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Board 255: Enabling In-Class Hands-On Electronics Opportunities through Flipped Classroom using Openly Available Videos

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Abstract

This discussion reports on our efforts to utilize open classroom time for hands-on experimental measurements as well as other hands-on engineering (ECE) projects. These in-class interactions increase student confidence with hands-on tools, where class time becomes time for group hardware discussions. This discussion will describe our efforts utilizing hardware-based class projects throughout the undergraduate and graduate ECE curriculum. Revolutionary integrated circuit platforms are part of these efforts, and a history of these efforts will be described in this paper. These efforts improves the student's confidence in using their system tools, whether computer controlled USB devices (e.g. Analog Discovery), linear and nonlinear hardware circuits, to IC layout tools, and MATLAB tools for signal processing.

Motivating Using A Flipped Classroom for Hands-On Electronics Opportunities

Developing student confidence with experimental measurements and their experimental tools becomes a major challenge for electrical and computer engineering (ECE), as well as other engineering disciplines. On the otherhand, the wide availability of electronic systems available to ECE students and the potential electronic components that can be attached to the student's systems opens significant opportunities. The ubiquitous availability of portable electronics enables individual ECE experiments with low cost components outside of a formal laboratory environment. Courses could be redesigned to where hands-on experiments are central to an ECE course.

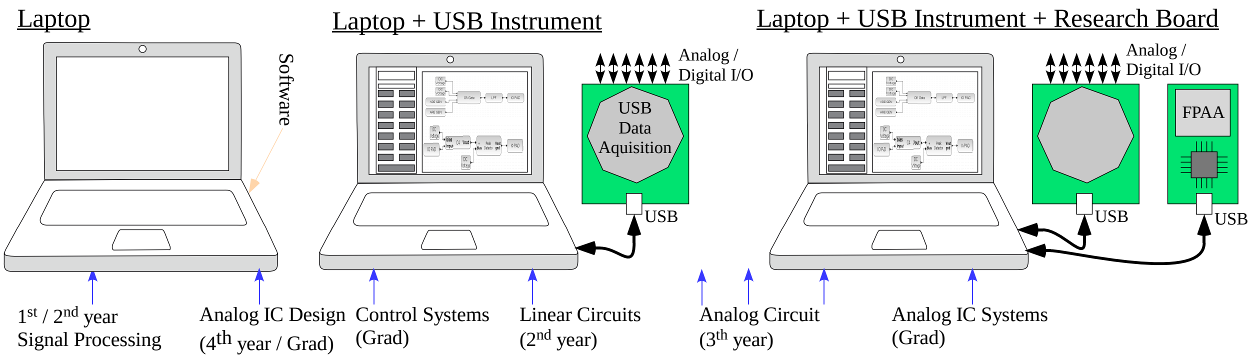
Utilizing recorded lecture nuggets (e.g. [1]) repurposes class time for in-class discussion as well as other activities [2]. Flipped classrooms research shows multiple new uses for traditional classroom lecture time [3, 4, 5, 6] with some effective uses of these capabilities [6, 7, 8, 9]. The student reactions to flipped classrooms vary, although often the additional quizes and tests lead towards some student concerns [10, 11, 12]. These openly available video nuggets developed (4-8 minutes, developed and recorded by the author, >250 nuggets) [2] that could be used to develop multiple courses through defining multiple threads (e.g. [1]), Classes can use a range of video techniques [13, 14, 15, 16, 17, 18, 19], where having videos watched before a class session enables many flipped classroom opportunities [2, 20, 21, 22, 23, 24, 25, 26], including interactive discussions and active learning. Open-source (e.g. MIT OpenCourseWare [2, 27]) or low-cost (e.g. Mooc [28]) video lectures by groups or individuals (e.g. [29, 30]) enable multiple communities to benefit from on-line lecture development and provide choices for a student's learning style.

Although several aspects within an ECE curriculum can be improved through these lecture nuggets and flipped classroom approaches, this discussion focuses on techniques to use the class time for in-class hands-on experimental activities. Flipped classroom techniques show that students watching videos before laboratory experiences generally improves student confidence, knowledge, & attitude between sections on-line lectures & control sections [31, 32]. Typically these laboratory experiments are fairly generic science experiments (e.g. [31]), and yet, ECE laboratory knowledge improves as measured through quizes and prework improvement [33]. These results would encourage development of flipped classroom techniques to encourage hands-on laboratory experiments. And yet, how does one build these kinds of ECE hands-on in-class experiments that are integrated with class objectives?

This discussion presents our efforts to utilize open classroom time for hands-on experimental measurements as well as other hands-on engineering (ECE) projects. The techniques, development, and lessons learned from more than a decade of developing flipped classrooms for hands-on experiments will focus primarily on courses in circuits (first/second year through graduate work), with some focus outside of circuit courses. Research efforts (by one of the authors) sometimes flow into these hands-on experiments. These discussions provide the opportunity for further efforts beyond this discussion to compare using these techniques with classes not using these approaches; in many ECE departments, implementing side by side comparisons of teaching is strongly resisted culturally. Low-cost available ECE devices and components empowers a wide space for Hands-on Opportunities (Sec. 1). These hands-on opportunities provided by these tools enables project centric courses (Sec. 2) where one can see the initial positive impact (Sec. 3).

1 A Wide Space of Low-Cost ECE Devices and Components for Hands-on Opportunities

Most items within an ECE curriculum are fairly easy to aquire as well as are straight forward to interface with existing student devices, such as laptops and smartphones (Fig. 1) . Our university requires every student to own, maintain, and use a laptop computer (PC, Mac, or Unix) with at least meeting minimum performance requirements; as a result, the costs can be incorporated into student financial aid calculations. Hands-on experiments should heavily utilize student laptops and other devices (e.g. smartphones), enabling access as students develop confidence using the tools that they possess. A laptop has existing processing capabilities, including sound (e.g. microphone, speaker) and imaging devices (e.g. camera) devices that can be directly controlled through MATLAB or Python or other programming languages to use these devices. A laptop typically has at least stereo sound input and output, effectively having two Digital-to-Analog Converters (DAC) and two Analog-to-Digital Converters (ADC) operating between 20Hz to 20kHz (typical 44.1kHz sampling rate) that are expected to be easily interfaced with programming languages. These capabilities only require having a few low cost cables to enable a full measurement system. Multiple microphones built into laptops and phones for handling sound



Course	Year(s)	Course	Year(s)
Linear Circuits (2^{nd} year)	Sp '19, F '20	Analog IC Design (4^{th} year/ Grad)	F '15, '17, '19, '21
1^{st} / 2^{nd} year Signal Processing	F '22, Su '23	Linear Control Systems (Grad)	F '22
Analog Circuits (3^{th} year)	F '16		
Analog IC Systems (Grad)	Sp '16, '18, '20, '22		

Figure 1: Students having a Laptop with one or more USB powered and controlled board(s) (e.g. Data Aquisition: Analog Discovery) enable most of the student experiments performed in an ECE undergraduate degree and often what a student would require for an ECE graduate degree. Having a research-transistioned devices into the classroom (e.g. FPAA device) enables a wide range of hands-on opportunities for undergraduate as well as graduate students. Where possible, one would want open-source software (e.g. Python, Scilab, Magic), although utilizing specialized tools becomes advantageous for certain student experiences (e.g. MATLAB, Cadence). This effort includes experiences by the authors using this approach for a 1^{st} / 2^{nd} year signal processing course (ECE 2026), an analog Integrated Circuits (IC) design course (4^{th} year / graduate level, ECE 4430), a control systems course (graduate level, ECE 6550), linear circuits (2^{nd} year, ECE 2040), analog transistor circuits (3^{nd} year, ECE 3400), and multiple analog IC Systems courses (graduate level, e.g. ECE 6435). The USB powered and controlled focuses labs towards low-power experiments, enabling students to have experience and confidence using edge devices.

& video conferencing. Students will have access to a number of real-world sound waveforms (e.g. music), and the circuit measurements can include using these realistic waveforms (e.g. [34, 35]). Multiple cables enable direct digital signals, such as SPI (Serial Peripheral Interface), from computer USB ports. Signal processing courses often can use only a laptop for a range of experiments, although the capability can stretch into controls and circuits opportunities

Adding one or two USB powered and controlled devices at the cost of 1-2 textbooks dramatically improves the types of student hands-on student experiences either in class or outside of class (Fig. 1) . For more than a decade, the best one-device, easily accessible commercial option has been an Analog Discovery device, currently in its third release version [36]. The device capabilities are similar to a typical oscilloscope (2 channel, 14bit, 100 to 125 MSPS), synchronized two channel function generator (14 bit), and logic analyzer in a single device. The fairly easy to use Waveform software runs on windows, MAC, and Linix platforms, has easy exporting of data to comma separated value (csv) files, and allows for direct connection with code libraries (e.g. MATLAB, Scilab). The controlling internal Analog Discovery FPGA can be reprogrammed where desired. Digilent has a number of related products that include protoboards and other form-factors used for class laboratories [37, 38]. Multiple experiments from lab courses (e.g. [39]), including upper-level ECE lab courses [40], could to be transitioned to this in-class & student-owned hands-on model. Additional commercial devices would include USB powered and controlled FPGA boards where multiple FPGA boards are at the cost, or below the cost, of an engineering textbook.

For faculty who can obtain novel or research-enabled devices with USB power and communication adds further educational opportunities and capabilities for the students (Fig. 1) . It is optimal if these boards can be obtained commercially, and where that is infeasible at a reasonable price point, having boards the students borrow can be effective. One example for analog and mixed-signal design is a Field Programmable Analog Array (FPAA) either in its commercial forms (e.g. Anadigm / Okika [41, 42, 43]) or in research & emerging commercial forms (e.g. GT [44], Aspinity [45, 46, 47]). The fine-grain capable SoC FPAA devices [44] enable a wide range of user creativity and flexibility [48], that allow for significant student design opportunities, particularly when coupled with IC design tools (e.g. [49]). These FPAA devices enable analog laboratory investigation (e.g. Fig. 2) as well as analog design & measurement (e.g. Design of an analog PID controller[50]), particularly for IC circuit design, measurement, and testing of circuits with 1 to 100s of transistors and amplifiers, important components of the many recent US educational directions. We expect the economics of scale will transform highly capable new research FPAA USB-enabled development boards to an Analog discovery price point.

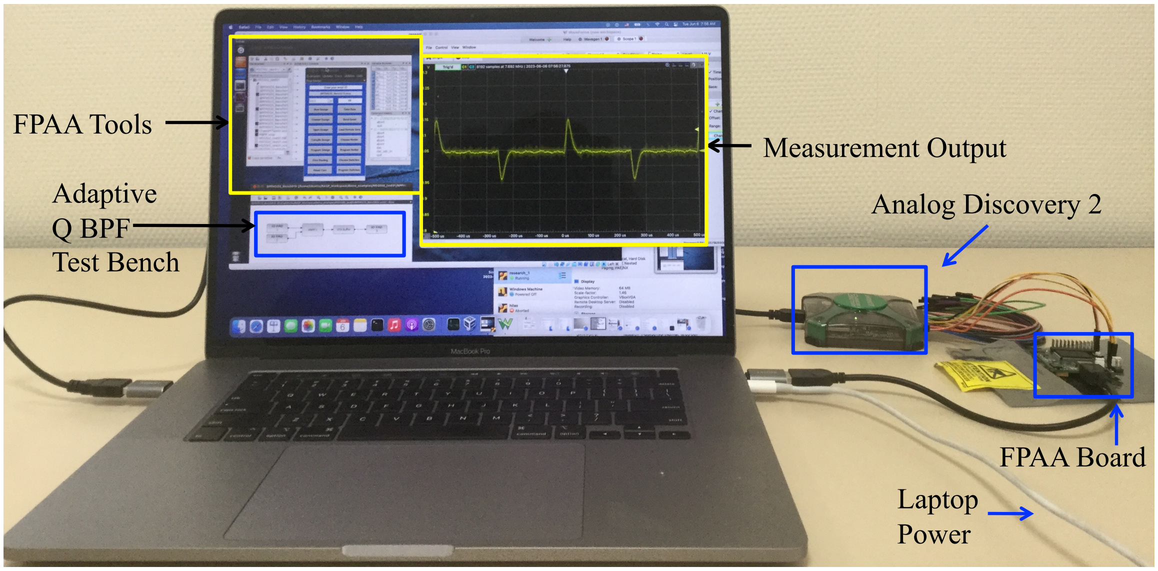


Figure 2: A typical FPAA enabled test setup that can be used for education that uses a an analog Discovery (Digilent), and laptop computer. This system is showing measurements for an Adaptive-resonance bandpass filter circuit. These techniques allow students to quickly transition between a classroom setting to an undergraduate or graduate research setting.

All of these capabilities enables having a portable and personal test system that is accessible to a wide range of students. For the price of a semester of textbooks, an undergraduate or graduate student would have their own lab tools, cables, and small components (handful of ICs) with the incentive for the students to gain confidence in their tools they will continue to use. These efforts incentivize commercialization upon graduation or even after graduation, as having ECE tools enables developing early prototypes in these spaces [51]. These efforts also reduce the school's infrastructure complexity in developing, aquiring, and decommisioning large lab spaces, as well as enable remote learning, places outside the university walls, that include students in places where having access to a large ECE laboratory would be challenging. Maker and Mentor spaces as well as a few specialized laboratories can fill in the gaps for more advanced laboratories Students having their own device provides motivation to develop confidence in their own tools improving the student's confidence in using their system tools, whether computer controlled USB devices (e.g. Analog Discovery), linear and nonlinear hardware circuits, to IC layout tools, and MATLAB tools for signal processing.

2 Hands-on Student Tools Enables Project Centric Courses

Open-source videos open class time for measurement and discussions on measurement. These efforts span over a wide number of semester courses including (Fig. 1) a 1^{st} / 2^{nd} year signal processing course (GT: ECE 2026) with computer projects with sound and images, a core linear circuits (2^{nd} year) course (GT: ECE 2040), an analog transistor circuits (3^{nd} year, GT: ECE 3400) [52], an analog Integrated Circuits (IC) design course (4^{th} year / graduate level) [53], a control systems course (graduate level, ECE 6550), and multiple analog IC Systems courses (graduate level) (e.g. [54, 55]). The course levels at GT are 1xxx and 2xxx are first and second year courses, 3xxx and 4xxx are third and fourth year courses, and 6xxx are graduate courses open to senior undergraduate students. These hands-on techniques started in graduate level IC courses with a priority on hands-on IC measurement for students over 10 years ago, and have continued into core undergraduate courses and non-circuit directions. Many of these initial concepts look to implement experimental courses that integrated lecture and weekly required laboratory experiences at Caltech (e.g. CNS 182) into a traditional engineering program (e.g. GT). Class sizes for these experiences ranged from 12 to 40 students in a class; these efforts were more about constructing these experiences rather than considering the interaction of very large (e.g. 100 or more student) classrooms. Larger classes would require more resources, potentially through faculty or instructor led recitation sections.

Students would watch a selected thread of openly available video nuggets before each class (Fig. 3). The class did not have any quizes checking whether the students watched the videos. Our approach was a combination of students quickly realizing they would be behind the rest of the class if they did not watch the videos as well as imparting trust on the students [2]. It seems that a major issue for students having negative viewpoints on flipped classrooms is the additional required tests and assignments (e.g. [9, 12]); from our experience, students were more positive than other flipped ECE courses that have quiz requirements.

The students are motivated by the availability of time to work through technical issues as a community with their design system physically present. As students often have their own laboratory devices, or have fairly direct access to research devices (e.g. in a particular room to stay within the ECE building), they can start working beforehand on the project, typical of a homework or analytical project. Our experience tends to show 25-40% of students attempt part of the experimental project before a class session, and that percentage of a class is sufficient for a useful discussion. Class time allows for the entire class to work through student's issues, as well as time for small group discussions to achieve the project goals; a lab session transforms into a larger group office hours. Those who do not start early realize they will have to address some things later. Open-source lecture nuggets are not typical at this institution, even during pandemic, although a few faculty do open-source videos at this school.

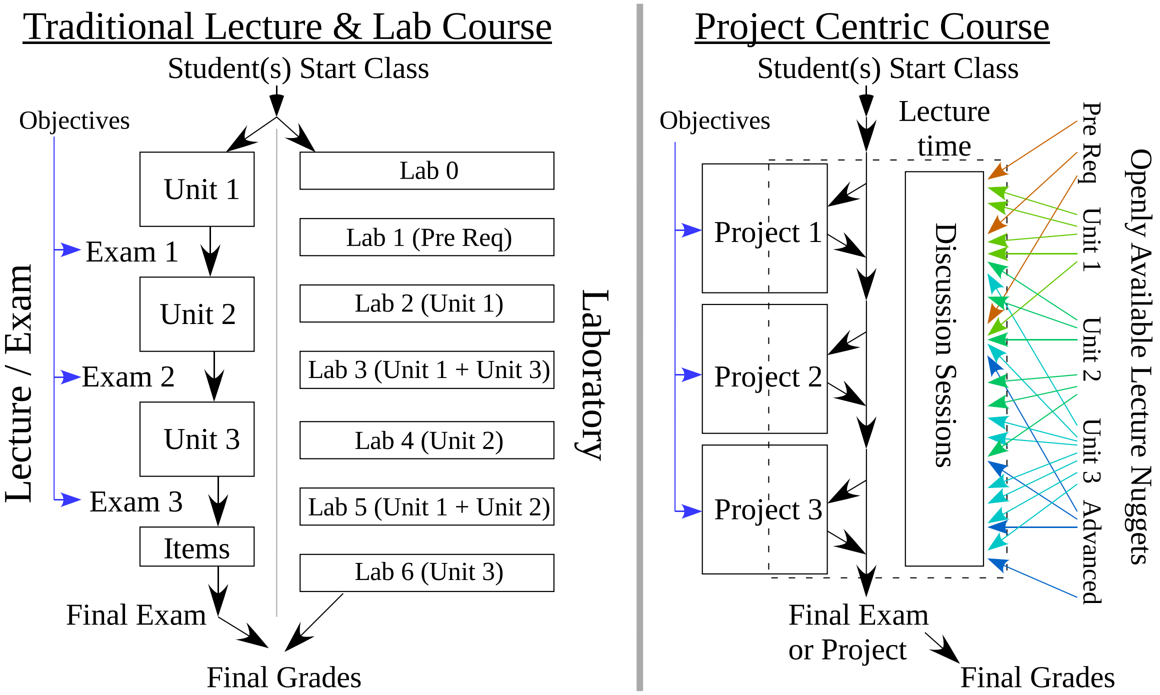


Figure 3: This effort utilizes a *project centric course* structure for enabling in-class or person hands-on student experiences that use openly available lecture nuggets created by the author as well as other individuals. This direction is contrasted with a *traditional lecture and lab course* where the lecture & exam part of the course often is decoupled or weakly from the laboratory experience until the assignment of final grades. Often these classes become separate classes, both because of the near zero coupling as well as other contextual reasons. In the traditional flow, the course objectives primarily influence the exams that often linearly follow expected breakpoints in a standard textbook. In this project centric flow, the course objectives are instantiated through the project definitions, and the course curriculum builds to support the students to achieve success in these areas. Openly available and independent lecture nuggets, nuggets related to a typical Units, will be assigned and discussed where they connect to a particular project / objective, and can include PreRequisite nuggets (nuggets from a previous course), as well as Advanced nuggets (nuggets for a next class)

We use a project-centric class structure for these lecture nugget flipped classrooms, where the course objectives are instantiated in the project goals and requirements, and everything else in the course supports that framework (Fig. 3). Class-level discussions are used to discuss concepts watched from the required lecture nuggets. The hands-on part of the course is seen as the primary function of the class, which is in contrast to cases where laboratory exercises are seen as a side effort of the class or something required for accreditation. Students are motivated by the availability of time to work through technical issues as a community with their design system physically present.

These project-based assignments tend to focus on higher-level learning, particularly synthesis / creation and reflection of the measured results. Each project is written in IEEE format with a hard page limit (e.g. 4 or 9 pages) depending on the exercise particularly to require students to fine-tune their submission and encourage reflection on the hands-on experience. These assignments are the engineering equivalent to reflective research paper writing in non-STEM courses. We avoid any easily graded simple worksheets to encourage this higher learning, to emphasize the importance of these hands-on measurements, and to avoid the typical sharing of answers / need for people to check off assignments. Requiring higher level reasoning makes these uniquely written assignments less vulnerable to Chat-GPT and other LLM systems and inappropriate collaboration is easily seen in grading.

Professor led class hardware efforts increases the student respect of hardware development as well as makes it more of a student priority to develop hardware skills and confidence in those skills. These hands-on class opportunities requires more faculty and other instructor time for developing project materials, developing specific open-source videos, as well as a higher amount of time for grading and student feedback. The approach requires faculty and instructors to dedicate time for grading the project reports. Faculty, as well as other instructors, must have confidence with the hands-on experiments to guide and debug student systems. Faculty experimental expertise sets a positive classroom culture on the importance of hands-on experimental work and measurements. If the faculty are not confident with hands-on experiences, one can not expect students to develop confidence. The increased effort is manageable, but requires more time than a traditional lecture course.

3 Impact and Next Directions

The impact of these flipped classrooms for hands-on experiences with open-source lectures was focused on enabling students to handle higher levels of complexity than related courses as well as increasing student confidence in their experimental tools and techniques. Handling higher levels of engineering complexity, such as analyzing, designing, and verifying larger transistor circuits within a semester, was both seen through the submitted project reports as well as responses to student surveys at the end of the course. Most students felt comfortable (agree to strongly agree) engaging with circuits with 5 to 20 transistors (the 3^{rd} year analog circuits, Analog IC design) where similar ECE courses (through individual discussions) would have students rarely comfortable with circuits above 5 transistors [2]. Students developed confidence in their experimental techniques and tools as witnessed by responses to student surveys at the end of the course as well as with observations of individual interacting on a design team (e.g. capstone design team) by this author as well as other colleagues. Class interactions demonstrated student confidence with these tools, as well as individual students stating they thought they would never be confident taking experimental measurements or they always thought they would be doing theory. Although many students come into ECE, and into the author's class, with a fear of exploring or a high fear of failure, within a few projects most students seem to get past these fears. Although there is far more required to put these directions on a firm statistical educational foundation, they seem consistent with laboratory studies where students had a USB acquisition system, an Analog Discovery device, where for the electrical circuits and digital electronic courses showed improved student final exam scores and that students who used the devices at home (around 30%) had much higher lab scores [38]. These efforts show there is a need for multiple systematic studies on the learning improvement for both using open-source lectures over the range of ECE courses, as well as the advantages of having hands-on experiences in these flipped classrooms, particularly since these techniques are possible and early experiences show positive results.

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