# It's All About Engagement: Infusing the Mobile Studio Approach Throughout the Electrical Engineering Curriculum

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**Abstract**

An ongoing trend in electrical engineering programs is the adoption of mobile studio pedagogy, which champions small, portable, low-cost hardware/software systems in support of student-centric educational activities. Engineering education literature on mobile studio usage has focused on the implementation of a mobile studio platform either in a single isolated course or several courses within a sequence. This work proposes infusing a hands-on mobile studio approach throughout the electrical engineering curriculum, providing cohesive experiential learning for students throughout their degree program and fostering a climate of inclusivity and accessibility. The electrical engineering curriculum at the Milwaukee School of Engineering (MSOE) is being redeveloped as part of a conversion from quarters to semesters, offering a unique opportunity to fully integrate a mobile studio approach as a core element of the curriculum. This paper presents a summary of the current state of the engineering education literature on mobile pedagogy and highlights empirically derived best practices. This sets the stage for a discussion of the proposed curriculum integration of a mobile studio model and the potential to significantly increase student engagement. Important logistics are examined, including considerations of a common mobile platform across multiple courses, models for student-owned hardware, mobile studio hardware selection, and classification of courses that still require traditional bench or specialized hardware to achieve learning outcomes. While this case study presents a unique opportunity for integrating mobile studio pedagogy into curriculum redevelopment, the best practices and approaches are applicable to any faculty seeking ways to incorporate mobile studio pedagogy into their courses.

## I  Introduction

If you ask the typical electrical engineer to imagine a laboratory from one of their engineering courses, they likely picture rows of workbenches, each filled with large, bulky, immobile electronic test equipment, historically the gold standard for laboratory test equipment. This laboratory model has not changed significantly in several generations of engineers, and this vision is remarkably common for seasoned engineers and fresh graduates alike. While bench electronic test equipment has traditionally filled a critical need in engineering education, it has several drawbacks.

Bench test equipment is expensive and outfitting a lab with a dozen or more stations is a major financial investment by the institution. The bench equipment wears out or becomes obsolete over time and has to be replaced periodically, with a recurring cost every 10-15 years. The equipment is physically large, taking up valuable lab space, and is heavy, rendering the equipment immobile.

It is common to have bench equipment permanently mounted to the bench itself. This makes it impossible for students to take measurements outside of the lab room with this equipment, and it creates scheduling challenges if more than one class needs the same equipment in a given term. This latter issue is often solved by having multiple labs outfitted with identical test equipment in order to simultaneously support the needs of multiple courses, further increasing the cost of outfitting and maintaining labs.

Students may be limited to only a few hours per week to use the equipment during lab sessions, making it difficult for them to get sufficient practice to master critical measurement skills. Due to cost and space limitations, typical lab rooms are designed to support two-person teams with a single set of fixed equipment for each bench. While teamwork is an important skill that students should practice, having only a single set of equipment per two-person team can lead to one student dominating usage of the equipment while the other student is passive and misses out on learning measurements skills.

In recent years there has been an increasing interest in mobile studio platforms for electrical engineering lab experiences utilizing low-cost, portable, USB-controlled hardware to compliment traditional bench lab equipment paradigms. This approach provides the following benefits over traditional bench lab equipment:

**Low-cost:** Mobile studio lab instrumentation is a fraction of the cost of traditional bench equipment. It is financially feasible for students to rent or own their own mobile studio platform.

**Accessibility:** Allows students to carry out measurements anywhere, anytime, and for unique integrations of measurements into in-class exercises, homework, and laboratory experiments.

**Experiential Learning:** Engages all students with hands-on, individualized measurement experiences that can extend beyond the confines of a traditional lab session.

**Inclusivity:** Students can work at their own pace since they are no longer bound to rigid laboratory session hours. Students can gain practice without fear of making mistakes in front of peers. Students can also make use of assistive technology tools [1] on their computer when taking measurements, particularly important for students who might have fine motor skills challenges.

Finally, bench electronic test equipment has traditionally represented the high fidelity, professional electronic test equipment engineers were likely to encounter in industry and has thus been considered the "gold standard" of laboratory equipment. However, seismic shifts in technology have reduced the cost and size of electronic test equipment. High fidelity, portable USB-based electronic test equipment is available from major test equipment companies and is becoming commonplace in industry. Traditional bench electronic test equipment is therefore no longer a necessarily accurate representation of the equipment students will be using in industry.

The Electrical Engineering (EE) program at MSOE is transitioning from a quarter-based academic calendar to a semester-based academic calendar and is uniquely situated to reimagine the curriculum with a mobile studio approach at its core. While exemplary case studies of mobile

studio platform usage in single courses or course sequences can be found in the literature, this work documents a proposal to design a new Electrical Engineering curriculum that utilizes a common mobile studio platform throughout all years of the curriculum, across many courses. This paper is organized as follows: Section II summarizes the current state of the literature on mobile studio pedagogy; Section III examines the proposed curriculum integration of a mobile studio lab instrumentation; Section IV presents important logistics for operating a mobile studio based curriculum; Section V presents lessons learned through the planning process; the paper concludes in Section VI.

## II   Literature Review

Our literature review focuses on strategies and best practices for implementing the use of portable instrumentation ("Mobile Studio") in an electrical engineering curriculum, and metrics for measuring the impact of implementing that concept on student learning. In the category of strategies, we found that Mobile Studio has the potential to include diverse groups into engineering programs. In [2], the implementation of Mobile Studio concepts were intended to empower female students. In [3], the focus is on African-American students. The authors in [4] examine the impact of new educational technology (NI myDAQ) when used by native and non-native English speaking students.

Several authors suggest that a strategy of unfettered access to laboratory-grade equipment is beneficial to student learning outcomes. Accessibility themes range from removing constraints on lab and equipment availability [2, 5], to enabling students to work at their own pace leading to better cognitive assimilation [6], to empowering students in doing laboratories anytime, anyplace, and repeating them as often as they need [7], and to claiming that unlimited access is more effective than traditional laboratory pedagogy in that it better addresses Felder's learning styles and helps students to achieve lab objectives. [5]

Exposing students to experiential learning in an ongoing manner is another strategy that Mobile Studio enables. In [3], the course is described as experiment-centric, hands-on constructivist learning with an emphasis on the Analog Discovery Board. In [8], Mobile Studio permits the introduction of more problem based learning into the course. For the authors in [6], Mobile Studio concepts applied to a controls course abetted real system identification and an understanding of the advantages and disadvantages of PID auto-tuning techniques compared with model-based PID control design. In [9], the authors recommend including hands-on work within the homework assignments, and in [10], there is a recommendation to design experiments with practical aspects beyond demonstrating fundamental principles.

In terms of best practices, the "flipped" classroom and lab concept is commonly encouraged in the literature. Authors in [2, 8, 11] used flipped labs and lectures, and the face-to-face lab sessions were for students to demonstrate the lab conducted beforehand. In [8], the authors propose a brief lecture by a Teaching Assistant (TA) to introduce the lab and "drop in" open lab sessions conducted by a TA. Authors of [12] recommend using the Analog Discovery in lecture for hands on experiential learning, made possible in part by the flipped format. Given a flipped classroom, the authors of [6] suggest offering remote labs as a complement to – not a replacement for – traditional face-to-face lab experiences.

Properly implementing a mobile studio requires special attention to student resources.

In [2, 3, 13], the authors recommend preparing and providing training materials for student use. Demonstration videos, slideshow presentations, clear diagrams, and assistance in acquiring resources should be provided to support initial and ongoing mobile equipment use. In [11], the authors recommend that students and instructors use the same equipment, and that instructors should have experience with the equipment to reduce barriers to student learning.

Another best-practice theme is to increase access to laboratory equipment. In[14], the authors recommend lending the equipment to students for the entire academic term so each student has their own set-up consisting of a NI myDAQ and miniature three degrees-of-freedom helicopter. In [3], the authors suggest allocating one Analog Discovery board per student to encourage tinkering – "play and share" not "share playing." The authors in [14] encourage making the equipment portable, robust, safe, low cost, and engaging. The author in [11] suggests that high availability of equipment allows students to mirror engineering design cycles. Authors of [14] recommend increasing exposure to the Mobile Studio equipment, giving students more time than normal with the equipment, and turn this concept into a full semester course. Specifically for control systems courses, the authors in [10] recommend using piecemeal kits for controls systems that require the students to physically build the system and think about where the feedback loop is occuring, rather than a traditional blackbox unit that removes visability of these concepts.

With the various implementation of a mobile studio into electrical engineering courses, a few metrics were commonly used. The most common was the use of surveys. Surveys were given at various times: at the end of a course, pre-/post-experiment, pre-/post-course, and in a subsequent semester all focusing on the over all effectiveness of the mobile studio approach on student learning  [5–7, 15]. Student interviews at the beginning and end of the term were conducted in [16]. The authors in  [12] examine effectiveness through both student surveys and grades at the beginning and end of the term.

Several studies have examined the impact of mobile studio approaches using test subjects and control groups. In [8] and  [4], student performance on midterm and final lab practical exams is compared between a control group that used standard physical lab equipment in a traditional laboratory setting and test subjects that used Mobile Studio style equipment in a flipped laboratory structure. All students used physical lab equipment neither had used before for the lab exams. Results show no significant statistical difference in lab scores between the two groups, suggesting that the two approaches were equally effective. The results also demonstrate successful transfer of laboratory skills to unfamiliar physical lab equipment. In [17], the control group used bench-top lab gear, and the test group used Mobile Studio style equipment. Both groups had limited access to the equipment. Likert scale surveys, exam scores, lab scores, and a knowledge inventory were used in an attempt to answer whether the student experience (e.g. time spent, satisfaction, feelings towards the laboratory) differ based on the type of equipment used. The lack of significant differences between the exam and concept inventory scores indicate that the students achieved the intended learning outcomes at the same level of proficiency no matter what type of equipment they used in the laboratory.

The educational research literature suggests positive benefits of the mobile studio approach compared to a traditional laboratory model using bench equipment. It is this evidence together with our own experiences that inspired us to re-imagine the electrical engineering curriculum at MSOE with the mobile studio approach at its core, as described in the following sections.

### III   Proposed Mobile Studio Curriculum Integration

The Electrical Engineering program at MSOE is currently operating on a quarter system, with three 10-week terms (plus a week of final exams) during the regular academic year, and an optional fourth quarter occurring over the summer. A campus committee was chartered to examine the literature and study trends across other universities to determine if a quarter or semester system was the best fit for the academic calendar at MSOE, ultimately finding that a semester-based calendar provided significant advantages across all stakeholders (students, faculty, staff, employers, etc.). This change in academic calendar requires a complete remimagining of all academic programs from the ground up. Based upon extensive literature studies (see Section II) and our own anecdotal experience in certain courses that currently utilize a mobile studio approach, such as the embedded systems sequence, we are proposing an integration of the mobile studio approach throughout the new semester-based curriculum.

In addition to elucidating the benefits of the mobile studio approach, the educational research literature also provides common themes on best practices for successful implementation. These best practices were considered in the context of the needs of the proposed Electrical Engineering semester curriculum and in considering the impact on the electronic measurement practices across all courses. Several of the key best practices are summarized below:

- **Utilization of common platforms when appropriate.** A single mobile measurement platform is to be used throughout the curriculum in order to minimize costs for students and avoid requiring students to constantly learn new hardware platforms.

- **Utilization of a flipped lab environment as appropriate.** With a mobile studio platform, the weekly lab is envisioned to serve as an open meeting where students can work on their experiments, ask questions, and demonstrate performance, but is *no longer* the sole work time for building and testing their projects. This allows students to work on their project on their own schedule, allowing for significantly more student engagement and increased practice of their measurement skills.

- **Development and delivery of student support resources outside the lab environment.** Given the expectation that students are doing more independent measurements outside of the lab compared to a traditional lab course, an increased level of support resources is necessary.

- **Use of the mobile platforms for homework assignments.** In addition to longer-form projects that are no longer tied to a weekly lab schedule, a mobile platform also enables shorter measurement exercises included as part of regular homework. This increases the frequency of measurement skills practice and allows for impactful hands-on reinforcement of theory and practice on the homework.

Our curriculum proposal recommends utilizing the mobile studio approach in as many courses as possible starting in year one, including lecture-only courses that do not traditionally have a lab component. This maximizes the consistent, structured development of measurement skills and incorporation of the hands-on, experiential learning that is the hallmark of MSOE. There are secondary benefits that may be realized from infusing the mobile approach in a semester-based curriculum starting in the first year of study. These benefits include an earlier, one-time learning curve due to uniformity and consistency of the platform, the ability to support project-based

learning owing to easier access of hardware, developing courses with a fresh start, and supporting self-directed courses for off-track access.

The Electrical Engineering program at MSOE is designed to provide a broad foundation that includes required courses across all major areas of electrical engineering: Embedded Systems, Digital Electronics, Circuits, Analog Electronics, Control Systems, Signals and Systems, Digital Signal Processing, Electromagnetics, and Electromechanical Systems. Students gain specialization in certain electrical engineering areas via senior-level technical electives. This broad range of courses poses some challenges to implementation of a mobile studio lab instrumentation, chiefly the task of selecting a common mobile studio platform that is appropriate for all domains. In certain courses, this is addressed by supplementing the base mobile studio platform with additional components as needed. It is also important to note that there are courses for which the mobile studio approach may not be appropriate, either due to hardware limitations or safety concerns, and our proposal acknowledges that traditional bench equipment may still be required in certain cases. Examples include Electromagnetics, which utilizes Vector Network Analyzer (VNA) equipment, and the Electromechanical Systems course, which utilizes high current/high voltage multi-phase power systems. Additionally, some courses may have experimentation that demands higher fidelity measurements to allow for effective learning, such as the measurement of very small voltages/currents, or observations of high frequency signals using a high-speed scope, and so forth. With this in mind, the mobile studio approach is truly seen as an additional tool to be utilized where possible, but is not a complete replacement for traditional laboratory equipment for all courses. We envision that aside from these very few exceptions, nearly all courses can be designed to utilize the mobile studio lab instrumentation effectively.

## IV   Mobile Studio Logistics

This section discusses the key considerations that informed the hardware selection process and guided the decision process for the practical logistics of implementing a mobile studio based electrical engineering curriculum.

### IV.A   Equipment Selection

It is remarkable to consider that the mobile studio approach considered in this work would not have been feasible prior to the last decade. Several companies now produce portable, USB-based, multi-function tools that have been made possible by significant advancements in technology and reductions in electronic manufacturing costs. Various aspects of the mobile studio hardware must be considered to address both educational goals and practical logistics. A few of the most important items are:

1. **Cost:** Requiring mobile platform devices for all students incurs a cost, whether to students or to the university (depending on the acquisition model selected), and thus low-cost is a critical goal.

2. **Functionality:** It is impractical and expensive to have distinct, dedicated mobile measurement hardware for each of the various course domains. The selected hardware should have measurement tools that can be used across the curriculum.

3. **User Experience:** To get student buy-in and to make the mobile studio platform a success, it is important to minimize technical issues that may impede learning or discourage students. For example, the platform should have: simple installation of the device and associated drivers, an intuitive/easy to learn GUI, and stable software with updates over time.

4. **Support Materials:** To help students learn the platform tools and resolve potential issues, there should be sufficient available materials such as videos, tutorials, and troubleshooting documentation from the manufacturer.

5. **Company Reputation/Longevity:** To equip students with a measurement tool that they will use throughout their academic career and after, the mobile studio lab instrumentation needs to be robust and of high quality for long-term reliability. It is imperative to choose a company that can supply the volume of devices required for students year-after-year, and has a stature that makes it likely the company will exist for the foreseeable future. This latter aspect is critical to ensure adequate technical support is available and to ensure the selected mobile platform will be available for future students.

6. **Measurement Fidelity:** As an educational application, measurement fidelity takes a backseat in this evaluation compared to the items above. Nevertheless, the measurement tools should operate within appropriate, reasonable accuracy bounds in order to cover the desired course domains. Insufficient accuracy can lead to confusing results that hinder, rather than enable, student learning.

We surveyed the mobile studio lab instrumentation marketplace and identified four candidate tools appropriate for our curriculum. Each of the candidate units are portable and have a two-channel oscilloscope and a waveform generator. These are the minimum tools required for typical electrical engineering laboratories. Table 1 shows the variety of electronic measurement tools on each device. To provide insight into the evaluation process, a sample comparison table is presented in Table 2 that highlights the pros and cons of the candidate devices, which heavily informed the device selection process. Similar tables were generated to compare the datasheet specifications of the various measurement tools on each candidate device. Additionally, the authors carried out extensive measurements to directly compare the performance of the candidate devices against one another as well as against traditional bench equipment. This data is available to interested readers upon request. After this thorough evaluation of the devices, we determined the Digilent Analog Discovery 2 [18] to be the most appropriate mobile studio measurement solution, and are recommending it for adoption in the new semester-based EE curriculum at MSOE. It is critical for any program considering usage of a mobile studio platform to do a complete, in-depth evaluation of the available solutions against clear metrics. An ill-fitting hardware platform can quickly become an obstacle, rather than an aid, to effective learning in the mobile studio model. Note that while the Digilent Analog Discovery 2 was chosen for our EE program at MSOE, this discussion is intended to demonstrate a viable selection process rather than promote a particular mobile studio platform.

Table 1: Sample comparison of electronic measurement tools available on four candidate mobile studio platforms.

| Feature | Analog Discovery 2 | Device 2 | Device 3 | Device 4 |
|---|---|---|---|---|
| AWG | ✓ | ✓ | ✓ | ✓ |
| Scope | ✓ | ✓ | ✓ | ✓ |
| SA | ✓ | ✓ | ✗ | ✓ |
| NA | ✓ | ✓ | ✗ | ✗ |
| Logic Analyzer | ✓ | ✓ | ✗ | ✗ |
| Pattern Gen. | ✓ | ✓ | ✗ | ✗ |
| Digital I/O | ✓ | ✓ | ✗ | ✗ |
| Voltmeter | ✓ | ✓ | ✓ | ✗ |
| Data Logger | ✓ | ✗ | ✗ | ✗ |
| Impedance Analyzer | ✓ | ✗ | ✗ | ✗ |
| Protocol Analyzer | ✓ | ✓ | ✗ | ✗ |
| Power Supplies | ✓ | ✓ | ✗ | ✗ |
| Heaphone Out | ✓ | ✗ | ✗ | ✗ |

Table 2: Sample comparison of four commercially available mobile studio platform candidates that offer electronic test equipment suites.

| | Analog Discovery 2 | Device 2 | Device 3 | Device 4 |
|---|---|---|---|---|
| Cost | $165 (edu discount) | ~$163 (third party vendor, edu discount unclear) | $130 | $120 |
| Features and capabilities | **Significant:** Scope, AWG, Spectrum Analyzer, Network Analyzer, Logic Analyzer, Pattern generator, Digital I/O, Voltmeter, Data logger, Impedance Analyzer, Protocol Analyzer, Power Supplies (+/-5V), Headphone amp/jack | **Significant:** Scope, AWG, Spectrum Analyzer, Network Analyzer, Logic Analyzer, Pattern generator, Digital I/O, Voltmeter, Protocol Analyzer, Power Supplies (+/-5V), | **Limited:** Scope, AWG, DMM | **Limited:** Scope, AWG, Spectrum Analyzer |
| measurement specs/fidelity | Moderate | Moderate | Moderate | Moderate |
| Availability (e.g. trusted vendors) | Established Brand, Good Availability | Established Brand, Good Availability | Unfamiliar brand, secondary markets | Moderately known brand, Good availability |
| Installation procedure | Extremely Easy | Somewhat Easy | Somewhat Difficult | Extremely Easy |
| Host System Requirements | Mac, Windows, Linux, ARM | Mac, Linux, Windows | Windows | Windows, Linux, Mac |
| Software interface (GUI quality, intuitive controls, mature software) | High quality graphics, easy to use, closed source but well maintained and regularly updated software | Plots hard to read, controls nice but not always intuitive, Open source and regularly maintained and updated | Clunky controls and display. Frustrating to use. | Graphics mediocre (artifacts), very difficult to use GUI, closed source but regularly maintained software |
| User Support Documentation | Excellent | Poor to Moderate | Poor | Poor |
| Matlab/scripting? | MATLAB, Python | MATLAB, Python | no | MATLAB, Python |
| Physical size | 6" x 4" x 1", 8oz | 3.5" x 3.5" x 1", 8.5oz | 7" x 3" x 1", 22oz | 5-5/8" x 3-5/8" x 3/4", 5oz |

*IV.B    Cost Models*

Moving to a mobile studio measurement platform requires careful consideration of the financial ramifications for students, who traditionally use laboratory equipment purchased by the university. We believe in minimizing costs to students when adopting a mobile studio platform. Six cost models for providing mobile studio equipment are evaluated here. The pros and cons of each are listed and recommendations made. The discussion focuses on costs related to the mobile studio lab instrumentation device itself, which is the most expensive individual device students need. The discussion could also apply to other expensive purchases. Note that the Electrical Engineering and Computer Science (EECS) Department at MSOE has a dedicated Technical Support Center (TSC) that manages the laboratories and allows students to check out equipment and parts, and their participation is included in several of the options.

1. **Student purchase; stand-alone.** Students are responsible for purchasing mobile studio lab instrumentation for coursework similar to purchasing a graphing calculator.

2. **Student purchase; course requirement.** Students purchase mobile studio lab instrumentation as a required course material. This model may allow students to pay using financial aid resources.

3. **Student purchase with industry sponsorship.** The cost to the student of mobile studio lab instrumentation is offset by industry-sponsorship.

4. **Term-by-term checkout from EECS Tech Support Center.** Requires sufficient institutional inventory to support long-term checkout to every EE student plus the daily and long-term needs of other EECS programs. In this model, EECS owns the equipment and bears the responsibility for repair and replacement costs.

5. **Term-by-term rental.** Students pay to rent mobile studio lab instrumentation like renting a textbook. A provider to facilitate such a program would need to be identified.

6. **Program specific technology package.** Students obtain mobile studio lab instrumentation through a technology package akin to the a student laptop program currently in use at MSOE. Like the laptop progam, students could pay a fee each term to have access to the hardware and the guarantee of a loaner device if a device breaks. As in the rental model a provider would need to be identified.

Each of these options has pros and cons that must be weighed carefully to ensure the transition to mobile studio hardware does not cause undue financial burdens on students. With this in mind, the EE faculty recommend option 2, with a long-term goal of offsetting the cost to students via industry sponsorship. Note that this model allows financial aid to be used to pay for hardware since the hardware is a course requirement. Aside from being the simplest ownership model, we believe there is educational value in having students own the equipment. The studies within this report make a strong case that the mobile studio platform will be used frequently for high value activities over students' academic career. The Digilent Analog Discovery 2 hardware platform recommended in this proposal is in the price range of a textbook, which should not significantly increase student expenses.

*IV.C    Equipment and Parts Acquisition*

Having selected a mobile studio lab instrumentation platform and an acquisition model for students, we next consider how students will obtain the parts kits required for coursework. Five candidate models for acquisition of mobile studio equipment were evaluated:

1. **Students purchase all 4 years of equipment on Day 1.** Giving students access to the entire set of mobile studio equipment on day 1 has the advantage that it most strongly supports independent "tinkering" and exploration by students, which is widely reported in the educational literature as valuable for student learning. It also has advantages in terms of organization and administration – the entire academic career of equipment is contained in one kit. However, this approach limits the program's ability to rapidly migrate to newer or improved hardware platforms, especially for courses later in the curriculum. There is also a large up-front cost to first-year students, and an increased likelihood that students may misplace parts that aren't needed until several years later in the curriculum.

2. **Students purchase equipment on a course-by-course basis.** This is the procurement model that EECS currently uses for its embedded systems courses and is coordinated by EECS Tech Support Center. The process of finalizing parts lists and procurement typically takes place in the summer prior to the start of each academic year, and provides flexibility to modify kits each academic year. Enrollment projections are used to determine the number of kits produced for any given course. Because students are purchasing components on a course-by-course basis, there is less opportunity for them to explore more advanced or more interesting concepts on their own. This limitation could be mitigated by students purchasing additional components on a voluntary basis (e.g., from TSC or external parts vendor), or expanding course parts kits to include components intended to encourage and enable more advanced concepts.

3. **Students purchase equipment for current academic year each Fall.** This model is a compromise between the previous two models. This may be a more complicated plan from a logistical standpoint because some students are off-track from the main cohort.

4. **Students purchase all major EE components on Day 1 of the first year and obtain supporting components as-needed (likely course-by-course).** The "major EE components" descriptor denotes devices such as mobile studio instrumentation, microcontroller and FPGA development boards, and components necessary for constructing basic electrical circuits and electronics. This approach equips students with those high-impact components that students are most likely to "tinker" and experiment with. However, this approach limits our ability to rapidly migrate to newer hardware platforms.

5. MSOE **Program specific technology package.** In this model, students obtain the mobile studio lab instrumentation through a technology package akin to the MSOE laptop program (see Section II.C, item 6). Like the rental model, a provider would need to be identified.

To strike a balance between the benefits of equipping students to explore and "tinker" while maintaining flexibility to modify course kits on a regular basis, we recommend every EE program student to have their own "EE Base Kit" prior to their first course at MSOE, via option 4. Students will utilize this kit in most required EE courses through different learning modalities (e.g., labs, homework). The "EE Base Kit" contents include:

- Mobile studio lab instrumentation device (as noted in Section IV.B, this curriculum is recommended to use the Digilent Analog Discovery 2).

- A "toybox" of assorted discrete electrical components

- Breadboard supplies (adaptors, terminal blocks, jumper wires, header pins, etc.)

- Digital Multimeter (DMM)

- Example projects for students interested in "tinkering" with personal projects to gain inspiration and additional experience.

In addition to this base starter kit, some courses may include add-on kits that are required at the time of that course. The cost of course-by-course kits should not exceed that of a typical course textbook, and these courses will be strongly encouraged to offset the cost of parts kits through adoption of inexpensive or free textbooks when appropriate.

*IV.D   Technical Support Model*

Since we propose students purchase their own mobile instrumentation platforms, a reliable and straightforward model for supporting students with faulty or damaged hardware is critical to minimize the disruption of student learning. Four support models are compared below:

1. **Students purchase from vendors.** MSOE does not offer support to the students, but instead requires the students purchase replacements for any broken or lost components from the vendor directly. This may be appropriate for simple or very inexpensive items, but it may result in negative student experiences due to the inconvenience of working with external vendors and shipping delays.

2. **Students purchase from MSOE's EECS Technical Support Center.** Students purchase replacements for broken devices from the EECS TSC. This is the model currently in use for embedded systems courses. The TSC is usually very liberal, often replacing parts for free if found to be faulty or if damaged through no fault of the student. If the part breaks due to negligence, then the student is obligated to purchase a replacement component. The benefit to purchasing from TSC, instead of from a vendor, is that with sufficient stock there will be no shipping delay, and students can get the new component immediately and continue their work. This model does require the TSC to purchase extra components that might not be used that academic year. It also requires identifying key components to stock and desired stocking levels.

3. **Vendor repair.** Students are required to work with the vendor to have a component repaired. This is likely only a realistic option if the device is extremely expensive or sophisticated – not typical of the kinds of devices we are expecting our students to

purchase. This option poses a risk to learning since students may be without their device while the device is serviced and in shipping.

4.  **Testing services from EECS Technical Support Center.** In this model the TSC adds testing services that would help the students determine what is wrong with the device and then the TSC can either fix the device for the student or equip the student to fix the device themselves.

Faulty or damaged equipment is always an irritation. We think the best approach to support students with faulty or broken equipment is to keep the support based within the TSC to the extent possible, via options 2 and 4. The TSC should keep its current practice of helping students source replacement parts. Assuming the complexity of the component warrants repair, TSC could help students diagnose and repair broken components. Basing student support in the TSC has the benefits of being convenient to the students and providing them quick and timely resolutions to their hardware problems that minimizes disruption to their learning.

*IV.E    Student Support Model*

In this section, we describe models for "anytime, anywhere" support for students who are experimenting in their dormitories, at coffee shops, between classes, and at night after hours. This discussion is divided into options for component acquisition, component testing, and component usage guidance:

1.  **Replacement/additional component acquisition**

    (a) **List of Online Vendor Resources.** Parts kits for each class would come with a full hardware list, including part numbers for ordering from common online vendors. This option has a delivery delay but allows students to get any number of whatever parts they need.

    (b) **Purchase Parts from Technical Support Center**; This is the typical default model at most universities. Inexpensive parts such as low-power resistors, small capacitors, and LEDs are free. This option has the limitation of being available only during TSC operating hours, and the limitation of a narrower selection of components compared to an external parts vendor.

    (c) **Electronic Component Vending Machine:** In future years, an elegant solution we'd like to consider is an electronic component vending machine, located in a public area, available 24/7. This has already been implemented at Louisiana Tech University with a repurposed snack vending machine [19]. A promising senior design project would be to design and build an electronic component vending machine for student use. This option offers instant parts delivery and off-hours support and could also support other campus labs in other departments. Stock could be monitored by the IEEE student branch and provide income to them to support IEEE activities.

2.  **Component testing**

    (a) **Inexpensive Part Testers:** Inexpensive (cost $< \$10$) tester units are available that can measure resistance, capacitance, inductance, diodes, and transistor pinouts with

reasonable accuracy for student needs. These units could be included in the "Base EE Kit."

    (b) **Tester Circuit in Technical Support Center:** A comprehensive testing system that can validate the Digilent Analog Discovery 2 itself could be located in TSC. It could have a testing suite to check for damaged Digilent Analog Discovery 2 units and distinguish what may be student use error from true device damage, saving staff time. Designing such a testing device could be a promising senior design project. The TSC at MSOE already has two bench-grade RLC bridge meters available for student use that could be supplemented with high quality parts test/evaluation equipment.

3. **Component Usage Guidance**

    (a) **Curated Videos:** Videos detailing how to use the Digilent Analog Discovery 2 would be published or curated. QR codes linking to these resources would be physically included in the "Base EE Kit" and would link to course for EE students on the campus Learning Management System, or to YouTube, or similar repository.

    (b) **Student Experts:** A community of experienced students could volunteer/be paid to support other students in off hours.

    (c) **Faculty Support:** Faculty would create and upload video tutorials for the students to view. Again, QR codes to these resources would be physically included with the "Base EE Kit" to ensure all students can find them.

    (d) **Workshops:** The IEEE student branch facilitates workshops.

Considering all of these options, we recommend the following support models (broken out by the three major areas):

1. **Option 1b (Purchase in TSC)** for component acquisition for the immediate future, since this offers students the lowest barrier to quickly getting the parts they need while avoiding problematic delays. We envision option 1a being a modest investment to spin up as a secondary option for interested students, and we envision option 1c being the best overall solution but furthest in the future for actual implementation.

2. **Option 2a (Inexpensive Part Testers)** for the initial implementation of mobile studio, with a more expansive component tester a future possibility. Option 2b might still be a worthwhile long-term goal to provide students with the option of more accurate, industry-grade parts testing capability.

3. **Option 3a (Curated Videos)** for immediate implementation, with a mixture of option 3b, 3c and 3d possible in the future depending on resources. We hope that as the mobile studio model is integrated into the curriculum, student involvement in providing tutorial sessions and support to fellow students will mirror the community formation that often occurs within campus makerspaces.

As this section makes clear, there are many important aspects to consider when implementing a mobile studio approach in a curriculum. Careful planning can help avoid unforeseen adverse

impacts and ensure the mobile studio approach delivers on its promise of increasing student engagement and learning.

## V   Lessons Learned From the Planning Process

The mobile studio approach offers significant pedagogical benefits over traditional lab modalities, as outlined in Section II. But moving away from a curriculum that mainly utilizes fixed laboratories with traditional bench equipment to one that fully integrates a mobile studio lab instrumentation throughout nearly all courses is no small feat. Several of the faculty involved in this effort have used mobile studio platform for a few courses, in isolation from the rest of the program. Planning for a much larger scale of implementation has forced us to consider a much broader range of logistics and important questions about the curriculum in this process, as demonstrated in Section III. Some of our major take-aways from this planning process are summarized here:

- Mobile studio platforms allow students to practice their skills more frequently, on their own time, with weekly "check-ins", much more like how one learns a musical instrument than a traditional lab.

- Most lab experiences that rely on traditional bench scope, signal generator, DMM, etc., can be redesigned to work within the performance limitations of the low-cost mobile platform measurement hardware.

- There may be entire courses, or particular labs, for which it is infeasible to utilize a mobile studio approach. This is OK! The mobile studio approach is not a magic bullet, and it is important to do what is best for student learning on a course-by-course basis– even if it occasionally goes against the adopted hardware approach in the curriculum. We firmly believe that the mobile studio approach can be used in all but a few outlier cases, as described in Section III.

- A benefit of traditional labs is that all costs are handled behind the scenes. It is critical to ensure the mobile studio approach does not create additional financial burden for students. We have made an effort to minimize cost of the hardware and find ways to offset the cost to the students, such as considering reduced cost (or freely available) textbooks where applicable, and by planning to seek out industry sponsors to fully or partially subsidize student hardware purchases.

- Scaling up mobile studio usage from a few isolated courses, as in our current EE curriculum, to mobile studio instrumentation being at the core of the new proposed curriculum has been daunting, but not intractable and well worth the expected student learning benefits.

- Faculty buy-in across the program is critical, and not a guarantee. Skeptical faculty may require convincing of the efficacy of this approach. Utilizing the overwhelmingly positive support for mobile studio learning that is documented in educational research literature can help convince the skeptics (Section II).

- A robust technical support system is needed to avoid negative impacts on student learning, such as forced delays due to broken/faulty hardware.

- While students are still encouraged to ask questions and seek guidance when they get stuck, a mobile studio platform more closely resembles the self-sufficiency they will need in their careers. Working outside of lab will require students to more often utilize tutorials and other materials to seek answers or learn how to use a measurement tool, before asking for help from faculty.

## VI    Conclusion

This work presents a faculty proposal to infuse the design of a new Electrical Engineering Curriculum at MSOE with a mobile studio approach, supplanting the traditional laboratory experience using fixed bench electronic measurement equipment that currently dominates the EE curriculum. MSOE is transitioning from a quarter-based academic calendar to a semester-based calendar, offering a unique opportunity to reimagine the curriculum from the ground up. The proposed mobile studio EE curriculum was informed and inspired by a close study of the educational research literature, which documents the significant learning advantages of a mobile studio approach in engineering education. This work began with a summary of these findings from the literature. The proposed mobile studio approach was then presented in the context of the Electrical Engineering program at MSOE. Following this was a summary of the logistical considerations for implementing the mobile studio approach at this large scale, which impacts every student in every course in the curriculum. This discussion highlighted the importance of thoughtful planning to effectively facilitate key aspects such as hardware acquisition, technical support, and operational training, among others. Finally, the paper summarized the major lessons learned throughout the development of this curriculum proposal. Ultimately, we hope that this work serves as an inspirational example that other programs can utilize to reimagine their own curriculum to better engage and prepare their engineering students for their careers.

## VII    Acknowledgement

## References

[1] Y. P. Weatherton, R. D. Mayes, and C. Villanueva-Perez, "Barriers to persistence for engineering students with disabilities," in *American Society for Engineering Education Annual Conference & Exposition*, Columbus, Ohio, June 2017.

[2] R. J. Bowman, "Inspiring electrical engineering students through fully-engaged hands-on learning," in *2013 IEEE 56th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2013, pp. 574–577.

[3] K. A. Connor, D. Newman, K. A. Gullie, Y. Astatke, C. J. Kim, J. O. Attia, P. Andrei, and M. Ndoye, "The implementation of experimental centric pedagogy in 13 ece programs – the view from students and instructors," in *American Society for Engineering Education Annual Conference & Exposition*, 2016.

[4] R. F. A. Hamilton, "Comparison of learning outcomes for native and non-native speakers of the language of instruction in a flipped laboratory," in *2017 IEEE Global Engineering Education Conference (EDUCON)*, 2017, pp. 621–624.

[5] M. E. Radu, C. Cole, M. A. Dabacan, J. Harris, and S. Sexton, "The impact of providing unlimited access to

programmable boards in digital design education," *IEEE Transactions on Education*, vol. 54, no. 2, pp. 174–183, 2011.

[6] C. M. Ionescu, E. Fabregas, S. M. Cristescu, S. Dormido, and R. De Keyser, "A remote laboratory as an innovative educational tool for practicing control engineering concepts," in *Education, IEEE Transactions on*, vol. 56, no. 4, 2013.

[7] T. Klinger and C. Madritsch, "Collaborative learning using pocket labs," in *2015 International Conference on Interactive Mobile Communication Technologies and Learning (IMCL)*, 2015, pp. 185–189.

[8] R. F. Hamilton, "Improving learning outcomes in ee2010l using ni mydaq in an inverted lab," Ph.D. dissertation, Wright State University, 2014.

[9] C. Kim, M. Chouikha, and V. Thomas, "A mobile studio experience of experiential learning in electrical engineering class," in *American Society for Engineering Education Annual Conference & Exposition*, 2008.

[10] M. Gunasekaran and R. Potluri, "Low-cost undergraduate control systems experiments using microcontroller-based control of a dc motor," in *Education, IEEE Transactions on*, vol. 55, no. 3, 2012.

[11] K. A. Connor, "With a mobile circuit board, students can work like practicing engineers," in *The Chronicle of Higher Education*, 2012.

[12] L. Zhang, I. Dabipi, Y. Jin, and P. Matin, "Inspiring undergraduate students in engineering learning, comprehending and practicing by the use of analog discovery kits," in *2015 IEEE Frontiers in Education Conference (FIE)*, 2015, pp. 1–4.

[13] K. A. Connor, D. L. Newman, M. Morris Deyoe, C. J. Scott, M. F. Chouikha, and Y. Astatke, "Mobile studio pedagogy, part 1: Overcoming the barriers that impede adoption," in *American Society for Engineering Education Annual Conference & Exposition*, 2012.

[14] B. Taylor, P. Eastwood, and B. L. Jones, "Development of a low-cost, portable hardware platform for teaching control and systems theory," in *10th IFAC Symposium Advances in Control Education The International Federation of Automatic Control August 28-30, 2013, Sheffield, UK*, 2013.

[15] E. W. Maby, A. B. Carlson, K. A. Connor, W. C. Jennings, and P. M. Schoch, "A studio format for innovative pedagogy in circuits and electronics," in *Proceedings Frontiers in Education 1997 27th Annual Conference. Teaching and Learning in an Era of Change*, vol. 3, 1997, pp. 1431–1434 vol.3.

[16] F. Trede, R. Braun, and W. Brookes, "Studio-based learning in a first year engineering curriculum: Exploring students' learning experiences and reflections using the rich picture method," in *2019 18th International Conference on Information Technology Based Higher Education and Training (ITHET)*, 2019, pp. 1–5.

[17] R. M. Reck, "Experiential learning in control systems laboratories and engineering project management," Ph.D. dissertation, University of Illinois at Urbana-Champaign, 2016.

[18] Digilent. Analog discovery 2 board. [Online]. Available: https://store.digilentinc.com/

[19] K. Crittenden, C. Hall, and P. Brackin, "Living with the lab: Sustainable lab experiences for freshman engineering students," in *American Society for Engineering Education Annual Conference & Exposition*, 2010.