AC 2011-2039: MULTI-INSTITUTIONAL DEVELOPMENT OF MOBILE STUDIO BASED EDUCATION AND OUTREACH

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Craig Scott, Chair of the Electrical and Computer Engineering Department at Morgan State University, has extensive experience in the development of advanced engineering visualization tools and courseware. Additionally, he has been conducting empirical studies on effective learning technologies, as well as remedial math preparation for engineering students. He teaches courses in electromagnetics, solid state theory, characterization of semiconductor materials, computer vision and computational electrical engineering.

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Adam Wilson received his BS in computer science from College of Saint Rose in August 2010. He is currently employed at the Computational Center for Nanotechnology Innovations at Rensselaer Polytechnic Institute.

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I am an undergraduate student at The College of Saint Rose. I am majoring in Adolescence Education (7-12) in Mathematics. My goal is to be a teacher that goes beyond the math curriculum to engage and motivate students. Many Middle and High School students do not see the use of math in their lives. This is why I want to introduce students to the many applications of math. One way to accomplish this is to encourage STEM education. The classroom should be a place where students learn to make connections to other areas of interest and other subjects. They should know the significance of their education. Therefore, it is my pursuit to make learning meaningful and applicable.

Yacob Astatke, Morgan State University

Dr. Yacob Astatke completed both his Doctor of Engineering and B.S.E.E. degrees from Morgan State University (MSU) and his M.S.E.E. from Johns Hopkins University. He has been a full time faculty member in the Electrical and Computer Engineering (ECE) department at MSU since August 1994 and currently serves as the Associate Chair for Undergraduate Studies. He teaches courses in both analog and digital electronic circuit design and instrumentation. Dr. Astatke has more than 15 years experience in the development and delivery of synchronous and asynchronous web-based course supplements for electrical engineering courses.

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Thomas D.C. Little is a professor in the Department of Electrical and Computer Engineering at Boston University. He is Associate Chair for Undergraduate Studies for the department and is director of the Multimedia Communications Lab where he is involved in the development of enabling technologies and applications for networked and distributed systems. Prof. Little is Associate Director of the Smart Lighting Engineering Research Center – a collaboration of Rensselaer Polytechnic Institute, the University of New Mexico, and Boston University. Recent efforts include research in video sensor networks and streaming in wireless settings, ubiquitous optical networking with visible light, vehicle-to-vehicle/infrastructure (V2X) communications, and the application of wireless sensors in health monitoring.

Dr. Little received the BS degree in biomedical engineering from Rensselaer Polytechnic Institute in 1983, and the MS degree in electrical engineering and PhD degree in computer engineering from Syracuse University in 1989 and 1991. He is a Senior member of the IEEE, a member of the IEEE Computer and Communications Societies and a member of the Association for Computing Machinery. He serves on the editorial board of the Journal of Multimedia Tools and Applications and on various program committees.

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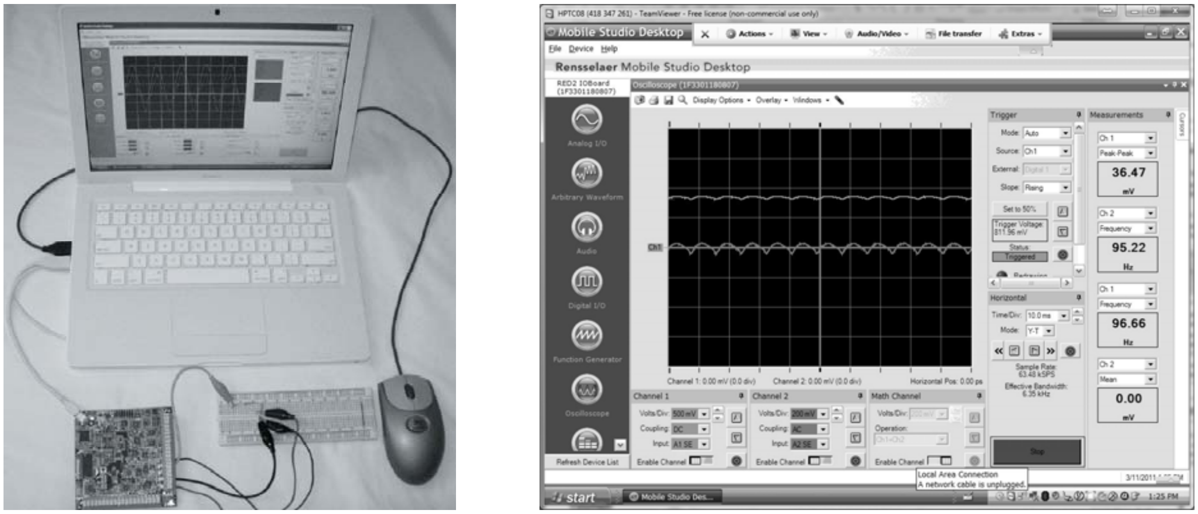
Dr. Millard is a Program Director in the Division of Undergraduate Education at the National Science Foundation (NSF). He is involved with the Advanced Technology Education (ATE) program, the Math and Science Partnership (MSP) program and leads the Transforming Undergraduate Education in Science, Technology, Engineering and Math (TUES) program. Prior to joining NSF, he was the Director of Engineering Education and the Academy of Electronic Media at Rensselaer Polytechnic Institute. During his many years at Rensselaer, he served as a faculty member of the Electrical, Computer, and Systems Department and directed a number of research centers; including the Center for Integrated Electronics. He is the founder of the Mobile Studio project, which enables students to learn and perform experiments that use an oscilloscope, function generator, digital control, and some form of power supply at anytime, anyplace. He holds a patent for the development of a laser-induced, plasma-based Non-Contact Electrical Pathway and has received such awards as the Premier Award for Excellence in Engineering Education Courseware and the Best Paper Award of the Institute of Electronics and Electrical Engineers (IEEE). Dr. Millard has been voted Professor of the Year on three occasions, selected as RHA Professor of the Month and was chosen as the Eta Kappa Nu Outstanding Professor in 2009.

Multi-Institutional Development of Mobile Studio Based Education and Outreach

Abstract: *The Mobile Studio I/O Board is a small, inexpensive 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 often used to teach electrical engineering, computer engineering, control systems, physics courses and K-12 technology-oriented courses. The project's 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. The Mobile Studio Project is now being utilized to enhance STEM education around the world. Mobile Studio instrumentation capabilities are similar to those available with traditional, stand alone instruments, but the experience of building a course or outreach activity can be quite different. Thus, a significant milestone for this new pedagogy is the expansion of its use beyond the original core partner institutions. The Mobile Studio learning platform began development at three schools, where it has been used to teach electrical engineering courses for both majors and non-majors. This activity has recently been expanded to additional schools with some notable early success that demonstrates how this approach can be transferred elsewhere, eventually improving programs at the original partner schools. Content development continues at several schools with new partners being added, including some in Africa. In addition to application in electrical engineering education and outreach, Mobile Studio materials are being developed by and for students in adolescent education and computer science at a small liberal arts college. Activities at all involved schools have added significantly to the value of Mobile Studio pedagogy.*

1. INTRODUCTION

The Mobile Studio was originally developed at Rensselaer Polytechnic Institute and then shown that it could be enthusiastically transferred elsewhere by Rose-Hulman Institute of Technology and Howard University. This was the first big hurdle to demonstrate that any school could find effective use for this new educational tool. (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.) The Mobile Studio includes Mobile Studio Desktop software and a small, portable Input/Output (I/O) board that together connect to the USB port of laptop computers and duplicate the measurement capabilities usually provided by an oscilloscope, function generators, a computer interface, (e.g. GPIB) and a computer to store and analyze the data (see Figure below). This enables students to use the technology in regular classrooms and anywhere they can use a computer so they can monitor signals from almost any sensor located almost anywhere.



(Left) Example of Mobile Studio setup to study a simple circuit showing the Mobile Studio I/O Board and the circuit under test, with power supplied from the Mobile Studio board. (Right) The Mobile Studio Desktop screen for a solar cell detecting light from an LED light bulb (this experiment was run remotely using screen sharing software).

At each of the original three partner institutions, the emphasis has been on application in courses that have a primary focus on electronics, whether the audience is electrical engineering students or students from other engineering disciplines. In addition, Mobile Studio has been used in outreach activities that cover most of K-12 in programs for both students and teachers. We have found that application at any level helps to inform the development at all levels[17], with high school and even elementary school programs impacting college courses and, of course, vice versa. The Mobile Studio was originally conceived for undergraduate courses, with the expectation that it would also be useful for outreach; to have materials developed for K-12, useful in more advanced settings, was a pleasant surprise. (Background on studio circuits and electronics and on Mobile Studio activities to date can be found in references 10-15.)

The second hurdle in the spread of Mobile Studio for undergrads is transfer to other institutions beyond the original three. Through their collaboration in the SMART LIGHTING NSF Engineering Research Center, two more institutions have now begun to contribute to understanding how best to use Mobile Studio – Boston University and Morgan State University. The five schools in this group include two with large research enterprises, two comprehensive HBCUs, one undergraduate engineering school and all with a very strong commitment to high quality engineering education. Each school has its own strengths and issues to deal with and, thus, each brings something unique to the project. Two other types of schools are now just beginning their work with Mobile Studio – a liberal arts school with a very strong focus on educating future teachers (College of St. Rose) and universities from Africa (Addis Ababa, University of Ghana, University of Buea and others). By combining the variety of levels (K-16) with very different schools, a true multi-institutional effort has resulted. In this paper we describe results from this effort.

2. THE THREE ORIGINAL PARTNERS

As part of its implementation of the Mobile Studio approach, independent evaluation and validation of use is being conducted to document outcomes. The following is a summary of current findings for the Mobile Studio I/O Board as it supports instruction and learning across multiple learning sites.

In 2007, the RPI developer piloted the use of the I/O boards in a controlled setting during the academic year using regular classrooms; use was fully integrated with a smaller class in the Summer of 2008. In the following year, use was further extended through field-testing at Howard University and Rose-Hulman in addition to full integration of use at RPI.[18] In 2008-09, use of the module was field tested in additional courses at RPI (*Electronic Instrumentation* and *Introduction to Electronics*) with replication continued into 2009-10. Currently, I/O board use has been expanded to include both didactic and experiential instructional settings as well as use by multiple instructors and in different levels of curriculum. Evaluator observations at RPI confirmed use of the IO Board to support instructor demonstrations of theory and real life examples, step by step modeling of processes, guided problem solving, independent practice, and small group or autonomous modeling of hypothetical work problems[19]. Evaluators also noted integrated board use within lectures, embedded lab exercises and stand alone lab exercises. Students' responses also evidenced this use noting frequent embedded use, citing that *"Class was lab"* and that use of the I/O Board brought the lab and classroom together.

Observers and students documented successful support for both autonomous and collaborative learning through use of the Mobile Studio approach. Students in lower level classes reported successful use in both group and single student learning; the developer's class reported high instances of independent use (91%) while students in the replication class (same material, non-developer instructor) reported partner-use (91%). Students in higher level courses, where the board was used to supplement transfer learning, reported primarily autonomous (91%) use.

Students also reported use in an unexpected area. Nearly 20% of students in the lower level courses (both in refinement and replication phases) and in the context-transfer phase indicated they utilized the I/O board with another student for homework purposes. Nearly half of the students (48%) indicated autonomous use of the board to support out of class learning, and 29% indicated that they used the board with one or more peers to support out of class work. When queried, these students noted that even though the work was not required, they used it to help rehearse, review, and explore concepts. Those working with peers also reported sharing new uses and applications.

The application of Mobile Studio at Rose-Hulman is similar to RPI except that the order of the courses chosen is reversed, since the first courses addressed were electrical systems courses for other majors, not EE. Two different courses were offered in the first phase, one for civil and chemical engineers and one for mechanical engineers. The former was previously offered in a studio classroom, but was moved to a traditional room once most labs were converted. The latter had no labs so mini-labs were added to incorporate more hands-on activities and help students develop a deeper understanding of the theoretical relationships. In phase two, intro ECE courses also were converted to Mobile Studio format. With inclusion of the Mobile Studio, all basic electrical courses could support educational objectives that involved measurement. To assess whether this objective was being met, students were given a lab practical exam worth about 5% of their course grade. Nearly all students achieved a grade of A on this practical, with those that did not usually not passing the course.

Table 1
Verified Frequency and Perceptions of Use at RPI
Percent of Occurrence*

Statements	Refinement/Expansion (Electric Circuits) (n=56)	Replication with different instructor (Electric Circuits) (n=65)	Transfer to Higher Level Course# (Introduction to Electronics) (n=42)	Transfer Outside Original content (Electronic Instrumentation)# (n=67)
Instructor used I/O boards to demonstrate material/concepts				
In Class	36	19	0	36
In Lab	98	72	51	30
Students used I/O boards independently				
In Class	20	13	10	60
In Lab	91	63	91	58
Homework	48	19	7	13
Students used I/O boards with 1 peer				
In Class	7	26	12	93
In Lab	45	91	83	97
Homework	20	19	7	19
Students used I/O boards with 2 or more peers				
In Class	7	19	7	49
In Lab	16	20	34	52
Homework	9	8	5	8

**Numbers represent percentages of student participants who responded that the event "often" or "most of the time" .*

Application at Howard has involved only ECE courses at this time; all of these courses address circuits or electronics. There is increased enthusiasm on the part of the student towards learning opportunities that involve hands-on activities as well as a general improvement in course grades after the implementation of Mobile Studio. In fact, grades have continued to improve each term for these basic subjects since they have been in Mobile Studio format. A general studio approach was not possible at Howard previously because they did not have the resources to build the necessary, very expensive, facilities. The experiences at Howard and Rose-Hulman demonstrate that the Mobile Studio offers an increased level of flexibility in facility use which can either free up expensive lab/studio classrooms for other uses (as at Rose-Hulman) and/or make it possible to add hands-on activities to any existing course, achieving at least some aspect a studio experience for students, in a standard classroom (as at Howard).

3. Boston University

At Boston University, ECE faculty have begun to use Mobile Studio to engage students as part of K-12 outreach, STEM activities, and in the freshman year. This use spans multiple courses, instructors, and serves a variety of goals. Following are examples of how the boards were used.

- *SMART LIGHTING: An Engineering Course* – part of the Boston University Summer Challenge program that attracts students internationally from the 10^{th}-12^{th} grades. This course will be offered for the third consecutive year in the summer of 2011 and is comprised of three two-week sessions. Students gain exposure to LED devices, circuits, and optics and exploit Mobile Studio as the primary tool for experimentation. The course attracts approximately 60 students per year. No assumptions are made about the math, science, or engineering preparation of the students in this course.

- *Smart Lighting EK 131/132* – this is one of the Boston University College of Engineering freshman modules intended to introduce new engineering students to electrical engineering concepts as part of a retention program. Students use a similar syllabus to the outreach course above, but the course assumes pre-selection to engineering. The modules are developed more leisurely than in the summer program and cover far more supporting material. There is much more time for hands-on Mobile Studio work. This course is now in its second year.

For both applications, the Mobile Studio I/O Board is combined with a simple optical transceiver circuit, designed and built by Boston University SMART LIGHTING ERC students. Two types of communications experiments are done, one that combines the Mobile Studio with the transceiver so that students can better understand what it takes to configure a working communications system and one that uses only the transceiver, for which the Mobile Studio is only used for its basic measurement functionality.

The transceiver boards and lab write-ups have been provided to other partner schools, who are integrating them into their activities. This effort has demonstrated that materials developed for

K-12 outreach (the summer high school program) can impact undergraduate courses. All of the hardware from the high school class is now located in the Boston University *High Tech Tools and Toys Lab*, where it is used in the first year intro to engineering class, in other high school programs and for undergraduate research.

4. AFRICAN UNIVERSITIES

In the summer of 2009, Mobile Studio was introduced to all three Ethiopian engineering schools (Hawassa, Addis Ababa, and the Defence Engineering College) through their connections with Morgan State. As with schools in other developing nations, the Ethiopian universities have very limited experimental facilities to support their engineering programs. At Addis Ababa, for example, it is typical for all students in an electronics class to share one experimental setup, so most students watch while a very small number get to do experiments. With the addition of even 5 or 10 Mobile Studio I/O Boards, the students not only can all do hands-on activities in class, they also can do independent projects. One example of what they have been able to do is at Addis Ababa in biomedical instrumentation. (Biomedical and computer engineering are growth disciplines in Africa, based on new programs at the University of Ghana). The Mobile Studio incorporates two arbitrary waveform generators (AWG) in which the students downloaded sample ECG waveforms so that they could be used to test various signal conditioning schemes in their project. Another set of students used the precise control of the sine wave phase from the two AWGs to test power devices for their project.

In late 2010, three new African schools began working with Mobile Studio. A Mobile Studio workshop was held at the University of Ghana as part of a Conference on Appropriate Technology that engaged universities primarily from West Africa. As a result, the Computer Engineering Program at UG, along with Kwame Nkrumah University of Science and Technology in Ghana and The University of Buea in Cameroon will be using Mobile Studio in their coming terms. The low cost and the ability to use laptops for data collection and analysis makes the Mobile Studio attractive to these very resource strapped institutions. In many cases these sites literally have no other options, but the successful application of Mobile Studio at RPI, Howard and Rose-Hulman shows that their choice to embrace this approach should be successful by any measure.

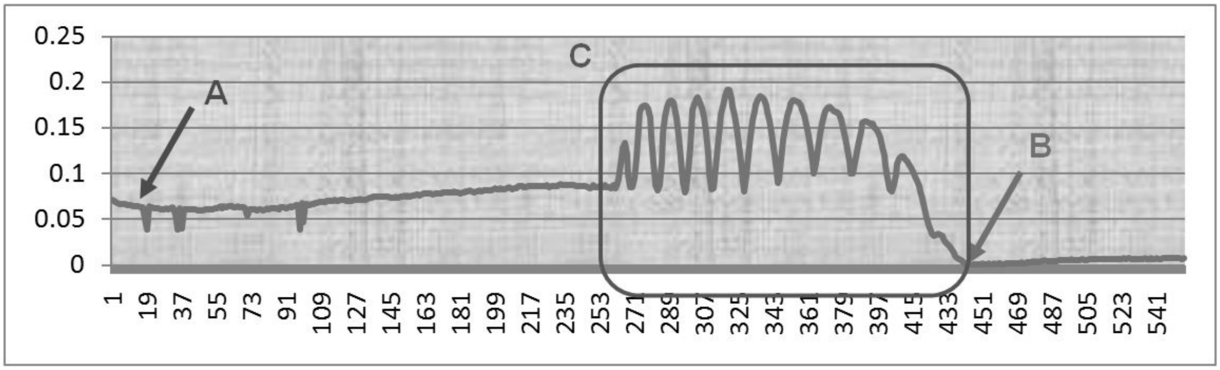
5. OTHER INSTITUTIONS

Components of the Mobile Studio I/O board have been used in multiple settings beyond IHE/engineering classrooms. These include presentation of units for 4th grade students in a science class at a suburban elementary school; use in high school classes in two urban sites, two high school student summer institutes, one summer institute for underrepresented students in engineering; and in-depth use in introductory and advanced physics courses at the undergraduate level. The board also has been used as components of pre-service education for science teachers at a private urban college and as the focus of in-service science teachers' professional development at two sites (one site offered during the academic year, and one offered as a summer institute). Following is a more in-depth summary of selected uses.

The College of St. Rose is using the Mobile Studio to support STEM teacher preparation. For the last two summers, students from St. Rose have participated in the SMART LIGHTING ERC summer REU program. Working with and learning from primarily electrical engineering students, these future teachers have succeeded in learning to use the Mobile Studio and developing ideas for application of it in their courses at St. Rose and in their future work as teachers. Several Mobile Studio math activities have been developed that include full instructions, assessment, identification of state standards addressed, etc. The lesson plan called *Wave to the Sine* is an activity that uses the introduction of the technical functions of the Mobile Studio to teach the properties of sine waves, like frequency, amplitude, and period. Students learn how to use data collected by Mobile Studio in a spreadsheet, where they practice creating functions and graphs and interpreting data. *Wave to the Sine* also has an extension for calculus where students apply derivatives and integrals to their wave data. This lesson serves an as introduction to the next lesson called *I Sense a Pattern* which can be used in almost any grade level. This module requires a sensor device and program (also developed at St. Rose, see below) that collects data via Mobile Studio. The teacher can input a function corresponding to the type of data, like temperature or light intensity, to be collected and analyzed by students. The lesson also contains formative assessment. Before the activity, students must fill out a questionnaire given only an overview of the activity. Throughout the activity, students are asked questions on the handout that can be compared to corresponding questions from the questionnaire to assess what knowledge or understanding students gained through the activity.

Based on the ability of the board to generate signals of any kind, activities like *Wave to the Sine* can provide a teacher with a mechanism to create mathematical functions as voltages that students had only seen previously as computer generated plots. This effort has the potential to be especially effective when the signals are in the audio range of frequencies and students can hear what they are analyzing. The audio capabilities of the Mobile Studio have provided very engaging activities for students of all ages. For K-12 outreach, students get very involved with concepts like frequency or pitch when they can hear as well as see signals. As part of the REU program, several K-12 outreach programs were offered that involved the REU students first as mentors and finally as activity leaders. In the last program of the summer, one of the St. Rose students led the program in which 9^{th} graders learned to use the Mobile Studio as part of their morning program one day of their week-long tech camp. Essentially all students were able to complete the activities after this training, yielding strong evidence that a future math teacher can learn to use Mobile Studio well enough to teach the kind of students he/she will see in the future.

The second aspect of the work with St. Rose mentioned above was to investigate whether it was possible to develop new software tools for controlling Mobile Studio at schools with no electrical engineering program. This too was successful; a computer science student was able to use C# to write a data tracker program that can be used by students of all ages to, for example, collect environmental data (e.g. temperature, light levels, etc.) over long periods of time by sampling sensor voltages once every several minutes (used in *I Sense a Pattern)*. This example also shows that any talented student can write a program to control the Mobile Studio. A simple example of the use of this program (shown below) maybe one of the very best demonstrations of how someone outside of the electrical engineering community can use this powerful learning tool.



Solar cell voltage sampled over 12 hour period from noon to midnight on 30 July 2010 for sunlight entering a west-facing window in Troy, NY. The point marked B is sunset (about 8:20PM)

For this plot, a simple home-made solar cell was used to measure the intensity of the light collected on the top of a table located in front of a large, west-facing window in CITY, STATE. Data collection was begun at noon and ceased at about midnight, with a measurement made once each minute. By taking data over the interesting half of the daily cycle, quite a story can be seen in the resulting plot. First, note that there are three general regions. From the beginning to about point 256, there is no direct sunlight entering the west-facing window, but it was a bright, sunny day with no need for artificial lighting in the office. From about 256 to 443, the intensity of the light goes up because direct sunlight does enter the window. After 443, the light level is very low. For the third region, the point labeled B is the time of sunset for that day (officially listed as 8:22pm) and it remains dark after that until midnight. During the first period, there are a few points where the light level drops (see point A). At these points, the person running the experiment passed his hand over the detector to be sure it was working. Thus, these points show the light level in the shadow of a human hand. The second region, shown inside the box marked C, shows an oscillating signal level. This oscillation occurs because the detector is small (about $1cm^2$) and the widows are covered with mini-blinds (in their open position). As the sun progresses toward setting in the west, a series of bright stripes are created by the blinds, which pass over the solar cell. This accounts for the oscillating signal level. Note also that the width of the oscillations increases for later times because the sun angle is becoming lower with time which makes the stripes of light larger. Having data like this in almost any level of classroom (K-12 through college) has the potential to stimulate a lively discussion as students and teachers reflect on the various features observed.

Evaluators (using direct observation, interviews with project staff, and student surveys) also have validated the implementation of Mobile Studio as sound support for STEM education in K-14 settings.[15] Indicators of preliminary as well as long term learning were noted. For example, when used in a 4th grade class, students were observed to be actively engaged in and enjoying module use. In this setting, the board was used to reinforce and expand on their prior learning of connectivity; the board helped them to engage in hands-on discovery and self exploration by allowing them to see virtual changes when they manipulated variables. This visualization and immediate feedback was noted to motivate continued working with the module. Later on-site testing, in the classroom and on a similar unit on a state exam, indicated that the module was adaptable to their varied ability levels and learning styles and facilitated transfer of knowledge from practice to direct assessment.

Similar data were obtained when piloting use of the I/O board at other K-14 sites and during professional development. Users were observed to be actively engaged in hypothesis development and testing, perceived the material to be relevant to the topics covered during their regular instruction, and reported that they enjoyed learning through this device more than in regular lab settings. Teachers also reported potential for far greater flexibility and differentiated instruction in the classroom as a result of having immediate, integrated practice available in the classroom.

5. CONCLUSIONS

The evolution of Mobile Studio from an RPI project to extensive implementation at other schools provides strong evidence of its universal applicability. With most courses focused on the teaching of electronics, the low cost and mobility make Mobile Studio a very attractive choice for essentially all STEM programs. What has been more of a pleasant surprise is how even organizations new to the effort can have a big impact on others using this technology. The summer high school program at Boston University and the data tracker capabilities developed at St. Rose show that the sum of all participants is definitely greater than the individual parts. The detailed assessment at RPI and application of traditional course objective assessment at Rose-Hulman also have shown that the kind of learning that can occur with Mobile Studio is outstanding. The findings from broader non-engineering uses offer strong support for integration of the board within general STEM curriculum as a supplement to or a replacement for stand-alone lab work.

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