephone switch that provides ISDN and telephone connections.

The onsite laboratory elements have been translated into the online RIL environment by allowing students at geographically remote sites to access and interact with internetworking hardware, simulators and software located at Halifax laboratory facility and is shown in Figure 1. The Internetworking laboratory network, INWKNet, consists of a number of enterprise and carrier-level internetworking devices such as routers and switches. The backbone network consists of special purpose devices that are commonly found in carrier networks and is configured in a fixed topology. The laboratory backbone is called the LabNet and resembles a miniature "Internet" that is always available to carry ATM, FR and Ethernet data traffic. The other internetworking devices are organized into a number of student racks, each containing an identical set of devices to be accessed by students and called the StudentNet. The StudentNet devices are used to build topologies similar to the topologies found in an enterprise network. The INWKNet mimics a typical network scenario where small enterprise LANs represented by the StudentNet are connected to a carrier's WAN represented by the LabNet. The remote Internetworking laboratory (RIL) is accessible by remote students through the Internet. The onsite internetworking laboratories have been redesigned and the equipment rewired in a manner that allows online students to construct different networks topologies without changing the physical wiring/cabling. The RIL is devised using de-facto networking standards, free software and commercial Internet browser. Real-time interaction and information transfer with the Halifax site are achieved independent of the technology available to the remote student. The RIL design and delivery mechanism are tailored to i) provide a constructivist pedagogical approach (Palloff and Pratt, 2003) ii) model a collaborative learning environment for group interaction (Hiltz et al., 2000) iii) match the characteristics of the delivery media to specific learning processes including the provision of unambiguous feedback and guidance iv) assign appropriate instructional roles and v) determine desirable student competency outcomes; all in a remote learning context. A 4-tier RIL role architecture consisting of faculty, facilitators at both the Halifax and remote sites and students, has been determined appropriate and adapted to maintain academic integrity, provide continuous assessment to track student performance, provide real-time interaction with equipment, and offer strong student instructional experience. The RIL is modeled as a remote synchronous, collaborative and directed lear-

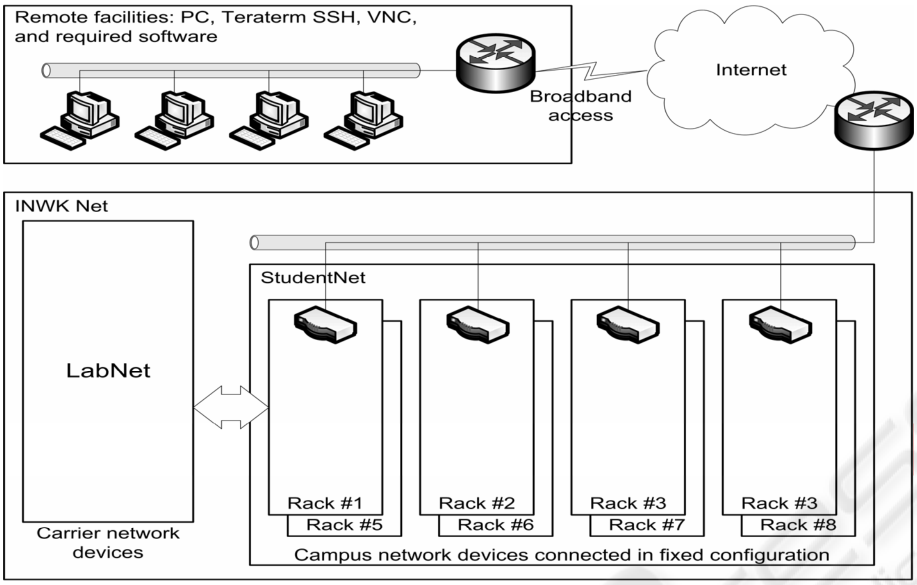

Figure 1: RIL - Logical architecture.

ning environment as remote students interact simultaneously with Internetworking equipment under the active supervision and guidance of the remote site facilitator to achieve specific learning outcomes. The RIL limits individual access to laboratory resources only to authenticated students using an access control server. In this paper, our work supports the special requirements for, and is assessed for usability and student instructional experience in this online synchronous INWK laboratory framework.

3 FACTORS INFLUENCING RIL USABILITY AND INSTRUCTIONAL EXPERIENCE

The e-learning research framework proposed by Alavi and Leidner (Alavi and Leidner, 2001) urges study within the context of pedagogical strategies and learning processes. At the intersection of these strategies and processes are the methods of instructional delivery that can be viewed from student-centric, university-centric and technology-centric perspectives. E-learning system designers and universities use these metrics to guide the design, development/adoption and implementation of learn-ware, assessment of trade-offs, e-learning system infrastructure and to measure the usability of the system. Specifically, issues in the design of the pedagogical strategy that implements a student-centric learning process in a web based remote internetworking laboratory system must encourage student interaction by employing state-of-the-art networking equipment/simulators (Linge and Parsons, 2005) (Llamas et al., 2001), provide real-time response from equipment to engage students in active learning, ensure repeat student interaction, provide a collaborative learning environment for group interaction at a remote site, provide feedback and guidance when learning outcomes are not met and, track student performance to meet learning outcomes (Sivakumar et al, 2005).

The university-centric issues in implementing instructional delivery methods include curriculum quality, instructional pedagogy employed in the remote laboratory, technical infrastructure management for delivering learning material, scalability of laboratory infrastructure to handle increases in student enrolment, and continuous student assessment for grading purposes (Sivakumar et al, 2005)

From the technology-centric view point, the instructional delivery framework must use standard networking protocols and free software to connect the remote site to the central equipment facility, use secure interaction between the remote site and equipment facility, deliver laboratory notes, wiring information and diagrams to students at remote locations over the world wide web, and authenticate the student at the time of initial access to laboratory resources (Sivakumar and Robertson, 2004).

A detailed study of the above factors is given in (Sivakumar and Robertson, 2004) (Sivakumar et al, 2005). The design of the remote internetworking laboratory (RIL) is aimed at delivering an effective remote laboratory experience moderated by the laboratory facilitators.

4 RIL INSTRUCTIONAL SCENARIO

In the RIL environment, students typically work in groups of 2-3 per group in the introductory and intermediate laboratory experiments. In advanced laboratory experiments, they still have to configure the networking equipment individually and then have to interact as a group with the equipment. It is essential that the remote site laboratory design makes use of active learning strategies in a collaborative environment (Palloff and Pratt, 2003) (Hiltz et al., 2000) (Jonassen et al., 1999) (Wenger, 1998). The activities in the remote laboratory are modeled to implement the nine instructional objectives as outlined by Gagne et al. (Gagne et al., 1992): 1) gain student attention, 2) inform students of the objective, 3) recall prior learning, 4) present stimuli, 5) provide learning guidance, 6) elicit performance, 7) provide feedback, 8) assess performance and 9) enhance retention. A typical remote online INWK laboratory exercise requires students to configure, analyze and troubleshoot the performance of the routing information protocol (RIP). Each group is assigned Internetworking devices in the StudentNet (see Figure 1) for configuration. The RIP experiment first requires each student learn to configure RIP on a router. Students capture and analyze the data packets using sniffers or protocol analyzers. The convergence of the RIP protocol is observed and analyzed by capturing routing protocol updates after intentionally generating a link failure event in the network. The typical work scenario in this environment is discussed in (Sivakumar and Robertson, 2004). All necessary wiring needed for this exercise is made in advance at the Halifax equipment facility. The wiring diagrams for laboratory equipment is available from the program website. In the following sections we measure the usability and student instructional experience in the RIL.

5 RIL USABILITY

The usability of an e-laboratory system is a function of system design and is determined by factors including ease of use, interactivity with the system, system accessibility, system reliability, availability of online help including lab handouts and wiring diagram information, support for multiple simultaneous interactions, system responsiveness, appropriateness of system response to student input, authenticity and state of art-ness of the networking laboratory environment, feedback from the lab instructor, and hands-on feeling. A survey questionnaire that has been developed based on these 12 issues is summarized in the Table 1.

Students were asked to respond on a five point scale of 1-5, from very poor, poor, satisfactory, good to very good, the usability of the online remote equipment laboratory. The survey was conducted as an anonymous post-course evaluation of the RIL environment design, organization and performance. Of a sample size of 83 students over 3 years (2004, 2005 and 2006), a total of 65 students took part voluntarily in the survey once. In determining the sample size the factors that played a major role are the student enrolment in these years. On average, the program intake consists of 28-30 students each year. Table 2 gives the cumulative percentages of students in these 3 years who rated the 12 different aspects of the online lab as very good, good or satisfactory. Table 3 gives the mean rating, the standard deviation and confidence measure for the 12 aspects of the remote laboratory. From Tables 2 and 3 it is seen that the students are highly satisfied with the technical design of the RIL environment as reflected by the cumulative (2004, 2005 and 2006) results for ease-of-use, response time, accessibility, reliability, system response characteristics, authenticity, and the "state-of-art"-ness of the equipment. Over 90% of the students rated these technical characteristics of the INWK networking equipment to be satisfactory, good or very good. 87% of students rated the state-of-art-ness of the networking environment to be satisfactory or good or very good. Also, the students are highly satisfied with the format of the online wiring information and laboratory handouts as over 90% of students rated these to be satisfactory or good or very good. The level of interactivity is generally considered a key indicator of quality [20]. Tables 2 and 3 indicate that, although 83% of students rated the interactivity with laboratory components to be satisfactory or good or very good, only 80% of students rated the level of "hands on" feeling experienced in lab sessions to be satisfactory or good or very good. Hence, the program needs to improve student interactivity with laboratory equipment and the "hands-on" feeling experienced by the student to improve the quality of interaction

Table 1: Questionnaire used to measure the usability of the Remote Internetworking Laboratory.

	On a scale of 1 to 5 rate: (1=Very poor, 2 = Poor, 3= Satisfactory, 4 = Good, 5= Very Good
UQ1	whether the INWK lab equipment was **easy to use**
UQ2	the level of **interaction** with lab components
UQ3	the **response time** of lab components
UQ4	Whether the switches, router and other networking gear could be **remotely accessed** on entering userID/password)
UQ5	the **reliability** of operation of switches, router and other networking gear
UQ6	the **appropriateness of the response** from switches, routers and other networking gear i.e., did the response from equipment help you better understand networking concepts and theories
UQ7	whether the **feedback from the lab instructor** was useful
UQ8	the **usefulness of lab handouts** and extra online information
UQ9	the **usefulness of the online wiring diagram information** (cabling between networking gear)
UQ10	the level of **“hands on” feeling** experienced when configuring/ troubleshooting networks with equipment in Internetworking labs
UQ11	the **authenticity of the networking environment** in the INWK lab (i.e., is the networking equipment used in the INWK labs similar to those in a real world networking environment)
UQ12	the **“state-of-the-art”-ness of lab components** / networking gear in the INWK lab (i.e., are the router/switches and other networking gear current)

Table 2: Usability: Percentage of student vs. ratings.

	Percentage of students who rated various aspects of the online labs as either very good (5), good (4) or satisfactory (3)											
Rating Years	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
2004	78.6	80.0	100	86.7	86.7	92.3	66.7	86.7	86.7	53.3	80.0	80.0
2004 and 2005	90.4	81.1	90.4	92.5	90.6	98.1	78.9	90.6	90.6	77.4	90.6	86.8
2004, 2005 and 2006	89.1	83.1	90.6	93.9	92.3	96.9	82.8	90.8	92.3	80.0	89.2	87.7

Table 3: Usability: Cumulative Mean, Standard Deviation and Confidence measures (2004, 2005 and 2006 data set).

Rating	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12
Mean	3.61	3.34	3.66	4.14	3.85	3.81	3.45	3.72	3.74	3.37	3.58	3.45
Std. Deviation	0.95	1.00	0.88	0.93	0.83	0.75	1.13	0.98	0.92	1.15	0.92	0.87
95% CI	0.23	0.24	0.21	0.23	0.21	0.18	0.28	0.24	0.22	0.28	0.22	0.21
90% CI	0.20	0.20	0.18	0.19	0.17	0.15	0.23	0.20	0.19	0.24	0.19	0.18

Note: CI - Confidence interval

between the student and the equipment. Also, only 83% of students rated the feedback from the laboratory facilitator to be satisfactory or good or very good and this aspect showed the most variability. The program needs to better train the remote facilitator in providing timely and useful feedback to the student.

6 INSTRUCTIONAL EXPERIENCE

As part of this study, students were asked to rate their instructional experience in the RIL. The student learning experience measures student perceptions regarding their level of confidence and the increase in the student’s ability to configure, trouble shoot, monitor, design, implement, plan and manage a state-of-the-art networking environment. In addition, student’s perception regarding their ability to understand and apply internetworking concepts and select appropriate technology was also measured. A student instructional experience survey questionnaire that has been developed based on these 10 issues is summarized in Table 4. Students were asked to respond on a five point scale of 1-5, from very poor, poor, satisfactory, good to very good, to rate the student instructional experience in the RIL. Of a sample size of 55 (37 students in 2005 and 18 students in 2006), a total of 42 students (30 in 2005 and 12 in 2006) took part voluntarily in the student instructional experience survey once. Table 5 gives the cumulative percentages of students in the two years who rated the 10 different aspects of the student instructional experience in the RIL as very good, good or satisfactory. Table 6 gives the mean rating, the standard deviation and confidence measure for these 10 student instructional experience issues. From Tables 5 and 6 it is seen that the students rated their instructional experience as highly satisfactory. From Table 5, it is seen that about 70% of the students found a good or very good increase in their level of confidence in working with Internetworking equipment. Also, over 90% of the students rated a satisfactory, good or very good increase in their understanding of concepts, ability to configure equipment, application of theoretical concepts, selection of appropriate technology, and plan and implement networks. Over 80% of the students rated a satisfactory, good or very good increase in their ability to trouble shoot, monitor, manage, and design networks.

7 ONLINE VS. ONSITE LABS

Onsite students were asked to respond on a five point scale of 1-5, from very poor, poor, satisfactory, good to very good, the following aspects of the onsite equipment laboratory: the physical access to equipment, suitability of the networking equipment, their experience using the lab and whether the lab helped them understand networking concepts better. Specific questions of the online survey were more detailed and refined than that of the onsite survey.

Table 4: Questionnaire used to measure the instructional experience in the RIL.

	On a scale of 1 to 5 rate: (1=Very poor, 2 = Poor, 3= Satisfactory, 4 = Good, 5= Very Good) the extent to which the INWK laboratory learning experience has increased
IQ1	your overall level of confidence in working with INWK equipment
IQ2	your understanding of INWK theories, concepts and technologies
IQ3	your ability to configure equipment
IQ4	your ability to troubleshoot networks
IQ5	your ability to monitor networks
IQ6	your ability to design networks
IQ7	your ability to implement networks
IQ8	your ability to apply theoretical networking concepts
IQ9	your ability to select appropriate networking technologies
IQ10	your ability to plan and manage networks

Table 5: Student instructional experience: Percentage of student vs. ratings.

	Percentage of students who rated various aspects of the online instructional experience as either very good (5), good (4) or satisfactory (3)									
Rating	IQ1	IQ2	IQ3	IQ4	IQ5	IQ6	IQ7	IQ8	IQ9	IQ10
Very Good	11.9	19.1	12.2	4.9	7.3	2.4	4.9	17.1	7.5	2.5
Very Good or Good	69.1	71.4	73.2	48.8	43.9	34.2	43.9	73.2	57.5	37.5
Very Good or Good or Satisfactory	95.2	90.4	97.6	87.8	87.8	85.3	87.8	95.1	92.5	90.0

Table 6: Student instructional experience: Mean, Standard Deviation and Confidence measures.

Rating	IQ1	IQ2	IQ3	IQ4	IQ5	IQ6	IQ7	IQ8	IQ9	IQ10
Mean	3.76	3.81	3.83	3.39	3.37	3.20	3.32	3.85	3.58	3.30
Standard Deviation	0.73	0.86	0.67	0.83	0.86	0.78	0.88	0.76	0.75	0.69
95% CI	0.22	0.26	0.20	0.25	0.26	0.24	0.27	0.23	0.23	0.21
90% CI	0.18	0.22	0.17	0.21	0.22	0.20	0.22	0.20	0.19	0.18

Note: CI - Confidence interval

Table 7: Onsite issues and their correspondence to online usability measures.

Onsite Survey		Online Survey	
Issue	Onsite Issue no.	Issues	Question no. (See Table 2, 5)
Physical access to equipment in laboratory	OQ1	"Hands on feeling"	UQ10
		Student interactivity with equipment	UQ2
Suitability of networking equipment	OQ2	Authenticity	UQ11
		State-of-art ness	UQ12
Experience using the lab	OQ3	Ease of use	UQ1
		Response time	UQ3
		Remote access to lab	UQ4
		Reliability	UQ5
Understand networking concepts	OQ4	Understand INWK theories, concepts and technologies	IQ2

Note: UQ: usability questionnaire. IQ: instructional experience questionnaire, OQ: onsite questionnaire

Table 8: Onsite vs. Online Surveys (2004, 2005, 2006): Mean, Standard Deviation and Confidence measures.

Measure	Onsite				On line			
	OQ1	OQ2	OQ3	OQ4	UQ2, UQ10	UQ11, UQ12	UQ1, UQ3, UQ4, UQ5	IQ2
Mean	3.87	3.97	3.57	3.97	3.35	3.52	3.81	3.81
SD	0.86	0.98	1.22	1.07	1.08	0.89	0.92	0.86
CI – 95%	0.31	0.36	0.44	0.38	0.19	0.15	0.11	0.26

Note: CI – Confidence Interval

However, as shown in Table 7 the four onsite issues can be mapped to one or more corresponding online questions to enable comparison.

Table 8 lists the mean, standard deviation and confidence measures for the four onsite issues used to measure the design and implementation of the onsite laboratory and compares it with the corresponding figures for the online laboratory. From Table 8, it is seen that on average, onsite students are more satisfied with the physical accessibility to the equipment than their online counterparts. Similarly, students in the onsite program are more aware of the suitability of the networking equipment employed in the labs. The online students consistently rated the authenticity and the state-of-art ness of the networking environment lower than their onsite counterparts. Also, the onsite students were marginally more satisfied than the online students when asked whether the laboratory equipment helped them understand networking concepts better. However, the online students were more satisfied with their online laboratory experience than the onsite students and this may be attributed to the flexibility that the remote access provides to online students. For example, online students can access the laboratory at a time and from a place convenient to them and perform the labs at a suitable pace.

8 CONCLUSIONS

This paper describes an online remote internetworking laboratory (RIL) environment used to deliver remote laboratory experience by allowing students at geographically remote sites to access and utilize devices including routers, switches, LAN analyzers, and simulators located at Halifax. In the early stages, much of the development of the remote internetworking laboratory, has focused on understanding the system requirements and developing a viable test-bed to deliver the labs online by connecting students at remote sites to internetworking equipment at Halifax. The RIL system design ensures an accessible, reliable, easy-to-use and responsive remote laboratory environment that supports multiple simultaneous real-time interactions and effective information transfer between the remote site and the equipment at the Halifax equipment facility. The RIL uses effective student interaction with remote equipment and simulations that employ multimedia to create an engaging environment that enhances problem-solving skills. This is reflected by highly satisfactory ratings for the student instructional measures. Survey results used to measure the usability of the remote laboratory demonstrate the success achieved in designing and implementing the remote access

Internetworking laboratory. Survey results also indicate that the online laboratory is perceived to be easier to use and more flexible than the onsite laboratory due to the formers remote access capability. However, the online laboratory is perceived to be less physically accessible and less interactive than the onsite laboratory. Based on the feedback from the faculty who have been involved both in the onsite and the online programs and the students' historical performance measures including grades, switching to the online remote laboratory format has not resulted in any degradation of the expected learning outcomes.

Future research will focus on evaluating how the facilitation process together with system use result in achieving the pedagogical goals of the program. System limitations include the fact that the current INWK laboratory can accommodate only 35 students maximum in a given time slot. The long-term goal of the program is to implement an asynchronous internetworking laboratory accessible from the student's home. Additional work is planned to address online facilitation and student instructional experience in the asynchronous environment.

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