Developing and Teaching Sophomore Level Electrical Engineering Courses Completely Online

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***Abstract*- This paper presents our experiences and results in developing and delivering three core Electrical and Computer Engineering (ECE) courses with laboratory components completely online using an internet based distance learning delivery system. It first describes how we used the Mobile Studio™ technology and pedagogy to redesign and offer ECE courses with laboratory components that can be conducted by students without using traditional laboratory space and equipment. It then follows with a description of the steps required to convert the face-to-face courses to online courses using the eight components of the 2008 – 2010 Quality Matters™ Rubric. The paper concludes with a discussion of the results obtained by offering the online courses over three semesters. The results show that the students were able to conduct design and laboratory experiments required in the face-to-face courses without the need to be on campus. Majority of the students enrolled in the three online ECE courses have successfully completed the courses and are currently enrolled in the follow-up courses.**

***Index Terms*—Online Electrical Engineering Courses, Mobile Studio IOBoard™, Quality Matters™, Blackboard Learn™, Panapto Focus™**

I. INTRODUCTION

Trends in higher education for the past 10 years have shown that enrollments in online courses or online degree programs have been growing substantially faster than overall higher education enrollment. A survey of online learning conducted in 2009 by the Sloan Consortium indicated that enrollment in one or more online courses reached 4.6 million students in 2008 [1]. The 17 percent growth rate for online enrollments is significantly higher than the 1.2 percent growth rate of the overall higher education student population during the same time period [2]. A follow-up report published in 2011 [3] , and other papers [4] , [5], [6] seek to address and provide answers to some of the fundamental questions related to the nature and extent of online education. Some of the questions addressed in the report are, whether retention of students is harder in online courses, if the learning outcomes in online courses are comparable to face-to-face (F2F) courses, whether faculty acceptance of online education has increased, or the impact of the current economic conditions on online education. The results of the surveys conducted in [3] based on the responses from 2,500 colleges and universities are summarized in Table I. The authors of the survey conclude their report by stating that "online enrollments in U.S. higher education show no signs of slowing."

One discipline that has lagged behind all others in the development and delivery of online education is engineering. While close to 320 engineering schools in the USA have received accreditation from ABET, formerly known as the Accreditation Board for Engineering and Technology (ABET) for their undergraduate programs, only a handful of those offer engineering programs that are completely online at the graduate and/or undergraduate level. The trend has started to change lately, and each year more engineering programs add an online component to their regular curriculum. The main obstacle impeding adoption is that most engineering curriculums require intensive hands-on laboratory components that can be challenging to implement and deliver completely online due to cost and inability of students to manipulate equipment remotely.

Most online engineering programs currently available are at the Master of Science (MS) level, and are targeted at engineers in professional practice, most of whom have received their undergraduate degrees from a campus based program. A summary of the list of engineering programs that offer an online Master of Science (MS) degree is published by the Sloan Consortium [2]. The list in [2] indicates that the Master of Science in Bioinformatics from Johns Hopkins University (JHU) is the only program that is accredited by ABET. An even smaller number of institutions offer an online Bachelor of Science (BS) engineering degree program. They are listed in Table II.

Table I.
RESULTS FROM ONLINE EDUCATION SURVEY [3]

Survey Question	Survey Results
Is Online Learning strategic ?	65% of all reporting institutions said that online education is a critical part of their long term strategy.
Are learning outcomes in online courses comparable to face-to-face ?	67% of academic leaders rated their learning outcomes in online education to be the same to those in F2F. This number was 57% in 2003.
Has faculty acceptance of online learning increased ?	Less than one-third of chief academic officers (VPs or Provosts) believe that their faculty accept the value and legitimacy of online education. This number has not changed since 2003.
What training do faculty receive for teaching online ?	72% of institutions conduct internally run training courses, and 58% provide informal mentoring.
What is the future of online education enrollment growth ?	There is growth in fully online programs by disciplines in public institutions. However, private and for-profit institutions that currently have the largest enrollment are showing a slight decline.

Most of the universities that offer an online engineering curriculum indicate to their students that their online program is separate and different from their regular on campus program. Some universities on the other hand make no differentiation between their online and their on campus degree programs. For example, the MS degrees in Chemical engineering offered at Kansas State, and North Carolina State and the BS degree in Chemical engineering offered the University of North Dakota are equivalent to the regular on campus degree programs [2]. One way universities are assuring that their online courses and degree programs are on par with their on campus programs is by implementing rigorous quality assurance standards from the development to the final delivery of the courses[7],[8]. This implies that they have to be able provide answers to the following questions [8]:

- “What quality assurance policies and practices does the institution have in place or in the process of development to assure the quality of its teaching and learning performance?”
- “How effective and how fully deployed are these?”
- “What processes does the institution have to evaluate and monitor the quality of its outcomes?”
- “What quality related indicators does the institution use and why?”

Table II.
ONLINE B.S. ENGINEERING PROGRAMS [3]

University	B.S. Degree Program offered online
University of North Dakota	Chemical, Civil, Electrical, and Mechanical Engineering
The State University of New York (SUNY): Binghamton, Buffalo, and Stony Brooke campuses	Electrical Engineering

Universities also utilize various types of technologies to increase and enhance the learning experience of their online students [9]. Most institutions provide online courses using live video and streaming technologies. For example, the University of Florida utilizes a distance learning delivery platform called the “UF Edge” to digitally record on-campus lectures and deliver them to online students anytime, anywhere. Similar approaches are utilized at other institutions [10], [11]. This allows online students to have a very flexible academic schedule, while providing them with a learning experience that closely mirrors that of on-campus students. Johns Hopkins University’s (JHU)-ABET accredited MS program in Bioinformatics utilizes an online delivery platform that allows live courses to be streamed to the students. JHU supplements the synchronous steaming technology with a web conferencing technology that allows students to participate in the class-room in real time. Although the web-conferencing and synchronous streaming technology provide a high degree of interactivity to the online students, they put constraints on their scheduling flexibility. Another approach is to use technology that allows online students to attend live lectures delivered on campus to the regular students. Some institutions also take into account the fact that online students might not have a stable and reliable internet connectivity by providing them with CD-ROMs and video tapes of the all the course contents.

The electrical and computer engineering (ECE) courses offered to online students at our institution will utilize various technologies and tools that are commercially available and used by many other engineering schools with online programs. However, our approach is slightly different from the other two universities that offer a BS degree in Electrical engineering because we are able to utilize a new technology, the “Mobile Studio IOBoard™” developed at Rensselaer Polytechnic Institute (RPI) to implement the laboratory and design components of our undergraduate courses. We also supplement our online courses with captured lectures of our face-to-face, on campus courses using the Panopto Focus™ software. All online courses developed at our institution have to undergo a thorough evaluation process to assure that they conform to “The 2008 – 2010 Quality Matters™ (QM) Rubric” [12]. This rubric outlines many of the practices that are generally accepted for teaching engineering courses and includes some items that are critical for an online student's success [13]. Finally, we use the Adobe Connect™ software to allow online students to demonstrate their projects and laboratory assignments to their instructors from another location. The results of our implementation in three ECE courses over a three semester period are discussed in the rest of the paper.

II. ONLINE COURSE DEVELOPMENT

A. *Phase I- Pedagogy and Implementation of the Mobile Laboratory*

The development of the three online ECE courses discussed in this paper started about 10 years ago with the addition of web-based course supplements for the face-to-face courses [14] [15]. The web-based course supplements consisted of additional course materials such as PowerPoint slides, animations, short video, and other website links that were there to help students understand the course material better. Regardless of the amount of supplementary course materials available to the students, the one thing that was always required by all students is fact that they had to come to the electrical engineering laboratories on campus to use the laboratory equipment to design, build, and demonstrate their projects and laboratory experiments to the course instructor. This changed three years ago, when our university joined the Mobile Studio project that was funded by a five year NSF grant at Rensselaer Polytechnic Institute (RPI). The addition of the Mobile Studio IOBoard™ allowed us to redesign our face-to-face laboratory ECE courses such that students can complete most of their laboratory work outside of the ECE laboratories.

In the first phase of our implementation, students enrolled in face-to-face courses were allowed to use the Mobile Studio IOBoard™ to complete laboratory and design projects in their dorms or the library. However, they were still required to see the course instructor in his/her office or in the ECE laboratory to conduct a live demonstration of their final projects. Figure 1 shows a student working on his laboratory experiments in the library. It should be noted that this approach allows students to tinker and experiment with their designs anywhere and at any time. Various papers on the use of the Mobile Studio IOBoard™ technology and pedagogy have been published by the other members of the Mobile Studio project at several conferences [16],[17],[18].

Figure 1: student working on his ECE laboratory experiment in the library.

The faculty at our institution worked with peers at other institutions involved in the Mobile Studio project to redesign various laboratory and design experiments so that they can be completed by the students using the Mobile Studio IOBoard™. The key issue that we had to address was the fact that the Mobile Studio IOBoard™ is limited to very low voltages (plus or minus 4 Volts) because it draws its power from the USB port of the laptop it is connected to. This implied that laboratory experiments that required a "Power Supply" or "Function Generator" with more than 5 volts had to be redesigned in such a way that the overall concept of the experiments could still be understood by the students. This constraint was primarily applicable to analog circuits since the use of CMOS components would satisfy this requirement for digital circuits. The instructors involved in the Mobile Studio project at the various institutions worked closely together to develop sound pedagogy to deliver the educational content using the Mobile Studio IOBoard™ technology.

The face-to-face circuits course is now taught with a combination of lecture and hands on experiments that are conducted using the Mobile Studio IOBoard™ technology and pedagogy. This is different from a typical circuits course where students learn the theory in the classroom and perform hands-on experiments in the laboratory course. The addition of the Mobile Studio IOBoard™ technology and pedagogy allowed us to teach both theory and applications of circuits concepts at the same time in any classroom setting. This approach proved beneficial to all students because the hands on experiments allowed them to verify and better understand theoretical concepts covered in the course without the need to wait until they conducted separate lab experiments in the lab course that his held on another day at a different time. Tables III and IV show the contents of a sample laboratory experiment that was redesigned using the Mobile Studio IOBoard™ technology and pedagogy.

Table III.
INSTRUCTIONS ON HOW TO USE THE MOBILE STUDIO IOBOARD™.

EEGR 202: Dr. Yacob Astatke

Mobile Studio (MS) Lab 4 – Thevenin Equivalent Circuit and Max Power Transfer

1. Mobile Studio and Instrumentation Board

MS is a technology-based new learning tool comprising a tablet PC (or any PC) and an instrumentation board, which replaces most of the lab equipment. Therefore, MS allows for small foot-print, mobile laboratory experiments any place any time. The measurement by MS is possible by a Windows-based software, Mobile Studio Desktop, which is already installed in the tablet PCs. The icon for the Mobile Studio Desktop is illustrated below.

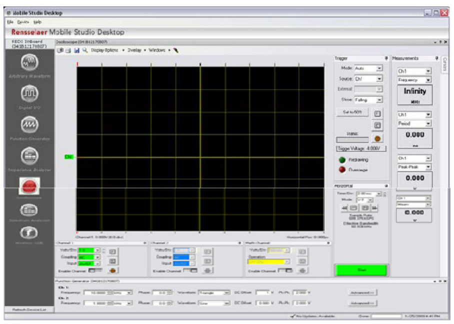
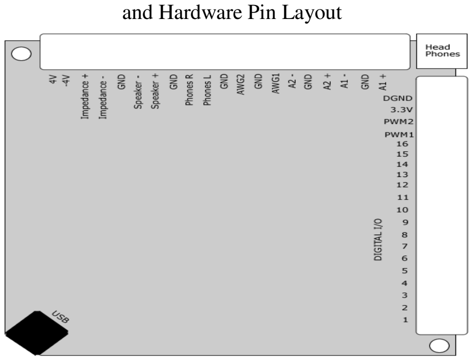


Figure #1: Mobile Studio Desktop™ Software and Hardware Pin Layout



The instrumentation board can function as :

(a) Oscilloscope, (b) Digital Multi Meter (DMM),
(c) Power supply, and (d) Function generator.

There are, however, important limitations in using the Red board
(1) No direct measurement of current -- You get current indirectly (by measuring voltage across a resistor, etc), or by using a DMM.
(2) No direct measurement of resistance -- You get it indirectly or by using hand held DMM.

All students have to initially complete a laboratory experiment that teaches them how to use the software and hardware of the Mobile Studio IOBoard™ , and how it can be connected to circuits they design on their bread-boards. Table IV shows a typical laboratory experiment that has been redesigned in order to be conducted using the Mobile Studio IOBoard™. It should be noted that the concepts covered in this lab experiment are the same as those conducted using the laboratory equipment on campus, although different test instruments are used. The laboratory experiments in the digital course did not have to be redesigned because all the experiments could be conducted using the Mobile Studio IOBoard™ as long as the integrated circuits are CMOS, which can be powered by 3.3 V, which is available on the digital side of the IOBoard™. Once the laboratory experiments were redesigned to be offered completely online, the next step was to convert our face-to-face ECE courses into online courses.

Table IV.
TYPICAL LABORATORY EXPERIMENT REDESIGNED USING MOBILE STUDIO IOBOARD™.

EEGR 202: Dr. Yacob Astatke

Mobile Studio (MS) Lab 4 –

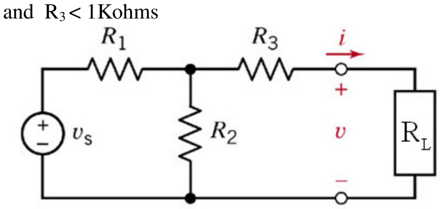
Thevenin Equivalent Circuit and Max Power Transfer

The circuit shown Figure 1(a) has four unknowns:
Vs, R_1, R_2, and R_3.

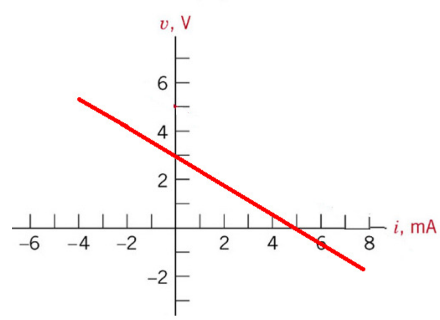
- Please **design the circuit by choosing the values for Vs, R_1, R_2, and R_3** such that the **voltage current relationship** for the **load Resistor R_L** is given by the **graph in Figure 1(b).**
- Please **choose** the correct value of the load **Resistor R_L** such that **it absorbs maximum power**. Prove your answer by **varying R_L from 100 to 1Kohms** and **measuring the current in each case** (note: you need to **use your handheld multimeter**). Then **compute the power absorbed** by the **load Resistor R_L** and **plot** it to prove that the value you chose for R_L is actually the max power value.
- This project should be completed using the Mobile Studio IOBoard™. You are also required to use of Electronics Workbench circuit simulator, to validate your results.

Here are the **design requirements**:

1. Assume the line shown in figure 1b can be represented by the following equation:
   $V_{out} = -(R_{th} * i) + V_{oc}$
   - Where: R_{th} represents the Thev equivalent resistance as seen by the load resistor
   - Where: V_{oc} represents the open circuit voltage as seen by the load resistor
2. Make sure that : Vs <= 4 Volts (use this requirement to choose R_1 and R_2)
3. Assume all your resistors have to be: 100 ohms < R_1 and R_2 and R_3 < 1Kohms



(a)



(b)

B. Phase II- Converting the F2F courses to online courses

The circuits course is a four credit course that meets twice a week for one hundred minute time periods. The digital logic course is a three-credit course that meets for three fifty-minute periods each week. The circuits laboratory course is a one credit course that meets for three hours, once a week. The circuits and circuits lab courses are prerequisites for the digital logic course. Each of the three courses enroll about 70 students during the academic year. Most of the class time in both lecture courses is spent lecturing the students. The circuits laboratory course meets in the electronics laboratory, to allow students complete assignments in groups, under the guidance of the instructor. Some of the digital logic course periods are for laboratory assignments and are held in computer engineering laboratories. During these sessions, students demonstrate, to the instructor, laboratory exercises and projects that they have built on a prototyping board and tested using the Mobile Studio IOBoard™ or the regular laboratory equipment. These laboratory exercises are completed outside of the classroom, in groups of two or three. The laboratory exercises and projects allow students to apply the topics covered in the course and are used to reinforce the material in the course.

Course materials for all three courses are available to students through Blackboard Learn™, a course management and delivery platform. It is used to store the online course documents such as, PowerPoint lecture slides, lecture videos, handouts for homework and laboratory assignments, announcements, etc… It is also used to collect documents submitted by students electronically, to record and share student's grades, and for student-teacher or student-student communication. Features of Blackboard Learn™ such as blogs, discussion boards, and virtual chat rooms are not utilized in the F2F sections. They are only used in the online version of the courses.

The F2F courses were converted to asynchronous online courses over a four to six month period from January to July 2010. The "Electric Circuits" and "Intro to Electrical Lab" online courses were completed by June 2010 and were both offered completely online in July 2010 as pilot courses. The digital logic course was converted to an online course by July 2010. It was then offered to a few students as an online course in the Fall 2010 semester. All online courses were designed so that students would be able to access course resources at their own time. However, the pace at which the course material is to be reviewed is established by the instructor using the course calendar. All assignments and examinations were to be completed by a certain deadline. Students enrolled in the online ECE courses were expected to complete the same amount of course material and assignments as the F2F students.

MSU requires all online course builders to attend an "Online Course Design Workshop" that is offered on campus. This course is delivered online, via Blackboard Learn™. The course topics include the online teaching environment, creating modules, the role of discussion, technology integration and assessment. The main goal of the "Online Course Design Workshop" is to teach instructors interested in developing and teaching online courses how to divide the course into modules that last approximately one to two weeks. These modules have to further be divided into sub-modules with topics that students can work through in about an hour.

All courses were required to conform to "The 2008 – 2010 Quality Matters™ (QM) Rubric" [12]. This rubric outlines many of the practices that are generally accepted for teaching engineering courses and includes some items that are critical for an online student's success[7],[8]. The rubric assigns points to several aspects of an online course to ensure a student's success. Any MSU course that is converted to an online course cannot be offered to students until it meets and passes the grading scale set by the instructor of the "Online Course Design Workshop" course. This is done to ensure that all online courses meet the minimum course development standard to assure the success of the students who will be enrolled in it. Samples of the different components of the rubric used to evaluate all online courses at MSU are shown in Table V [12].

Table V.
COMPONENTS OF A QM RUBRIC [12]

1.	<u>Course Overview and Introduction:</u> Ensure that all instructions for students are easy to find including establishing expectations for the course and how to use the modules developed for the course.
2.	<u>Learning Objectives:</u> Students are provided measurable learning objectives for each module and information on how to meet the objectives.
3.	<u>Assessment and Measurement:</u> The course assessment must be aligned with the course objectives and at a level appropriate for the course. Grading criteria must be explicitly stated.
4.	<u>Instructional Materials:</u> Course materials must allow students to meet the course and module objectives.
5.	<u>Learner Interaction and Engagement:</u> Interactions that occur between the student and the teacher must foster interaction between course participants and instructors.
6.	<u>Course Technology:</u> The tools and media must support student learning and be accessible to students. Students must have access to all tools and instructions must be provided on how to use these resources.
7.	<u>Learner Support:</u> Students must be aware of technical, academic and student support services available for the course and at the university.
8.	<u>Accessibility:</u> The course should be accessible by all students and provide alternate means of access.

C. Phase III- Integrating Technology for Online Delivery

In the third stage of the implementation of our online courses, we started evaluating various hardware and software technologies that would make the course experience of online students as close as possible to the F2F students. We had to carefully evaluate the advantages and disadvantages of synchronous and asynchronous modes of content delivery for our online students. Since our goal was to offer the online ECE courses to students from within the United States or abroad, we decided to use a tool that can offer both synchronous and asynchronous course contents to the online student.

The course instructors enhanced the PowerPoint based lesson files by recording lectures for each sub-module using the Panopto Focus™ lecture capture software. Some instructors used the lecture capture software to record "live", the daily course lectures of their regular ECE courses, while others recorded separate lectures for each PowerPoint lesson file outside of the regular classroom. The online lectures can be watched over the internet using streaming technology, or can be downloaded as podcasts. The lecture recordings were initially available to the students enrolled in the F2F ECE courses as a supplementary material in order to help them learn and understand the course material better. A screen capture of a digital logic lecture recording is shown in Fig. 2. The different time stamps on the left indicate that the students can access any part of the lecture recording by forwarding and rewinding the lesson. This allows the students to focus on a specific section of the lecture without the need to go through the whole recording. The students had access to daily course lectures through their Blackboard Learn™ software. Most students downloaded podcast versions of the daily course lectures and watched them as often as they wanted until they understood the topics covered in each lecture. This approach increased the interactions and discussions between the students involved in the F2F courses.

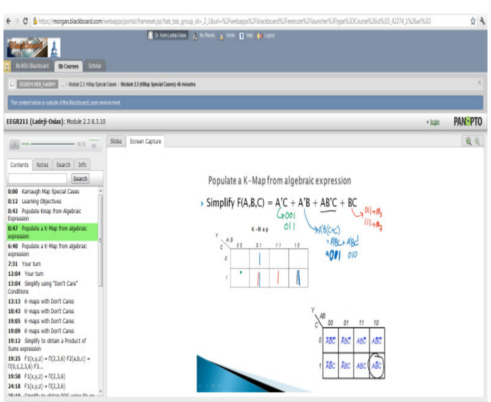


Figure 2: Panopto Focus™ lecture recording for digital logic course

The last phase of our project was to determine how to allow students to demonstrate their project and laboratory experiments to their instructors without being present on our campus. Although our on-campus students used the Mobile Studio IOBoard™ to complete their project and laboratory experiments outside of the laboratory classrooms, they were still required to come to our campus in order to demonstrate their final work in front of the course instructor. Since we wanted our online students to be able to complete all of their course requirements without being physically being present on our campus, we started evaluating various video conferencing software packages. After careful evaluation, we chose the Adobe Connect™ software because it was available on our campus. The Adobe Connect™ software is commonly used by other institutions and corporations to conduct face-to-face video conferencing in real time. It provides instructors with a virtual classroom environment for sharing their presentations, and desktop applications with remote participants such as online students anytime, anywhere. The main advantage of the software is that it works via a web browser, and does not require users to download any special software to join a meeting. It also allows instructors to go beyond simple PowerPoint and screen sharing by providing with additional options such as interactive chat, quizzes/polls, and breakout rooms for individual interactions. The instructors tested the various features of the Adobe Connect™ software by allowing some of the students enrolled in their F2F courses to use it for project and laboratory experiment demonstrations.

Once the different parts of the online ECE courses were completed and tested, the next step was to offer the courses as pilot courses to ECE students who were interested in taking some of their courses online.

III. ONLINE COURSE DELIVERY

A. "Electric Circuits" and "Intro to Electrical Lab" Pilot Course Results

The "Electric Circuits" and "Introduction to Electrical Lab" online courses were offered for the first time as pilot courses to ECE students in the Summer of 2010. Six students enrolled in the "Electric Circuits" course and only five students enrolled in the "Introduction to Electrical Lab" because one student had already taken the lab in the previous semester. Five of the six students were local students who wanted to take the summer online course in order to move ahead in their ECE curriculum. Although the local students enrolled in our two pilot ECE online courses had access to all the facilities on our campuses, the courses were conducted as if the students were completely online. Therefore, they were not required to come to our campus on a daily basis to download and view the lecture notes, to complete their project and lab assignments, or even demonstrate their project results. . We took this approach to ensure that the online courses that we developed could indeed be offered completely online to any student as long as they had access to the Internet. The sixth student was a true online student because he was working on his summer internship located in New York City. He only had to travel to our campus on two occasions to take his written exams and get parts for his projects and laboratory experiments.

The results of our two pilot courses are very encouraging although they suggested that more work needed to be done to make our online courses as effective and reliable as our F2F courses. One of the key issues that we faced during the summer session is the length of time available to complete the two ECE courses. The students enrolled in the pilot online ECE courses only had seven weeks to cover the course material that we usually cover in 14 weeks. The problem became more significant when students had to complete their laboratory and design experiments on their own. That is because the learning curve required to be familiar with the functionalities of the Mobile Studio IOBoards™ was steep. Since we did not have enough written documentation such as user manuals and troubleshooting tips on the Mobile Studio boards, the students had a difficult time completing their first laboratory assignment. Afterwards, their confidence level increased and they were able to successfully complete the remaining laboratory and design project experiments.

The students enrolled in the pilot online courses were given the same projects, homework assignments, and tests as the students enrolled in the regular courses. Although the students enrolled in the online course covered the same amount of material as the regular students, they were only given two hand written exams on campus instead of three or four exams that are given to the F2F students. They were given the exams on campus because they were all local students. This will not be a requirement for future online students because we plan to form partnerships with test centers or learning centers to allow them to take their exams from other locations. Due to time constraints and technical difficulties, the students enrolled in the pilot summer online courses completed fewer design projects compared to the regular students. Several of the topics covered in the regular course were combined into two projects instead of the usual three or four projects that are given in the regular course. All the students enrolled in both the "Electric Circuits," and "Introduction to Electrical Laboratory" pilot courses completed both courses successfully. However, their grade distributions were much lower compared to the 25 students enrolled in the regular course during the previous Spring 2010 semester as shown in Figure#3.

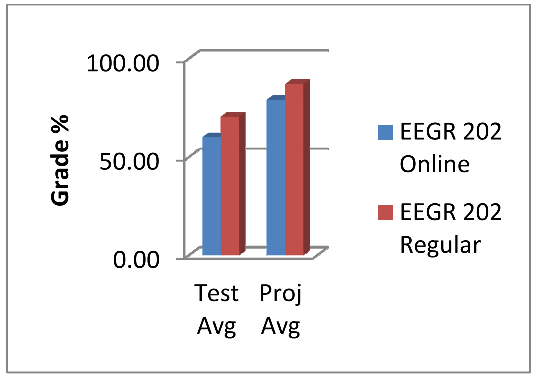


Figure 3: Grade Comparison between F2F and Online students for the Summer 2010 Pilot Course

This can be attributed to the lack of time available to complete all the course assignments in a very short amount of time. They initially had some technical difficulties downloading and viewing the Panopto Focus™ lecture recordings on their computers. The fact that the pilot courses employed several new technologies and pedagogies that the students were not familiar with, increased the learning curve of the students. The main reason is the lack of adequate time to study and understand the topics covered in each lesson in the summer pilot courses. Therefore, we have decided not to offer the two ECE online courses during the summer sessions.

The two courses were also offered during the Fall 2010 semester as hybrid courses and the Spring 2011 semester as completely online courses. A total of 12 students, 8 in the Fall 2010 and 4 in the Spring 2011 courses enrolled in both online courses. The results for the Fall 2010 and Spring 2011 semesters were much better than the ones from the Summer 2010 because the students had more time to complete their work and also had better interactions with the course instructor and the students enrolled in the F2F courses during the semester. The results indicate that the success of students enrolled in online or hybrid courses depend strongly on the background of the student and their commitment to the course. The students who performed poorly in the online courses did so because they either fell behind in completing the course work or missed a lot of weeks of course work due to various reasons. The students who performed well in the online courses proved that the courses were well designed and delivered because they were able to perform as well or even better than the students enrolled in the F2F courses. The results are shown in Figure 4. The data shows the comparison of the results for the 12 students enrolled in the online or hybrid courses during the Fall 2010 and Spring 2011 semesters, versus those enrolled in the F2F courses in the Fall 2010 semester (28 students) and the Spring 2011 semester (33 students).

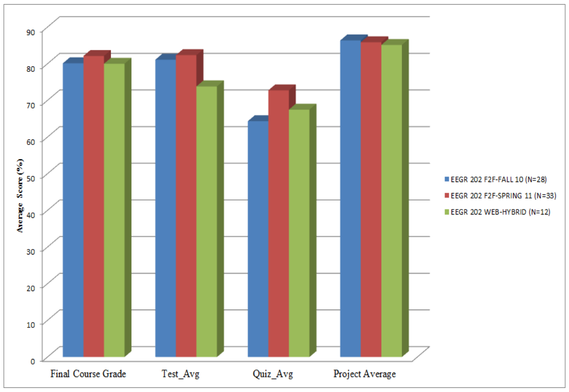


Figure 4: Grade Comparison between F2F and Online students for Fall 2010 and Spring 2011

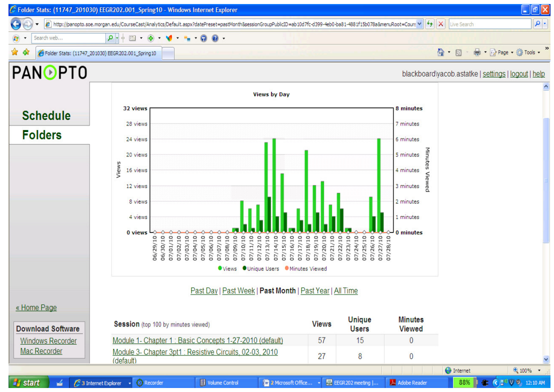


Figure 5: Monthly statistics on the use of the lecture recordings by online students

The two pilot courses allowed us to evaluate the various strengths and weaknesses of our online courses. The students enrolled in the online courses had access to lecture recordings from the Spring 2010, and Fall 2010 semesters. The statistics of the usage of the course lectures recordings suggest that the students enrolled in the two online courses found the Panopto Focus™ lecture recordings very valuable to their success in the courses. Figure 5 shows the overall monthly view statistics for the lesson recordings that were downloaded and viewed by the students during the summer 2010 session. The Panopto Focus™ also allows the instructor to check whether some students are ahead of other students by checking the unique number views of for each lesson.

The most difficult aspect of the online course delivery process was the implementation of the project and laboratory demonstrations online using the Adobe Connect™ software. First, we noticed that the video conferencing software requires users at both ends to have a good quality audio/video or web-cam in order to successfully conduct the meetings. This created a problem with one of the students enrolled in the online course because he had a very low quality web-cam on his laptop that prevented him from using all the features of the video conferencing software. Once the technical difficulties were taken care of, the students were able successfully demonstrate the results of their laboratory experiments to the course instructor completely online from three different locations. The course instructor was attending a conference in Troy, New York. Therefore, he conducted the project and laboratory experiments demonstrations from his hotel room. Two students were located in their dorms on the campus of our university. Two students were located in their apartment bedrooms in Baltimore, Maryland and one student was in his apartment in New York City, NY. Although the instructor could have conducted the online laboratory demonstrations from his office, he chose to do it while he was on travel to test the capability of the software to work from any location at any time.

The screen captures shown in Figure 6 and Figure 7 indicate how the instructor and the students were able to conduct the complete laboratory demonstration online. In figure 6, the student is seen making modifications to his circuit on his breadboard based on the instructions of the course instructor. The Adobe Connect™ software allows the instructor to open different screens that can be used to communicate with the student conducting the demonstration. The instructor can either share the whole screen or a specific software (such as PowerPoint) running on his or her machine. The instructor can also change the permission of the student(s) participating in the videoconference by changing their status from participant, to presenter or host. The Adobe Connect™ software also allows the instructor to remotely control the student's computer and make changes on the Mobile Studio Desktop™ software. This implies that the instructor can thoroughly check the performance of the circuit being evaluated by selecting different input values and evaluating the different outputs. Although the instructor cannot physically touch the student's circuit, he or she can easily thoroughly evaluate the performance of the circuit being demonstrated by the student. Figure 7 shows that other students can follow the demonstrations of their classmates while they wait for their turns. This is a typical scenario that happens when instructors evaluate project or laboratory experiments in a regular laboratory room.

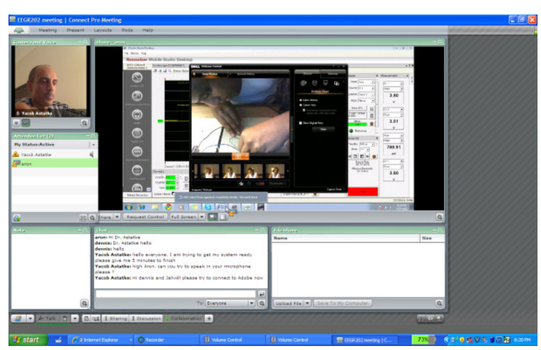


Figure 6: Student making modifications to his circuit on his breadboard based on the instructions by the instructor

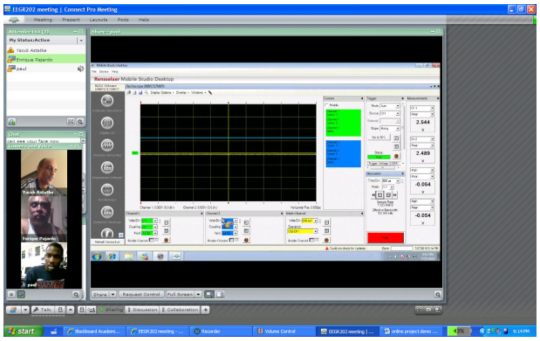


Figure 7: Screen capture showing the output of the circuit using the Mobile Studio Desktop™ software

B. *"Intro to Digital Logic" Pilot Course Results*

The "Introduction to Digital Logic" online course was offered for the first time as a pilot course in the Fall 2010 semester. It has since then been offered as an online course every semester. Since the Fall 2010 online course was a pilot, students were given the option of taking the course entirely online, or as a hybrid course, with the option of attending any face-to-face lectures. Subsequent offerings of the course have been online only. The enrollment in the online section of the course is usually less than 10 students. One aspect of teaching online courses without synchronous delivery is the lack of interaction with students during the lecture. A way to elicit student feedback on the lectures they watched is using the "Discussion Board" forum that is available in the Blackboard Learn™ software. In fact, having a weekly discussion forum that encourages instructor-to-student, and student-to-student interactions is a big part of the Quality Matters assessment rubric. For the "Introduction to Digital Logic" course, we observed that the discussion prompts tended to provide feedback on how students were processing the course topics. Sample of the questions included in the weekly discussion board activities are:

- Based on what you have done so far, what is the relationship between a truth table, a Boolean expression and a logic diagram?
- Boolean algebra is used to simplify with algebraic manipulation while K-Maps use a table. What are the advantages and disadvantages of each technique? Which do you prefer?
- This course is primarily a design course; you learn digital logic techniques and apply them to design problems. Which of the combinational design examples in Module 3.1 did you find most challenging to understand and why?
- We are using the Mobile Studio Boards for demonstration and building circuits at home. Please comment on how often you use the Boards and any recommendations you may have for the laboratory projects.

To allow students to complete the laboratory courses off-campus, students in the online section were provided with hardware and software that allowed them to test their circuits at home and demonstrate the circuits from off-campus locations using the Adobe Connect™ video conferencing software. All the digital logic experiments given to the F2F students were able to be conducted by the online students using CMOS chips that can be powered by the available 3.3V DC power supply on the Mobile Studio IOBoard™. The typical enrollment of the regular digital logic course ranges from 15 – 25 students per section, each semester. The enrollment for the online course has been less than ten students every semester because our online program is not currently available to all students. Therefore, comparisons of student performance between online and face-to-face students are limited by the low enrollment.

IV. SUMMARY AND CONCLUSION

The "Electric Circuits", "Introduction to Electrical Lab" and "Introduction to Digital Logic" online courses were offered for the first time as pilot courses to our regular during the Summer 2010 and Fall 2010 semesters. We have learned from the experiences of the three pilot courses and have taken additional steps to improve current and future online ECE courses offered at our institutions. We have already developed several additional training and teaching materials that clearly explain how to use the Mobile Studio IOBoards™ to future online students. All the laboratory experiments that were given to the students enrolled in the pilot summer courses have been updated and improved during the Fall 2010 and Spring 2011 semesters. We have also been able to test and evaluate new and improved laboratory experiments using the F2F students enrolled in the two ECE courses during the Fall 2010 and Spring 2011 semesters. The instructors have recorded additional lecture notes for the three pilot courses using the Panopto Focus™ software in the Fall 2010 and Spring 2011 semesters. This implies that students taking the three online ECE courses in the future will have access to additional lecture notes, example and homework problems, test and quiz solutions that were given in both the Fall 2010 and the Spring 2011 semesters. The final issue that we have to address is the approach we have to use for administering exams to future online students. We plan to use test centers or learning centers that are available in most cities and towns to allow our online students to take their exams without the need to travel to our campus. This approach is currently used by most programs that offer online courses to their students. We also plan to evaluate other portable ECE laboratory kits such as the National Instrument (NI) myDAQ™, and the Digilent "Electronic Explorer™" boards to evaluate their performances and compare them to the Mobile Studio IOBoards™ .

Although both the Mobile Studio technology, and the Adobe Connect™ software have previously been used separately by other institutions for similar applications, to the best of our knowledge no other higher education institution in the United States has combined both technologies to offer ECE undergraduate courses completely online. This new approach represents a major paradigm shift in the way higher education institutions can approach delivering Electrical Engineering education. We hope that it will open the door to many students who are candidates for joining the science, technology, engineering and mathematics workforce such as, current and new personnel relocating to new military bases, mid-career employees, and ex-military personnel because they typically require the opportunity to continue to earn a living while pursuing their education and are most often unable to relocate to college campuses for the two to three years required to complete the requisite courses for a Bachelor's degree. Online education is here to stay, therefore we hope that engineering schools nationwide can follow the path set by the other disciplines.

ACKNOWLEDGMENT

The authors would like to thank the Maryland Higher Education Commission (MHEC), and the Smart Lighting Engineering Research Center (ERC) at RPI for their financial support.

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