2006-1933: RE-ENGAGING ENGINEERING STUDENTS IN HANDS-ON EDUCATION

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Abstract

This paper presents the technologies and implementation activities that are under development to re-engage students in "hands-on", in and out of class exploration, experimentation and design to aid students' understanding of the "big ideas" in electrical engineering. It describes (while the presentation will demonstrate) the Mobile Laboratory hardware and software (developed by Rensselaer) which, when connected to the PC via a USB port, provides similar functionality to an oscilloscope (with a full 50KHz bandwidth), 2 function generators, a multimeter and bipolar power supplies (for less than the cost of a typical textbook – approximately $80). With the advent of this mobile instrumentation studio PC-based laboratory, many instrumentation-based course offerings can now be held in normal classrooms rather than in specially outfitted facilities. In addition, students are asked to perform hands-on experiments outside of the classroom anywhere/anytime, thus facilitating new opportunities for them to "tinker," to gain valuable insight through practical experience and to rekindle the passion for solving problems – potentially attracting/retaining a significantly larger fraction of the best students.

Rationale

Today's students are computer-savvy, exhibit a diminished attention span[1], and have tremendous demands upon their time. Research has shown that humans only retain approximately 20% of what they hear someone else tell them; yet retain as much as 90% of what they learn by doing.[2] Mobile studios with Tablet-based Laboratory equipment setups (TabLabs) can be set-up and removed in minutes, allowing for greater efficiencies in space utilization, scheduling (over a period of 24 hours/day), maintenance & support, enhanced student-teacher involvement and ultimately, improved student learning through engagement in hands-on activities.

Today's engineering students are typically running multiple applications while simultaneously using internet browsers, instant messaging and search engines on their computers. This results in competition for the user's attention and impedes the ability to focus – with the notable exception of the engrossment involved with a computer game. Consequently, the shortened attention spans, lowered tolerance for repetition, and dependence on computers seriously challenges educators to provide information in more dynamic, compelling, thorough, and interactive ways.[3]

As electronic designs have become increasingly complex, today's products require engineers with advanced skills and greater intuition in science, math, engineering and technology than prior generations exhibited.[4] Shortened attention spans hinder students from staying engaged and focused in technical classrooms, resulting in poorer performance and diminished interest in pursuing technical careers.[5] Notwithstanding the recent advances in educational technology, we need to incorporate more dynamic, hands-on opportunities to reach and motivate more diverse populations. Today's engineering students don't enter college with the same amount of hands-on experience that prior generations typically had.[6, 7]

Project Overview

The "Mobile Studio" project is developing hardware/software and pedagogy with support from both Analog Devices and HP which, when connected to a PC (via USB), provides similar functionality to that of the laboratory equipment (scope, function generator, power supplies, DMM, etc.) currently associated with an instrumented studio classroom. Our goal is to further expand the studio pedagogy (pioneered by Rensselaer with the help of HP) to have students learn with technology in mobile environments that are no longer limited by network access and equipment issues. Our aim is to develop and use educational technology to eliminate the boundaries between theories provided in a lecture and practice; apply concepts in directed problem sessions; and enable/encourage our students' "hands-on" exploration of engineering principles, devices, and systems that have historically been restricted to specific laboratory facilities.

Hardware

The Mobile Laboratory hardware is based upon a small (11.3 in^2) proprietary printed circuit board (shown below in Figure 1). This board contains all the components required to implement the system, as well as limited processing power to take some of the load off the user's PC. A majority of the devices on the board can be attributed to one of several main functionalities: power, digital input/output, analog input, analog output, waveform output, and daughterboard connectivity.

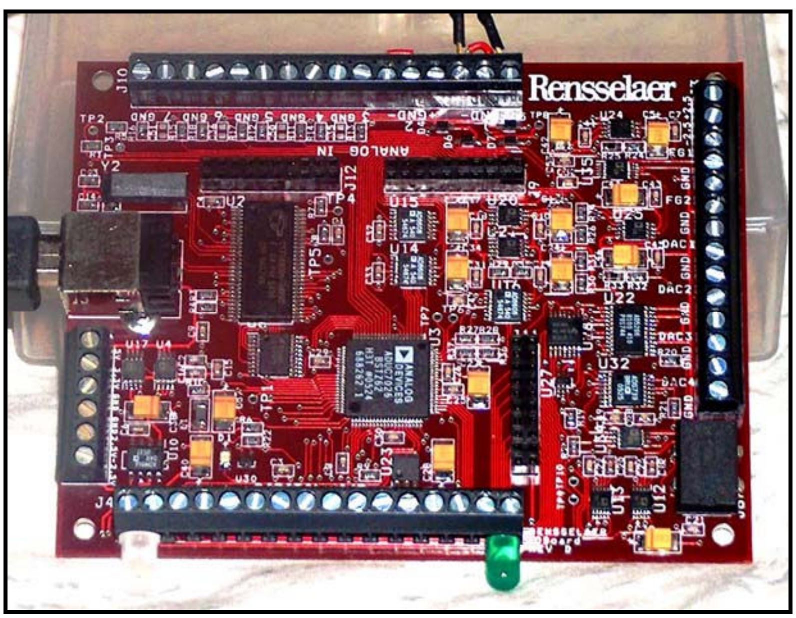

Figure 1. Mobile Laboratory Hardware Board

Power

One of the advantages of using USB for communications between the hardware and a PC is the 5V power supply provided by the PC on the same connector as the USB data. A device can draw up to 500mA, which is more than enough for this hardware. This eliminates the need for students to carry around a bulky wall wart and eliminates clutter (by requiring only one connection). Various regulators and an inverter circuit provide power to the digital and analog components on the board.

Digital Input/Output

The board has 16 digital channels, each of which can be individually selected as an input or an output. When a channel is set as an output, it can output a high voltage level of 3.3V (standard CMOS logic), and drive up to 1.6mA. When selected as an input, the channel is 5V tolerant which allows interfacing to TTL logic families. These digital pins can be used for various output modulation schemes (e.g. Pulse-Width Modulation, PWM) and as a logic analyzer; in addition to simple control and monitoring applications.

Analog Input

At the heart of the analog input system is a 1MS/s, 12-bit analog-to-digital converter. The ADC is multiplexed to 12 channels, seven of which are available to the user via a screw terminal mounted on the board. Channels 3 through 7 are able to read voltages between 0 and positive 2.5V. Channels 1 and 2 are enhanced in order to more closely match a commercial oscilloscope's input capabilities (though any analog channel can be used in oscilloscope mode). The input range is -10V to +10V on these two channels, which is achieved via a digitally-adjustable front end gain circuit. These enhanced channels can be operated in single-ended or differential mode and are designed with a high input impedance to minimize the loading effects of the hardware on the circuit under test. Many standard oscilloscope features that are traditionally implemented in hardware, such as AC coupling, are implemented in firmware or software in order to minimize cost.

Analog Output

Four independent digital-to-analog converters are supplied to compliment the analog input capabilities of the hardware. The output range of the DACs is 0 to 2.5V, with 12-bit resolution. These can be used to provide a DC voltage to an external circuit, or to produce AC voltage in an arbitrary waveform generator configuration. All four channels are internally tied to analog input channels to allow monitoring of the DAC output.

Waveform Output

Two independent function generator channels are provided on the board in addition to the DAC outputs. Each is capable of generating sine, triangle, and square waves at frequencies between 0.004 Hz and 500 kHz. These channels have adjustable DC offset and amplitude controls; similar to those available a bench top function generator. The phase of each generator can be varied to allow the output to be put in or out of phase or anywhere in between relative to the other channel. As with the DAC channels, these two channels are internally tied to analog input channels to monitor the output of each function generator.

Daughterboards

In addition to providing all of the aforementioned features, three vertical headers provide access for a daughterboard to interact with nearly all the capabilities of the board. A daughterboard can supply or monitor analog and digital signals to/from the main board, as well as communicate with the main processor; allowing a daughterboard to communicate with the user's PC. One such daughterboard that is populated with multiple sensors has been developed at the time of this writing; which adds a large collection of sensors commonly used in electrical circuits and physics classes.

Software

The PC software suite is designed to allow a collection of different features to easily communicate with a variety of on/off-board hardware. The components of the suite are grouped into three categories: the framework, the hardware interfaces, and feature displays.

Frameworks

The framework is the main application of the suite and provides a foundation for the other components. The application dynamically loads any features and interfaces that are available on a user's system, allowing for seamless addition and upgrading of components. This makes the system highly flexible to meet the expanding needs of the user's and hardware embellishments. Both the feature displays and the hardware interfaces abide by a set of "rules" which makes the interface between the two possible. Each feature display doesn't need to know the specifics associated with a particular hardware variant. Instead, it simply sends standardized commands to the framework, which then decides which hardware interface should be used to relay the commands.

The hardware interfaces take the standard commands and re-process them into a form that their specific hardware understands; ultimately transmitting those commands to the hardware. Both the hardware interfaces and feature displays are implemented as DLLs and the framework is implemented as an executable application. The framework cannot provide any useful functions without hardware interfaces and feature displays and conversely, the feature displays cannot function without being loaded into the framework application (although the Hardware Interfaces can be used by other applications – such as *National Instruments* **LabVIEW**). Once combined, the system is a powerful suite that allows virtually limitless expansion on both the hardware and software sides.

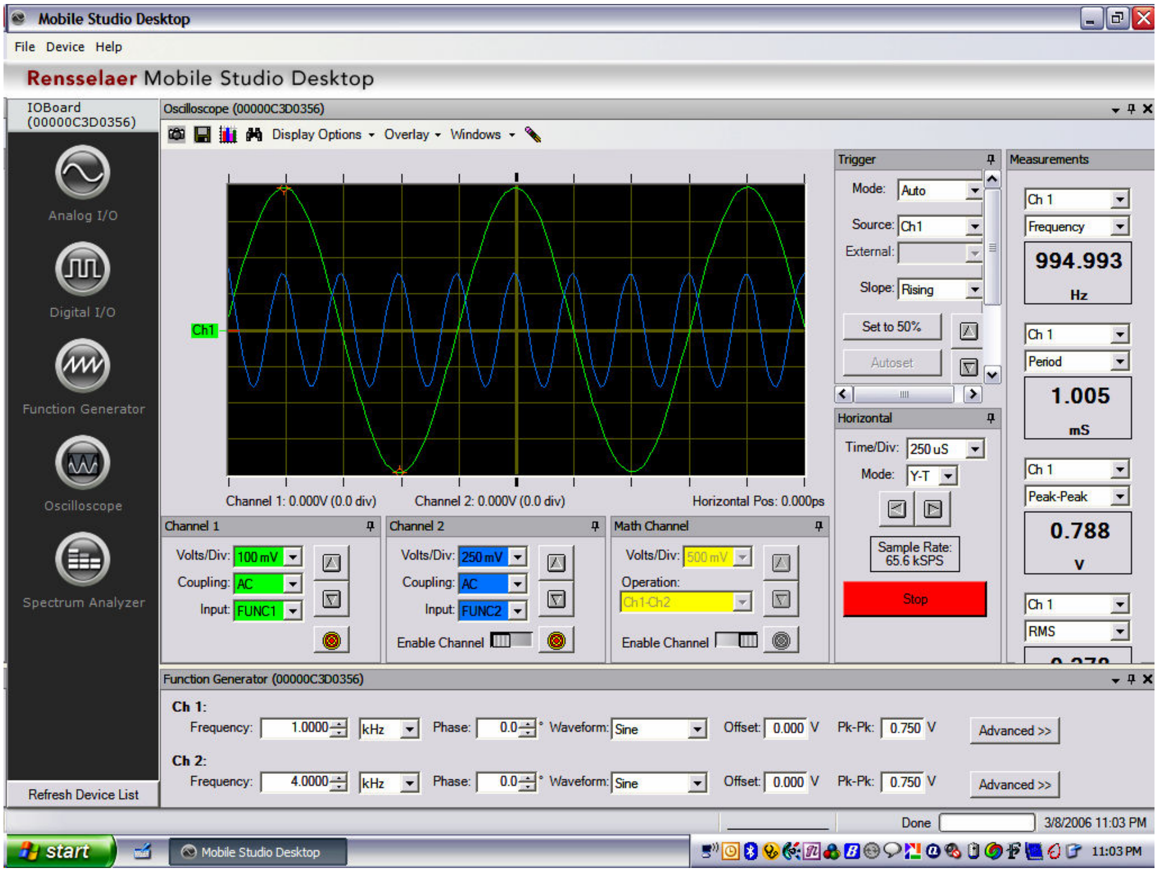

Figure 2. The Framework Application

The framework application manages the list of currently connected hardware boards (since the software can simultaneously connect to multiple devices) and provides the graphical interface for the user to select which features they want to use in conjunction with each board, as shown in
Figure . The application also manages the windows for each feature so that several features can be open at the same time; either from the same or different hardware.

Hardware Interfaces

A key goal in developing the software suite was to allow the feature displays to communicate with a variety of hardware; both that which currently is implemented and additional hardware which is yet to be realized. The individual hardware interfaces provide an identical interface to the rest of the suite; however the way in which each hardware interface handles the data is very different. The interfaces take the data provided to them from the feature displays and format it into the equivalent command set that their specific hardware understands. The same is done in reverse for data coming from the hardware destined for a feature display.

Separating the hardware interfacing from the rest of the software yields a number of advantages; one such advantage is that numerous communications interfaces can be utilized. While the current hardware communicates over USB, the hardware interfaces are equally capable of handling a device which communicates over serial or TCP/IP. A second advantage is that a feature display can be written without any knowledge of future hardware. As long as the required devices are still available on future hardware, the feature will still work. This works in reverse as well; new feature displays can be developed that work with both new and old hardware without any additional development time. In addition to providing services to the software suite; the hardware interfaces can be used by 3rd party applications to also create software tailored to a specific task.

Feature Displays

The feature displays are the user interaction part of the software. They provide a graphical interface tailored to a specific functionality that the hardware can perform. For example, the Oscilloscope Feature Display provides the user with a screen that mimics a stand-alone oscilloscope; while the controls react as they would on a bench top counterpart. Five feature displays have been developed at this time; including displays for the Analog I/O, Digital I/O, Function Generator, Oscilloscope, and Spectrum Analyzer functionalities.

The Analog I/O display provides a voltmeter-like display for analog inputs. All of the available analog channels can be selected; while the readout updates at rates similar to those of a mid-range multimeter (10 Hz). A slider and readout are available for each DAC channel output; the setting from which produces a DC output voltage between 0 and 2.5V. The slider provides an easy interface method for either a standard mouse-and-keyboard PC or a pen-based (tablet) PC. The readout provides a digital display of the output value. The voltmeter display can be set to show the output of a DAC channel at the same time the user is changing the DAC output; in order to verify that the expected output is indeed the actual output.

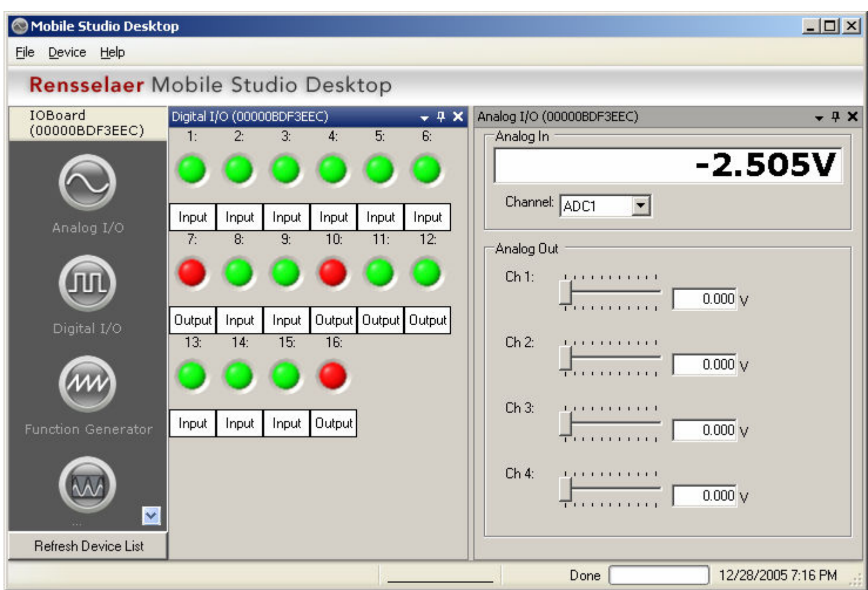

Figure 3. The Digital I/O and Analog I/O Displays

The Digital I/O page (shown in Figure 3) provides a very basic interface to set the direction (in/out) and state of each digital pin and view the current state via a virtual LED/logic probe display. This display will be upgraded to include digital modulation schemes such as PWM, as well as other digital options in the future.

The Function Generator display offers the ability to set the frequency, phase, waveform type, offset, and peak-peak level for each channel available on the connected hardware. In addition, a user can set the generator to automatically or manually sweep the frequency between two values (that can be chosen by the user).

Both the oscilloscope and spectrum analyzer displays are designed to mimic the actual instruments as closely as possible; while still exploiting the enormous advantages that a dynamic user interface on a PC provides in comparison to the fixed interface of a bench top instrument. Although the user "clicks" on something on the screen – instead of turning a physical knob – the proficiency garnered via the use of this PC-based scope will allow them to readily use a bench top scope with little or no retraining.

The oscilloscope display is set up as a multi-color, dual-channel scope with a math channel. Triggering options include: Single-Shot, Normal (where the display is only updated when the trigger condition is met) and Auto (where the display is updated "un-triggered" when no trigger condition is met for a set amount of time). The user also has the option of turning off triggering for viewing non-cyclical signals. The trigger source can be selected to utilize either Channel 1, Channel 2, or any one of the digital input pins; similar to the "external trigger" option of a conventional scope. The slope of the trigger (rising or falling) and the trigger voltage level are both selectable. An option to set the trigger to 50% of the current signal is also available, along with an "Autoset" button that determines an appropriate volts/div, time/div, and trigger level -- without any user interaction.

Any analog input can be chosen for viewing using either of the oscilloscope channels. For example, analog input pin 5 could be assigned to Channel 1, while the second function generator's output could be assigned to Channel 2. This functionality offers tremendous flexibility that is not typically found in bench top instruments. It allows the user to have a large collection of signals connected to the hardware at the same time; with an ability to easily select which input to observe. The software automatically adjusts the display to account for the differences between the various analog inputs. In addition to the standard "volts vs. time" display, the oscilloscope also includes a Channel 1 vs. Channel 2, commonly referred to as an "X-Y" display.

The oscilloscope feature display also includes a number of additions to aid the user in measuring a signal. A "Measurements panel" provides the user with the Frequency, Period, and Peak-Peak, RMS, and Mean voltage of either Channel 1 or Channel 2. Both time and voltage cursors are also available for use in a situation where the user wishes to measure something that is not directly available via the Measurements panel.

The Spectrum Analyzer Feature Display presents the user with a screen that mimics an entry-level, bench top spectrum analyzer. The user has the option of selecting a center frequency and span; or a start and end frequency. The vertical scale can be set manually or put into Auto mode. The user can select any available analog channel as the input source; as with the oscilloscope feature. User-controlled cursors are also implemented, along with automatically placed peak markers. A simple time-domain view is available to allow the user to ensure that the input signal appears as expected. Two separate collection modes are available. The first mode uses the hardware's maximum sample rate. The downside of utilizing this "high-speed mode" is that the buffer size is limited to 1k; since the buffer is implemented in hardware. This mode is good when a user whishes to see a wide spectrum of frequencies but is not concerned about resolution. The second mode uses a lower sample rate and allows for much larger buffers. Since the buffer is implemented in software, the user can select how large they wish the buffer to be. This mode offers far greater resolution; with the disadvantage of a lower maximum frequency.

Comparative Options

There are a number of other similar products that are commercially available for use in educational settings, however, none of them offer the full set of Analog/Digital Input/Output functionality provided by the Mobile Studio Laboratory board – especially at a potential retail price of less than $100. For example, National Instruments, Pasco, Vernier and others have a number of Data Acquisition products geared for the educational environment; yet the current offerings are either more expensive (>$500) and/or have significantly lower sampling rates; since they are primarily intended for use as a data logger (e.g. 48Ks/sec vs. 1Ms/sec) with minimal control capabilities. The Mobile Studio Laboratory board was specifically designed to be used in conjunction with engineering and science courses that currently involve numerous individual pieces of equipment which require large space allocations and, therefore, dedicated facilities. It is meant to serve as a general purpose instrumentation suite that is capable of being used by students with their PCs and protoboards, etc. - anywhere, at anytime.

Implementation

We have observed that by simultaneously stimulating a student's multiple senses, we can improve the student's understanding of the educational concepts – which leads to greater retention and application of the acquired knowledge.[8,9] In addition, the Mobile Studio has changed the way students make measurements; allowing for a nearly instantaneous comparison between theoretical predictions, virtual simulations and actual hands-on experimental results. Students can again "tinker" with the hardware aspects of engineering and science, providing open-ended opportunities to explore ideas – as prior generations did.

Student access to user-friendly, computer-controlled instrumentation and data analysis techniques offers immediate scaffolding of principles and concepts by obtaining experimental results – from the Mobile Studio hardware & software.[10,11] Current collaborations (student-student, student-teacher) in classes are typically limited to using static 2D data (e.g. on paper) and constrained problems. This project implements the utilization of dynamic data, graphical collaboration techniques, and in-class design scenarios to further engage students. For example, team results from the development of a treble circuit project are presented and distributed via the mobile studio's A/V system.

The Mobile Studio provides students with the equipment to grasp the fundamental concepts associated with engineering education by acquiring, utilizing and controlling real world phenomena (e.g. voltage, current, resistance, position, temperature, intensity, etc.); moving objects to precise locations; and developing systems to monitor, process & manipulate electrical signals and events.[12] The project's outcomes are intended to enable students to take measurements (using a scope, function generator, etc.) and test prototype designs from anywhere at anytime.

For example, students are given a statement of the problem to be explored (V=IR) or the quantities to be measured (voltage, current and resistance) and are asked to both devise and conduct experiments and techniques to acquire the data using the instrumentation card. They use the interactive learning modules and technologies in a manner where they aren't fully guided through prescribed laboratory activities. Take-home activities for Physics I, Physics II, Circuits and Electronics courses are being developed and implemented that have students designing and performing experiments that illustrate the theory – in contrast to the educational sequence historically used to present related concepts (theory – problem solving – experimentation).

Pilot Assessment

The assessment of the pilot efforts included a review of the educational technology, interviews with faculty, classroom observations, student evaluation surveys/interviews, and conventional student performance metrics (course work, HW, exams, etc.). Student performance on design-oriented problems by those using the Mobile Studio's TabLab instrumentation was significantly better than the group that did not participate in the Mobile Studio sessions - in contrast with analysis-oriented problems, in which similar results were achieved by both groups. The Mobile Studio allowed faculty to better present course concepts and foster student interactivity & collaboration.

Additional outreach activities were carried out with 4th grade science teachers from the Niskayuna, NY School District (at Craig Elementary School). Tablet PCs were used to explore interactive modules (developed by Rensselaer's Academy of Electronic Media) with the Mobile Studio hardware/software to aid the students' understanding of electrical connectivity, resistance and circuit testing. A subset of the Mobile Studio Tablet PCs was also used in an interactive session at Lansingburg High School (Troy, NY), which incorporated hands-on activities to demonstrate the impact that electronics had on music. Each of these efforts had a huge positive impact on the students involved; including a significant improvement on the corresponding section (focused on electrical concepts) of NY State's standard 4th grade exams.

One Year Ago

Even with the more engaging studio environments, student learning is still impeded by space constraints, insufficient time for laboratory activities (particularly to do the in-depth probing that leads to an intuitive feel for system design), and poorly designed equipment that takes up a great deal of space – and can't be brought home for individual study. Lab-equipped classrooms are both in high demand and in extremely short supply.

Today

Configuring a studio facility typically requires a large equipment allocation/expense and a specific space utilization plan. Renovation of existing facilities is currently cost-prohibitive for many schools, thus limiting the potential to leverage the advantages of the studio format. The hardware is being piloted in five courses at Rensselaer and Howard - providing studio classrooms for curricula that used to offer courses in lecture only formats; currently involving Electrical Engineering, Computer Engineering, Physics and Rensselaer's core engineering program. As a wonderful testament to the project's achievements, Jason Coutermarsh (the undergraduate student developing the instrumentation board hardware) won first prize at Rensselaer's 2005 Undergraduate Education/Research Project Competition.

One Year from Now

We will use the advanced mobile technologies to produce a new generation of classrooms that are more adaptive and less reliant on the construction of large facilities, allowing studio pedagogy to be readily deployed at a dramatically reduced cost. We plan to infuse the TabLab technology and pedagogy into Rensselaer's Physics and ECSE departments' large enrollment courses and expand the utilization of mobile studio classrooms campus-wide. Ultimately, we will develop the Mobile Studio practices and the TabLab technology into a model that can be readily adopted by home-schooling providers, community colleges, universities, and K-12 institutions – to significantly impact student learning on a national scale. It is anticipated that the Mobile Studio hardware will be readily available for others at an estimated cost of less than $80/board; while the software will be made available to interested parties via Rensselaer's Academy of Electronic Media website.

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