AC 2011-2250: USING THE MOBILE STUDIO TO FACILITATE NON-TRADITIONAL APPROACHES TO EDUCATION AND OUTREACH

Kenneth A Connor, Rensselaer Polytechnic Institute
Frederick C Berry, Milwaukee School of Engineering
Mohamed F. Chouikha, Howard University
Dianna Newman, University at Albany/SUNY
Meghan Morris Deyoe, The Evaluation Consortium
Gavin Anaya
William Brubaker, Rensselaer Polytechnic Institute

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Abstract: *STEM education at all levels from kindergarten through grad school generally requires expensive, complex equipment and thus is typically built around elaborate facilities with well-trained staff support. Mobile Studio Pedagogy (using the Mobile Studio Desktop software and the I/O board) makes it possible for instructors and students to participate in hands-on learning to any place they have a computer. Mobile Studio gives them access, at any time and any place, to a full electronics laboratory for the price of a textbook; students have a portable lab in which tinkering is again possible; requiring only a spark of interest - not a big budget. With a good start provided by interested and dedicated teachers, student accomplishments are only limited by their imagination. Since the Mobile Studio provides a portable lab facility, students can apply the tools they use in the classroom in their personal projects. The most obvious examples involve tinkering with cars (e.g., finding security system workarounds for someone building a car from an early 90's GM drivetrain) and robotics (e.g., adding a real electrical engineering component to a project for a robotics competition). Less obvious are the kinds of activities that show how exciting engineering can be provided by our students that make us so proud of them (e.g. finishing that great idea they had in their high school science fair on their own or a handicapped driver visiting science classes in their old high school).When students share these real world experiences, they are providing the best kind of motivation for future STEM professionals.*

When using the Mobile Studio, teachers are also free to reconfigure their courses, especially those with significant lab/experimental content, in a number new ways. In addition, many instrumentation-based course offerings can now be held in normal classrooms rather than in specially outfitted facilities. It is no longer necessary to tie students and instructors to the usual lectures, recitations and labs, especially since it is possible to give hardware-based homework. When the Mobile Studio approach is expanded to include video lectures, we are now free to organize courses in ways we would never have imagined in the past. Mobile Studio Pedagogy has been deployed and utilized in several electrical engineering, general engineering and physics courses to, for example, better enable instructors to employ the Kolb cycle of learning in their courses. Inertia from both students and faculty concerning the need for new types of learning materials can reduce the acceptance and effectiveness of new methodologies, but significant progress, demonstrated through an extensive evaluation process, has been made at several institutions.

1. INTRODUCTION

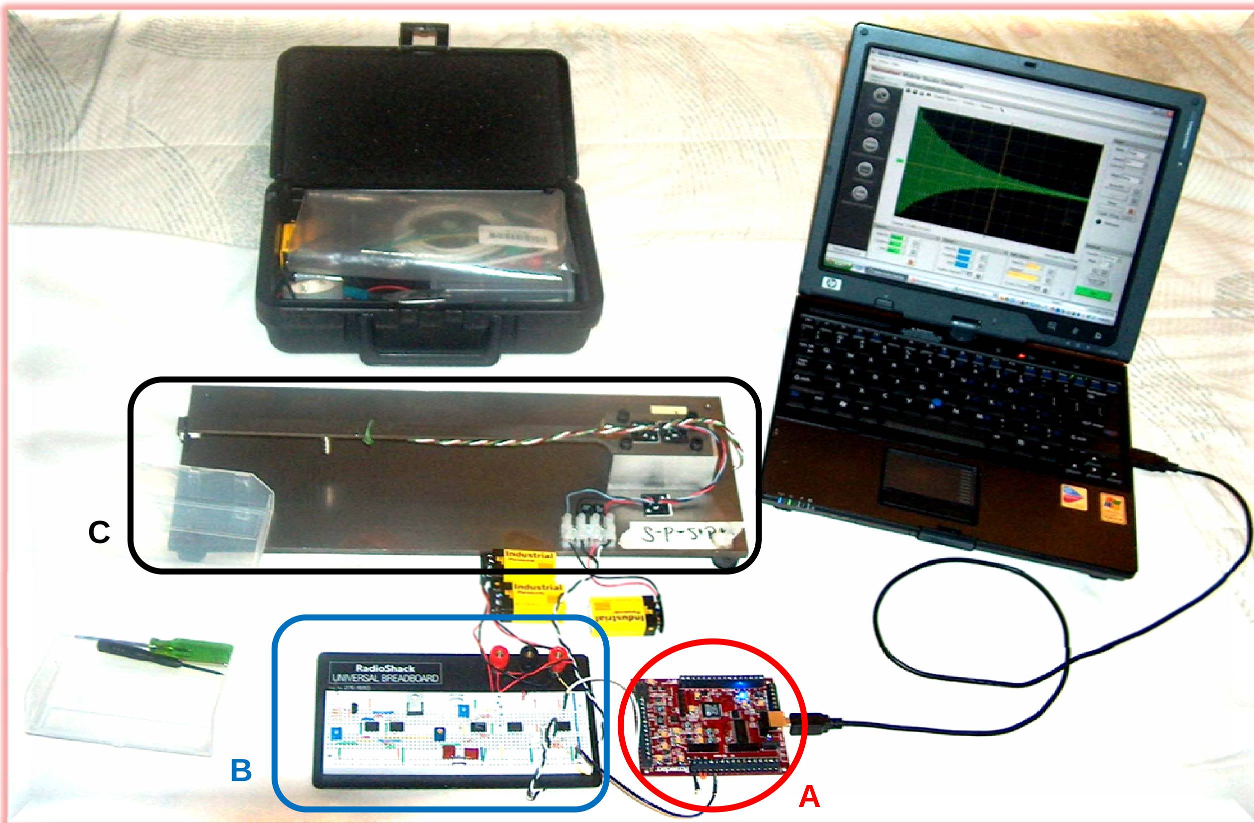
The Mobile Studio Project has developed and is continuing to develop pedagogy and supporting hardware and software which, when connected to a PC (via USB), provides functionality similar to that of standard laboratory equipment (oscilloscope, function generator, power supplies, Voltmeters, etc.) typically associated with a highly instrumented studio classroom or lab. The

Mobile Studio I/O Board is a small, inexpensive ($150) hardware platform for use in a home, classroom or remote environment. When coupled with the Mobile Studio Desktop software, the system duplicates a large amount of the hardware valued at around $10,000. Specifically, Mobile Studio Pedagogy promotes nontraditional education as its focus is on student-centered experimentation any time, anywhere utilizing hands-on learning to support more comprehensive, long-term knowledge retention of engineering concepts in a “real world” approach.

The project’s major goal is to enable hands-on exploration of science, technology, engineering and mathematics (STEM) education principles, devices, and systems that have historically been restricted to expensive laboratory facilities. (For background on the need for and efficacy of the hands-on activities made possible by the Mobile Studio, please see references 1-9, 16, and 17.) While designed to provide the functionality of a typical electronics lab, it can be set up to perform a large variety of functions, measurements, system control, etc. through the use of special purpose hardware and software, with many programming languages available for writing the software.

The project is now in refinement and beginning levels of dissemination. The Mobile Studio has been used to teach courses in electrical engineering, computer engineering, and general engineering electronics; physics courses; and K-12 technology-oriented courses. It has been exported from Rensselaer Polytechnic Institute (RPI) to partner institutions, Howard University and Rose-Hulman Institute of Technology, where several courses are using it, and has begun to be implemented at Boston University, Morgan State University, a STEM High School in Cleveland, Ohio (MC^{2}STEM) and universities in Africa (e.g., Addis Ababa). Evidence indicates the Mobile Studio can change the way students view their classroom experiences and the way we deliver the complex technical material in an engineering discipline. (Background on studio circuits and electronics and on Mobile Studio activities to date can be found in references 10-15.) In this paper, we summarize some of this evidence, describe how students have found personal uses for the Mobile Studio that could not be done previously outside expensive lab settings, and discuss how instructors are now free to change how they organize the educational experience they provide for their students.

A typical experimental configuration for a Mobile Studio based activity is shown below. The laptop, USB cable and Mobile Studio I/O Board and Desktop software provide the necessary measurement capabilities usually provided by an oscilloscope, a computer interface, (e.g. GPIB) and a computer to store and analyze the data. The Mobile Studio Desktop software can save any data to a useful file format for spreadsheet or other analysis tools. In the example shown, the experiment is a cantilever beam with strain gauges mounted on the top and bottom of the beam. The interface circuitry incorporates a Wheatstone bridge and instrumentation amplifier whose output is monitored by one of the Mobile Studio oscilloscope channels. The voltage from the bridge is calibrated to represent the displacement of the beam as it oscillates. Note the characteristic decaying sinusoid of an harmonic oscillator displayed on the laptop screen. This setup is used for a laboratory experiment and a design project in RPI's *Electronic Instrumentation* course, which is taken by students outside of electrical engineering.



Example of Mobile Studio Experimental Setup for a Cantilever Beam with strain gauges mounted on the top and bottom of the beam: (A) Mobile Studio Board, (B) Interface Circuitry for (C) The Device Under Test. Not labels are the tool and parts kits, the laptop computer, DC power (9V batteries) and the USB cable.

2. SUMMARY OF USE AT RPI

2.a. The Mobile Studio I/O Board

2.a.i. Status of Mobile Studio implementation at RPI

The I/O board has been successfully piloted within the Mobile Studio Pedagogy at RPI since Spring 2008 where it was first used in an *Electric Circuits* course. In the Summer of 2008, integration continued in a small group format. In Fall 2008-Summer 2009, full integration of the Mobile Studio approach began at RPI with the incorporation of all designed demonstrations and activities. Refinement of the demonstrations, activities, and the module began in the Spring and Summer of 2009. In Summer 2009, RPI's I/O board use expanded to include two classes, *Electric Circuits* and *Electronic Instrumentation*, which met concurrently. As a result, RPI established transferability of the I/O board across students' contextual academic experience[18]

In Fall 2009 and Spring 2010, refinement of the Mobile Studio Pedagogy continued in Fall 2009 and transitioned from instruction provided by the developer to a non-developer in Spring 2010, forming a new phase of replication. Widespread adoption of the Mobile Studio approach using I/O boards continued at RPI in Spring 2010 to include two additional classes resulting in on-site transferability of the module to an upper level course, *Introduction to Electronics*, in which the majority of students had previously used the I/O boards, and to a course outside of the original context, *Electronic Instrumentation*, in which students did not have a background in electrical engineering.

2.a.ii Evidence of successful use in multiple instructional and student settings.

As part of its ongoing development and implementation of the Mobile Studio I/O Board, designers and faculty at RPI are utilizing an independent evaluator to document and validate uses and outcome. First, the evaluators documented successful use of the Mobile Studio I/O Board with a diverse group of learners and a growing number of instructors and content settings. Students participating in the four courses that incorporated the Mobile Studio I/O Board represented learners typical of those enrolled in multiple engineering programs at RPI as well as at other schools teaching engineering content. For instance, overall, there were more males (80%) than females (20%) enrolled each semester in all courses; English was the primary language for the majority of the students; and multiple ethnicities were represented in all courses (e.g. Caucasian (74% and 64% respectively for the two Circuits classes; 78% Introduction to Electronics; 90% Electronic Instrumentation), Asian (13%; 20%; 12%; 5% respectively), and Hispanic (4%; 11%; 5%; 5% respectively).[19]

Similarly, evaluators have found successful use with students representing different stages of career development. Those enrolled in *Electric Circuits* in the replication phase were primarily in their second year while the courses in each transfer phase represented more advanced courses at RPI and generally served students at a higher level in their academic career. The majority of students enrolled in the course in the context-transfer phase were third and fourth year students in mechanical or aeronautical engineering while students enrolled in the content-transfer phase were generally advanced electrical engineering students enrolled in a course typically taken after *Electric Circuits*.

Data on learning styles also continues to support the ability of the Mobile Studio I/O Board to serve students across a diverse field of learning modalities.[15] For example, student responses to the Index of Learning Styles[3] indicated the presence of multiple preferred types of learning including visual, sensing, and sequential. Observations of classroom use indicate that use of the I/O board, with its ability to incorporate diagrams, pictures, concept maps, real-world connections, demonstrations, and hands-on practice of content supports these modalities of learning.

2.a.iii Support for student learning

Evaluators also found at RPI that use of the Mobile Studio I/O Board is directly supporting the process of student learning[14]. Through surveys, interviews, classroom observations, and reviews of cognitive assessments, it has been found that I/O boards assist in the structuring and enhancement of valuable learning outcomes. (See Table 1 for a summary of student reported outcomes.) In addition, during interviews and through observations it was noted that collaborative learning was facilitated by the use of the I/O board. Students who had not previously used the I/O boards reported that its integration into instruction enabled them to think about problems practically and graphically, thus enhancing learning, retention, and transfer.[17]

When queried during interviews, students expanded on the benefits of the I/O board in promoting different ways of thinking about problems noting, "*We learned material theoretically in lecture, equations, we learned how circuit components behave, but with the I/O board we could build them and put in any output and input you wanted so you could see just what you learned in class. You could see just what a circuit is doing, how to apply what was learned, and how to apply it to a real scenario like a guitar or cell phone. [The instructor] directly tied to the application as opposed to just equations in lecture.*"

Students also reported an unexpected area. Nearly 50% of students in the lower level courses (both in refinement and replication phases) and almost 30% in the context-transfer phase indicated they utilized the I/O board with another student for homework purposes.

As noted in Table 1, variations were found across settings and by phase of piloting. Data indicate that students in the most refined setting (e.g., all materials were developed and the instructor had used it before) found the Mobile Studio to be helpful in thinking about problems in a practical way, especially through the use of graphical or pictorial memory; it developed their problem solving skills and helped them to transfer knowledge and skills to other courses. Use in this setting also had an impact on affect toward learning. The students were more interested in the content, and more confident in their ability to learn. Similar findings were found for those students who used the Mobile Studio in a higher level course, Introduction to Electronics, where students had used the board in a previous course. Again, in this setting the material had been refined through previous use and the instructor had prior experience with the board as a pedagogical tool. Although of a lesser degree, positive trends also were found for first time use in the replication setting, in helping to think about problems in a graphical/pictorial/problem solving way and working collaboratively with fellow students; and in transfer outside the original electrical engineer content area, in developing problem solving skills, interest, confidence, and working collaboratively.

Table 1
Student Perceptions of I/O Board Benefits*

Statements	% Agree**			
	Refinement/ Expansion (Electric Circuits) (n=56)	Replication (Electric Circuits) (n=65)	Transfer to Higher Level Course (Introduction to Electronics) (n=42)	Transfer Outside Original Content (Electronic Instrumentation) (n=67)
Specific content learning				
Think about problems in graphical/pictorial or practical ways.	86	69	81	49
Develop skills in problem solving in the content area.	82	45	62	51
Recall course content.	73	38	67	40
General learning				
Transfer knowledge/skills to problems outside the course.	80	42	50	31
Apply course content to new problems.	80	41	60	40
Develop different ways of solving problems.	71	42	55	35
Work collaboratively with fellow students.	54	65	71	77
Affective learning				
Develop interest in the content area.	80	52	59	53
Develop confidence in content area.	77	45	81	54
Become motivated to learn course content.	68	37	55	31
Improve grades.	61	29	50	36
Develop attitudes of self-direction and self-responsibility.	57	32	49	37

** Numbers represents percentages of RPI participants who responded "Strongly Agree" or "Agree" on a 6-point Likert-type scale.*

Analysis of cognitive data[19] evidence outcomes related to use; students who received integrated IO board instruction at higher levels of practice and knowledge generation presented greater long term learning. Student scores on final exams were greater for items that reflected use of the Mobile Studio as part of instruction than were their scores on items that reflected content covered in the traditional way.

Preliminary findings[20] also indicate successful but differentiated use and outcomes by user characteristics. For instance, male students had higher perceptions of relevance toward practice than did female students, but female students reported greater gains on developing different and more flexible patterns of problems solving than did males. Use in autonomous or group settings also yielded differences in pilot sites. Those who worked in group or collaborative settings reported more of a relevance of practice towards the course, greater gains in pictorial or visualizing skills, greater recall, and better application to new problem settings. Students who worked alone reported use helped to improve their course grade.

2.b. Video Lectures

2.b.i. Status of Video Lectures at RPI

During 2010 a series of pilot videos also were developed and implemented at RPI as a function of Mobile Studio Pedgagogy. The purpose of the videos was to provide a method whereby instructors, advanced students, and external experts could provide material and context that might be used to replace, supplement, or enhance traditional classroom and laboratory instruction and be available in an anytime, any place scenario. A key specification of the design and development of the videos was that they must represent key components of content and context knowledge, be approximately five minutes in length after development and editing and the videos should be uploaded and available for use as deemed appropriate by faculty and/or instructional staff. (Jing is being used as the development tool in many cases.) Video lectures for the course were used concurrently with multiple power points, online handouts of notes for each experiment, online reading material from multiple websites, and in many cases, the Mobile Studio.

2.b.ii. Student perceptions of video lectures.

At the end of the Spring term, a sample of students were asked by the independent evaluator how the video lectures were used and if they contributed to their and other students' learning of the course material. Respondents indicated that the videos were used in multiple ways; many stated they used the videos for learning outside the classroom in ways that reflected both acquisition and rehearsal of knowledge (e.g., for homework where they both learned or practiced use of information) or for clarification if they were unclear about a specific topic. Several students elaborated on how the lectures were used in their statements, "*I would go through related lectures to refresh my memory of the topics and understand the explanations behind certain answers,*" and, "*to do pre-lab work and do whatever parts of the project I could outside of class to optimize group time*."

When queried further on how the video content supported instruction, several students replied that the videos were used to explain both basic and advanced concepts that would enable them to gain a deeper understanding of the upcoming laboratory assignments (e.g., as advanced organizers) and to provide visual solutions to practice problems on labs and tests (e.g., support for direct and guided instruction through repeated opportunities for clarification and rehearsal). The majority of students reported that the videos assisted them in reviewing for exams (e.g., rehearsal of knowledge) noting that the videos were "*quick and efficient ways to review*."

The videos were noted to be especially helpful in preparing for labs. Almost all students noted that that the videos allowed them to pre-view a demonstration of new material, and to review material for use in laboratory assignments (e.g., "*I was able to review videos prior to attending the labs, which gave me a head start with both the hands-on and conceptual aspects of the lab*," and "*The first video* [in the lecture] *usually reviewed necessary material for the lab.*") Half of the student respondents reported that the video lectures were also used to guide them through the laboratory assignments. For example, one student stated that the video gave a "*step-by-step guide for the procedure.*"

Students reported several barriers or deterrents to use that reflect 21st Century students' assumption that information will be independently, immediately, and non-sequentially available (e.g., at their fingertip when and where they want it). For instance, one significant barrier to using the video lectures noted by the students was the need to download each video separately; students noted that the process was "*time consuming*" and "*frustrating*." Additional barriers included having to wait/sequence through specific parts of the video to get to the exact information students needed or wanted (i.e., students reported each video lecture reviewed the previous video, causing redundancy). Students also noted lack of immediate responses to questions as a barrier, indicating that they wanted the opportunity to "*ask a question and get an answer right away*" as part of the learning process.

When queried as to the "best" aspects of using the video lectures, a common theme was the freedom and flexibility to watch the videos whenever, wherever, and as often as they wanted. Other comments concerning the best aspect included the ability to watch and re-watch a problem "*worked through from beginning to end*," Students also noted that the timesaving quality and accessibility of the video lectures and the format of showing one subject at a time (…"*was awesome*"), as was the ability to watch and re-watch a video so that they could increase their understanding of a concept.

In sum, the pilot use of video lectures has proven to be useful and relevant and is ready for the next phase of development and implementation. This includes further development, broader use, and beginning tests of transferability to other instructors and sites.

3. VIGNETTES OF STUDENTS' PERSONAL PROJECTS

One of the biggest rewards for a dedicated engineering professor is to hear back from their students about activities in which they find effective use for what we teach in our classes. Engineers make things and solve problems and if our students manage to accomplish something along these lines, especially while they are still students, we have additional evidence of successful instruction/learning. As noted earlier, the Mobile Studio was never meant to be just a tool for classroom teaching; it was meant to make it possible for students to tinker in our very complex technological world. As the project was developed and implemented into instruction, it was our hope that, with a completely portable electronics lab at their disposal, students would find ways to make things and solve problems. Following are a few examples that demonstrate what can be done by students as they transfer learning to their real world.

Vignette 1: Mechanical Engineering Student – One of the two RPI courses in which the Mobile Studio has been utilized the most extensively is *ENGR-4300 Electronic Instrumentation (EI)*. This is a course in which students outside of electrical and computer engineering receive most of their exposure to electronics. It is taken by nearly all engineering majors, but the majority of the students are from mechanical and/or aeronautical engineering. Many students come to this course with little innate enthusiasm for the material addressed and experience some conceptual difficulties because they cannot directly experience current or voltage. Based on the traditional measures of success (student exam performance and student attitude surveys), the present delivery of the course, based on the Mobile Studio, has been successful. More extensive assessment methodology has also been used to document this success, as reported elsewhere. Here, we are not specifically concerned with the course, but rather what the students in it do outside of class with what they have learned.

One EI student in Spring 2010 found a very interesting use of the portable electronics measurement capability made possible with his mobile studio. What makes his story particularly relevant for all engineering programs is that his interests coincide with possibly the first thing anyone thinks of when describing why a student decides to study mechanical engineering – he is a gearhead. He even has the banged-up knuckles to prove it. His personal project has been to build a car based on the drive train of an early 1990s Corvette, which he had more-or-less completed by the time he began studying electronics. However, he was faced with one very difficult problem, he could not get the ignition system to work. In the 1990s, GM cars came with a security system based on embedding a resistor in the ignition key called VATS (vehicle anti-theft system). When the key is inserted, the value of the resistor is measured and, if it has the correct value, a 5V- 50Hz square wave fuel enable signal is generated to let the PCM know it is okay to allow the engine to start. The student's problem was that he did not use the Corvette steering column so he had to find a work-around. His first approach was to place his laptop and mobile studio board on the passenger seat and use the Mobile Studio to generate the required square wave. Once connected to the ignition system, he was able to start his car. This was not a long-term solution, however, especially after his friends teased him about having to take his laptop everywhere. About the same time he had gotten his car to start, we had an experiment in which the students learn to use a 555 timer to generate trains of square pulses. He built such a circuit, tested it with his mobile studio and then was successful in getting his car to run. In the end, he did some further study of the ignition circuitry and was able to hard wire in the required resistor so he no longer needed even the simple 555 circuit.

Vignette 2: Electrical Engineering Student Helping Mechanical Engineering Students – One of the EE undergrads who has worked on a wide variety of Mobile Studio applications for education and outreach, is a particularly gregarious young man with lots of good friends in mechanical engineering. Since these friends must take *Electronic Instrumentation*, they typically come to him with questions. With his mobile studio, he is able to offer what amounts to an *ad hoc* open shop service anywhere he and his friends get together. He also helps with circuit modeling using a commercial PSpice program and paper and pencil analysis. There are very, very few activities in EI that require any kind of specialized equipment. Because he is such an excellent young man, who thinks all EI students should benefit from the kind of help he can offer his friends, he has produced a series of video tutorials on such topics as triggering, basic operation of both the Mobile Studio Desktop the PSpice program we use. These videos are available through the course website and the Mobile Studio Project website (mobilestudioproject.com) where there is also a link to the course. Note that the Mobile Studio is very easy to use in video presentations because all that is generally required is to record the screen on the laptop.

Vignette 3: Electrical Engineering Student – A young woman, graduating with her EE degree in Spring 2011, used her mobile studio to improve on a science fair project she worked on in high school. The goal of her project was to provide some kind of a visible warning to hearing impaired drivers when an emergency vehicle is nearby. Without the ability to hear a siren, such drivers must rely on recognizing a flashing light from the emergency vehicle. To supplement this information, she built a device that listened for signals with characteristics similar to sirens and then triggered a flashing light on the auto dashboard. (The device consisted of a microphone, band pass filters, and a series of LEDs.) Her task was made difficult because sirens do not all sound the same, but she was able to identify a frequency range characteristic of most sirens and designed a simple filter to look for such a signal. Without a good scope or spectrum analyzer, she could only base her design on analysis and field testing, based on her many recordings of sirens from her community. While it is fortunate that her application can tolerate false positives (it is better to be warned and then notice that no emergency vehicle is approaching) it was not as reliable as it could have been with better instrumentation. Included with the standard Mobile Studio Desktop (for scope, function generator, spectrum analyzer, etc) software is a set of LabVIEW .vi files including one that generates Bode Plots. She used the Bode Plot capability to design and implement a higher order filter (also using what she had learned in other EE courses) to improve upon her original design.

Vignette 4: Electrical Engineering Student – One of the most effective approaches for recruiting high school students into engineering is to have our undergraduates connect directly with students at their former schools. Historically, these visits have been largely limited to our students talking about what they do, maybe showing a presentation with lots of nice pictures, but without much opportunity for either real-time demos or hands-on activities. Another senior EE student has gone back to his high school where, as he described the experience, he "used it for fun on occasion; ***I used it in a one hour lecture I gave to my old high school physics class*** to demonstrate the effects of inductors and capacitors on circuits. The students were intrigued by seeing the effects in real time." This is a student who has integrated the Mobile Studio into nearly all aspects of his education. "My project was a ***variable audio bandpass filter circuit***.

Potentiometers where used in the high and low pass filter circuits to vary the value of the resistance and therefore the cutoff frequencies. The Mobile Studio was used to both input a signal and measure the magnitude and phase shift of the output. In addition, the output was connected to a buffer and in turn to a set of powered speakers to hear the output. The purpose of the project was to isolate frequency bands to hear specific instruments; in this particular case, I was attempting to isolate the bass instrument in a song to more accurately determine the notes and rhythm being played."

In another project, he "needed a ***12-bit data logger for portable data collection outside using a pyranometer (measures solar irradiance)***. Mobile studio proved to be the simplest, easiest, and most portable solution. Regular multi-meters aren't sensitive or accurate enough. Oscilloscopes are bulky, require external power, and don't have logging capability. 'Pro Loggers' cost in the range of $300+ and also lack logging capability. A microcontroller such as 8051 with a 12-bit ADC requires extensive coding and expertise that is beyond reach for other members in the group who are mechanical engineers, etc. ***Mobile studio is the only solution that is able to address all of these issues."***

Vignette 5: Electrical and Mechanical Engineering Students – In addition to these examples, students have used the Mobile Studio to repair a broken Blackberry obtained on their summer job (ME), built an alarm to make sure their refrigerator door was closed (ME), monitored the output of a solar panel in an engineering design class (EE), diagnosed the operation of a robot for a local high school's *First Robotics* team (EE), etc.

4. COURSE ORGANIZATION OPPORTUNITIES MADE POSSIBLE WITH MOBILE STUDIO

4.a. Managing Resources

The development of the Mobile Studio and its associated pedagogy began at RPI and then spread to its two partner schools, Howard and Rose-Hulman. One of the most important motivators for this rapid spread to new courses is that the Mobile Studio is inexpensive and mobile. It does not require the kind of infrastructure necessary for a typical lab. Because of its low cost (<$150), it is not difficult to find the necessary resources to bring it to a classroom where electrical measurements are useful. Because it is portable (requires nothing but a laptop, electrical power and, at times, connection to the internet), it can be implemented in most modern classrooms. At RPI, this has made it possible to move the *Electronic Instrumentation* course from its expensive but too small studio classroom to a room that holds twice as many students. For example, the largest of the first studios built at RPI is limited to 42 students and the studio used for Electronic Instrumentation serves 36. The new room using the Mobile Studio serves 72. In addition, the new room was originally designed for an embedded systems course and did not have any of the standard instruments (scope, function generator, etc.) required for EI. With the addition of 40 Mobile Studio boards (the cost of 40 textbooks) however, every pair of students now has the equipment required. Similarly, Intro to Electrical Systems for civil and chemical engineers (EE 206) at Rose-Hulman has now been moved from a studio to a conventional classroom thereby freeing that studio/lab space for other courses. Howard, which had no studio classrooms, can now offer both of its intro circuits courses (Networks I, II) and electronics courses (Electronics I, II) in studio mode (with labs integrated into the regular class meetings) without investing in any new classrooms. In sum, integration of the Mobile Studio makes it possible to utilize studio-based pedagogy without the need for expensive classrooms.

4.b. Improving and Enhancing Curriculum

Mobile Studio Pedagogy puts the focus on student centered activities that are naturally paced to the needs of individual students, decreasing and limiting ties to specified class meeting times and locations. Learning and practice can take place anywhere and anytime so students can find the approach that best meets their needs and styles. While the ability to apply studio-based pedagogy provides an exciting new approach to engineering education, standard studio also has its limits, because it is focused on an integrated classroom experience, which implies it is done in a classroom.

The Mobile Studio further frees the teacher and student to continue the integration of theory, experiment, paper and pencil problem solving, computer simulation, etc. anywhere and anytime. Thus, students can be given opportunities to do hardware-based homework. With this flexibility, students and instructors are not tied to formal classroom schedules incorporating lectures. Whether offered in a separate time period or as part of a studio experience, teaching can occur in a form that will meet the needs of students, content, and instructors. An example of this use is reflected in the following.

In RPI's *ECSE-2010 Electric Circuits*, students were given both in class and out of class projects to complete with the Mobile Studio. (In this class, unlike EI, each student has their own board. In EI each team of 2 students has a board.) Cognitive studies using *Electric Circuits* final exam questions demonstrated one of the most exciting results we have seen while assessing the effectiveness of the Mobile Studio. Typically, students perform very well on analysis questions, but not on synthesis. Questions that require students to pull together several concepts and then do a simple design have served more to help identify the top students in the class rather than elucidate the extent of learning for the class as a whole. The synthesis question on the final exam required the students to design a filter from a written spec, and then determine the resulting transfer function. The problem involved several concepts that were addressed in Mobile Studio activities both in class and out. Compared to results from earlier terms, an increase of 10 points per problem (out of 20) was realized, with the overall class median increasing from the low 60s to the mid 70s. Even students who performed poorly overall did well on the synthesis problem, which leads to the conclusion that the scaffolding of fundamental concepts (e.g. frequency response, filters and resonance) using paper/pencil, in-class hardware problem analysis, and an out-of-class project was very beneficial.

With the addition of techniques inspired by the Universities of Utah and Wisconsin in teaching electromagnetic theory (Prof. Cynthia Furse and Prof. John Booske, respectively) an additional feature, video lectures, can be added to the studio experience as noted in the assessment summary above. Lectures can be recorded and posted on the course website so students can work through the background materials for experiments and projects at home, at their own pace. Class time can then focus totally on student activities, discussion of common issues, and demonstrations that help students put their work into a broader context. This addition to the Mobile Studio also can be implemented in a standard studio/lab facility.

5. CONCLUSIONS

At RPI, Howard, Rose-Hulman and now other schools, we have shown that a new tool for learning engineering, the Mobile Studio, can effectively facilitate non-traditional approaches to education and outreach. Instructors are now free to integrate lab activities that require electrical measurements in any modern classroom without the use of a limited access, expensive facility. Students can be asked to do hardware-based homework and not be limited to lab openings and schedules. Students also can utilize the experimental capabilities they have learned in class while pursuing their own personal interests and in other classes where, in the past, they would have to hope for access to someone’s lab and, even then, could not make real-time measurements in the field.

Of more importance, use of the Mobile Studio makes it possible for students to carry their enthusiasm for engineering and science from the classroom to any place they have a computer. Students have a portable lab in which tinkering is again possible; requiring only a spark of interest - not a big budget. With the support of interested and dedicated teachers, student accomplishments are only limited by their imagination.

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