Flipped Classroom Experiences Built on Personal Instrumentation

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Abstract

The instructional practice of flipped classrooms is being investigated where specific content is provided via online video lectures, and class time is devoted to hands-on practice of concepts. There are two courses involved in this study. The first – *Electronic Instrumentation* (the main electronics course taken by student outside of Electrical and Computer Engineering) – was transitioned to flipped instruction in 2010 using the Mobile Studio as student-owned personal instrumentation. The flipped environment evolved with basically the same instrumentation toolset through the Fall of 2013, after which Analog Discovery became the platform of choice and course development continued through the Spring of 2015. During this period in which a single instructor developed and delivered the course, student and faculty perceptions of the use of online video lectures and the in-class active experiential learning (i.e., how both methods were used, their impact on student affect and cognition, as well as facilitators and barriers) and documentation of the process of continual development used to refine the implementation of the flipped classroom approach, were documented in a series of papers and book chapters. Although many students have some prior experience with video lectures, their comfort levels have not been consistently. A major focus of this development effort has been to provide students with scaffolding infrastructure so they can become more confident and successful in this learning environment. In the last year of this period, students demonstrated an acceptance in learning via the flipped classroom approach. The majority of students indicated they would not change anything about the group learning process in the flipped classroom. Students noted limitations to learning; individual learning characteristics appeared to have an effect on student perceptions of learning in a flipped classroom. With the general success of the flipped approach and the availability of new, higher performance personal instrumentation, we transitioned all course activities to new hardware and software while also enhancing the personal interaction between students, teaching assistants and the instructor to address, as much as possible, how each student could best raise their level of expertise in electronics. A major evolutionary event in *Electronic Instrumentation* occurred in Fall 2015 when it was taken over by a new instructor. The second course is an entirely new first year *Introduction to ECE Analysis*, first offered also in the Fall of 2015. Lessons learned in *Electronic Instrumentation* and even significant content have had a strong impact on this new course. This paper will address the impact of these changes measured through student surveys, performance on class assignments and examinations and, in the case of *Electronic Instrumentation*, feedback from the new instructor. The new first year course, while superficially similar in topics covered to *Electronic Instrumentation*, is a very different course. First, because there are no formal college level prerequisites (only a typical high school science and math experience is assumed), circuit analysis emphasizes algebraic methods and preparation for future circuits and electronics courses. An even more important distinction is the emphasis on a more complete and integrated Experimental Centric Pedagogy (ECP) than has been the case in *Electronic Instrumentation* (EI). Essentially every concept is first introduced through an experiment (experiment first) which requires that a substantial fraction of time spent in and out of class is dedicated to enhancing the students skills as electronics experimenters. A new outcome for EI and also included in the new course is that students will be able to identify online circuit designs that are relevant to their design projects (in these and other courses) and be able to effectively modify the designs to meet the specific needs of their projects. This concept has been under limited development in EI.

Introduction

The 21st century student requires major changes to traditional methods of teaching; engagement promoted through instructional strategies of visual stimulation as well as experiential/authentic learning[1]. Research has also shown that technology can play an active role in assisting instructors in providing constructivist and guided learning[2,3,4]. According to Bergmann and Sams[5], the flipped classrooms approach (i.e. allowing students to learn key concepts outside of class via online video lectures, leaving class time devoted to hands-on practice of the concepts[6], is an innovative technique that enhances content-based learning, while offering more time for individualized practice and skills acquisition. Additionally, when using web-based tools as well as local technology, learning can be scaffolded to meet both individual and group needs and can be tied to real life experiences, data sets, and simulated outcomes and can provide students with an environment that eases the transition and anxiety from traditional methods to more student-centered learning by using guided inquiry and scaffolding techniques[7].

The importance of the flipped classroom model is the focus on efficient use of class time which accommodates different learners, engages with problem-based experiential learning, increases student-teacher interaction, and allows students to take responsibility for learning so that they may transfer these skills to other contexts[8]. Additionally some research has shown that problem-based learning methods can be much more effective in fulfilling ABET 3a-k outcomes Felder and Bren[9]. However, adoption of problem-based learning is hindered by the fact that the curriculum for engineering programs is already tightly packed[10], and the flipped classroom model allows a flexibility around class time constraints. While a number of universities are implementing various models of the flipped classroom, the make up in the real time meeting varies across campuses. For the purposes of this paper, the focus is on the use of experiential and experimental activity when classes meet in order to apply what has been gained from the flipping of the lecture.

New Instructor in Electronic Instrumentation

Electronic Instrumentation has been a test case for blended learning for a few years[6]. During this time, many pedagogical ideas have been investigated, with the course undergoing more-or-less continuous change. This course is the only required electronics class for students outside of ECE and, as such, has historically not been very popular with the largely mechanical engineering majors who take it. They generally lack the desire and intuition necessary to learn this material. The hands-on, blended approach that is followed makes the atmosphere much more positive with the majority of the student leaving the course convinced of the value of electronics and their ability to use what they have learned in their careers. Nearly all prefer the time they get to spend doing hands-on activities rather than listening to lectures on topics they previously did not care about. Student response varies but probably the most eloquent description of the advantage of blended learning with lectures, homework, etc. flipped from what they usually experience came from a student in Fall 2014. "…EI was perhaps the most well-put-together engineering class I've ever taken at RPI. It's the first time I felt like my learning style was catered to (especially the online videos instead of real-time 2 hour lectures, as well as piazza), and I found the class format to be very effective. Having open access to all of the back tests was also extremely beneficial in preparing for the exams. This leveled out the playing field (usually Greeks are at an advantage here) and helped me to find my weak spots before the exams. Basically, you set us up for success, so it was up to us on whether we took advantage of all of the learning tools available."

As an instructor, one of the very best characteristics of the organizational structure of this course has been how easy it is to have other instructors fill in during a busy travel season. This freed up time to offer workshops on the ideas used in the course and there was never any problem finding willing colleagues to do the job of the instructor. Since there are no formal in-class lectures and all activities are thoroughly scheduled, the course basically runs itself, with, of course, the able assistance of the teaching assistant or assistants (depending on the size of the section). Because thing ran so smoothly, one of the professors who has filled in regularly agreed to take over full running of the course with two sections and about 140 total students. What follows are some of his observations.

Previously, he had tried to do a simple flip of the course ECSE-2050 Introduction to Electronics in spring of 2014, using PowerPoint presentations rather than videos. He did have short lectures each class to highlight a few key points in the PowerPoint files. He was completely involved in developing the “flip” but didn’t create any video content. Reflecting on this after the semester, it was a mistake to attempt what might be called a partial flip. He agreed to take of EI because he was given the opportunity to teach a well-developed flipped course. He also was building on his experience from the earlier course. The fundamental reason why he was interested is based on reading papers and forming a conviction that his time with the students is best served helping them get past difficulties by learning how they approach problems. Then he is able to help them determine where there are gaps in their knowledge and how to use the course resources to bridge those gaps. A lecture isn’t effective at doing these tasks.

He has extensive experience in experimental-centric instruction starting when he started teaching in 1991. He was one of the first professors to use the Mobile Studio Board, a board that was available before Analog Discovery. This was his first semester using the newer device. Other courses he has taught have used different instrumentation. He sees the need for an instrumentation board, but it doesn’t have to be Analog Discovery. The Mobile Studio Board was very effective and he believes that other boards have been and will be created that will be also very effective. He was pleased to see how easy it was to change from using one instrumentation board to another. Each board will have its own advantages but the course can be adapted as the hardware changes. Experimental Centered instruction is the only method he would consider for this course. The course content and outcomes lend themselves to this approach. The ADB enhances the student’s opportunity to work outside of the studio room and encourages them to experiment. While the students are in the room, they could just as effectively use bench instrumentation but that would require a lot of equipment, maintenance and scheduled replacement.

A clear benefit for students is that they use the ideal theory, simulation tools, and make actual measurements. All 3 of these will give slightly different “answers.” They are learning that the theory and simulation are based on models and is only as good as those models. One hopes that they remember this as they progress in their careers. Another benefit is that they gain experience on setting up experiments and making measurements. This includes gaining experience on debugging their setup. Faculty who enjoy teaching courses with a significant laboratory component understand the advantages and are interested in both the ADB and the flipped classroom. The research shows that the flipped classroom works for all types of courses, the experimental component isn't required, but faculty that teach courses that are much more theory based are much more skeptical that the flipped classroom could or would work. Given the constraints on our time it is difficult to convince them to read some of the many publications. He, on the other hand, wishes he had this when he was a student. He would say the same for other low cost technologies, including LEGO Robotics, Arduino Boards, and others. More of this kind of technology needs to get into the elementary and middle school years to excite youths to follow paths in STEM.

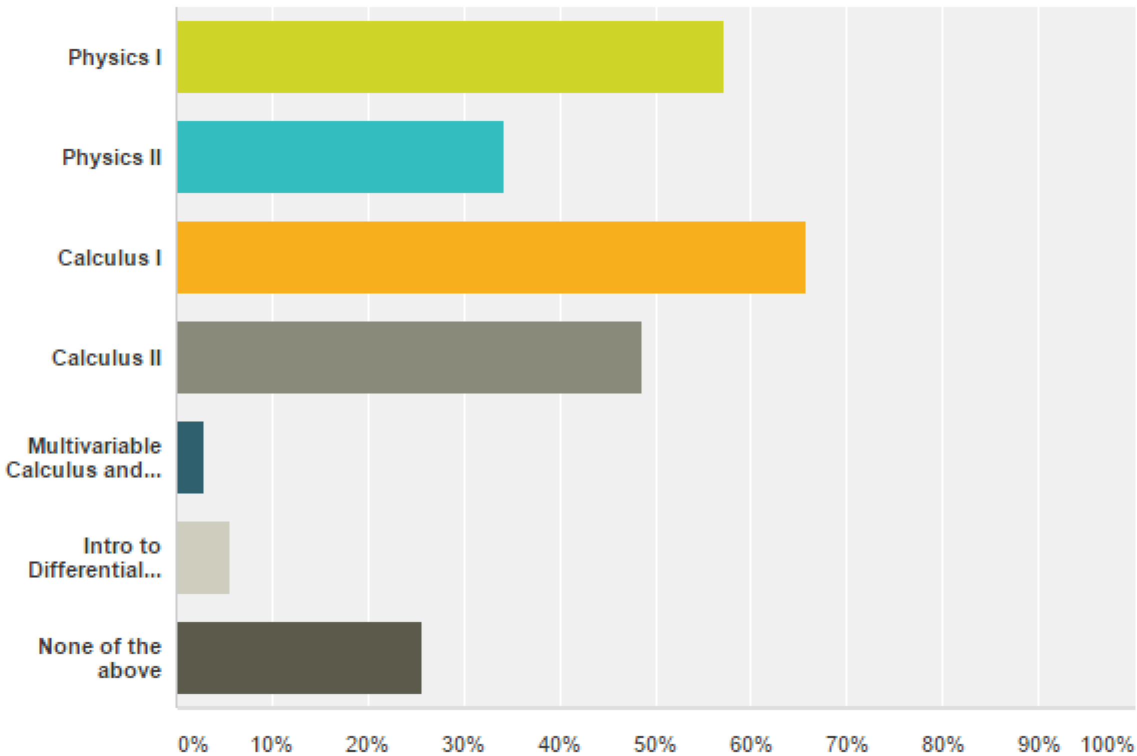
New First Year Intro to ECE Course Based on Electronic Instrumentation

For more than two decades, Rensselaer has had for its first course in engineering, *Introduction to Engineering Analysis*[11], a course focused on statics, linear algebra and computing. This course has never been popular with electrical and computer engineering students and had minimal impact on student performance in core ECE courses like circuits, electronics, signals and systems, etc. While teaching the flipped, studio-type version of *Electronic Instrumentation* (electronics for students outside of ECE), instructors often had eureka moments when they thought ECE students should be getting the same learning experience, but as first year students. When the opportunity arose to create such a new course, at least one instructor (which is all it takes) was ready.

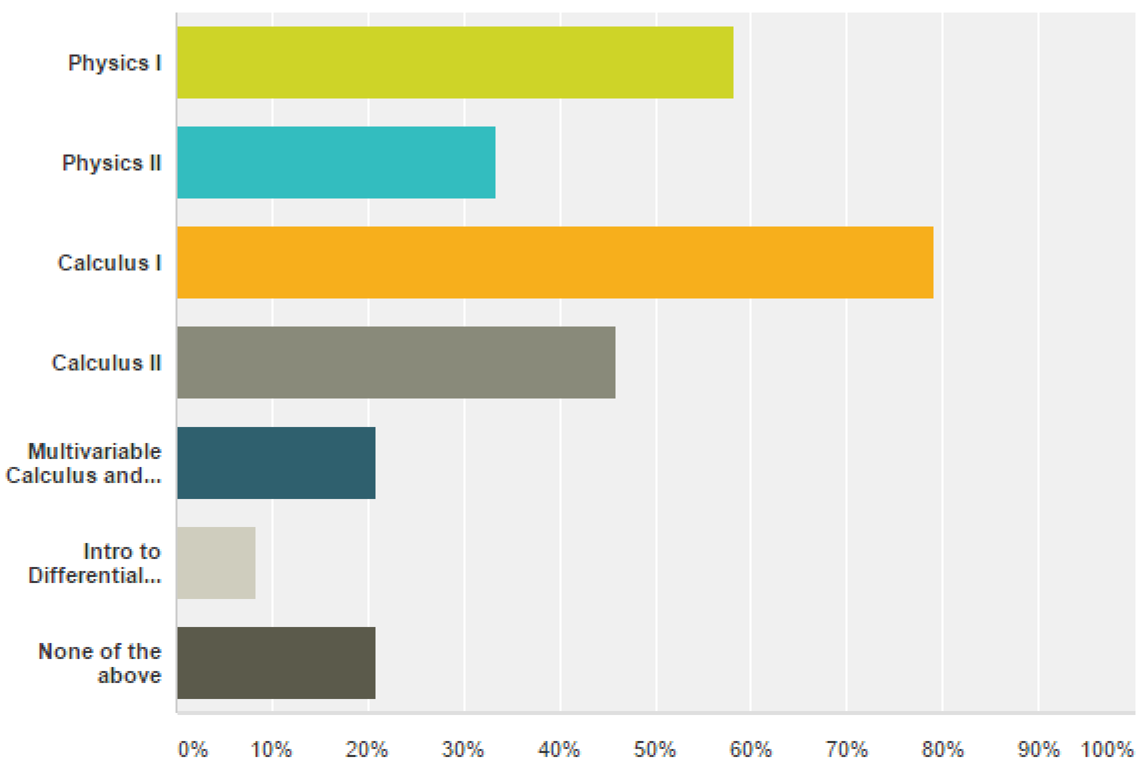
Before beginning with the course design, the significant differences between the students in *Electronic Instrumentation* (aka EI, which is populated mostly by mechanical engineering juniors) and the new course (all brand new electrical and computer engineering students) were studied, with the help of a high school STEM teacher who runs a special, engineering-focused STEM program on the Rensselaer campus. Her students nearly all go on to excellent engineering schools like Rensselaer, Clarkson, WPI, Penn State … so they make a very relevant cohort to study when trying to understand the background and capabilities of first year engineering students.

First, the non-majors in EI had all completed Physics II (E&M) and Differential Equations and about half had taken either an embedded systems class or a controls class or both. The 1st year ECE students had quite a wide variety of backgrounds. On the first day of classes for both the Fall 2015 and Spring 2016 terms, the students in the new course were surveyed on their background preparation and interests. The most concrete information on background came from their advanced placement courses, which are shown in the next two figures.

The data in the two figures show two striking bits of useful information. About 25% of students had no advanced placement at all and more than half had at least two. There are a few transfer students in the Spring 2016 term, which skews the data even more toward additional AP or transfer courses, so it is best to focus on the fall. When coupled with the additional info that about 20% of the students had some kind of electronics course in high school, it is easy to see that the range of student backgrounds is very large indeed. The interest of the students in studying ECE content was uniformly strong, most likely because they self-selected this option to the previously required general engineering course and because they knew the material would be more useful to their future career than what they would experience in *Introduction to Engineering Analysis.*



Fall 2015 Advanced Placement and Transfer Data



Spring 2016 Advanced Placement and Transfer Data

Based on discussions primarily with the high school teacher mentioned above, the content in the first third of the new course had two key goals. The first was to reinforce what the students should have learned in high school about electrical topics and the second was to help the students to build their skills with circuit experimentation and simulation. Two sources of information were used for high school topics. The first is the New York State Regents Physics Exam Prep[12]. The second is the CK-12 Project online textbooks on Engineering and Physics[13]. The latter had more specifics on circuits, so she went through their list of topics and indicated what the students can and cannot easily do.

What someone completing regular high school physics should know (based only on the content on that web site):

1. **Ohm's Law** – Piece of cake. They'll know it flat (or a 2 second reminder). They've seen it in middle school
2. **Circuits** – Again, should be completely familiar, could use a one second reminder that flow is out of positive terminal
3. **Electric transfer in energy circuit** – yes, they've got this. The difference between kilowatts and kilowatt hours just never clicks for many students. It's simple, but they stumble a bit.
4. **Controlling current in electric circuits** – probably not, though the idea of a fuse or circuit breaker is probably familiar to them from every day light, it's not officially something they delve into.
5. **Capacitors/RC circuits** – NO. These are new if a student just had NY State Regents physics. If they had AP they would be familiar or if they were from a different state then maybe they are covered. They do study electric fields in parallel plates but the word capacitor or capacitor in a circuit is new as far as I can tell. I double checked on a few Regents sites to be sure and I don't see the word capacitor anywhere.
6. **Series and parallel** – absolutely. Again, they need a 30 second refresher, but they all understand this. Even my students who have not had high school physics catch onto this super quickly.
7. **Internal resistance** – NO. But they pick up on it really quickly when it's introduced.

In general, here is what is <u>unfamiliar</u> to students that may surprise you:

- **Reading resistance of a resistor** – unless they took a technology class, this is likely unfamiliar, but easy to learn.
- **Circuit boards** – Again, this would vary, but if they didn't have a technology or Project Lead the Way class or something like that, they may have never seen a circuit board or its components. Some physics classes use them but not all.
- **Oscilloscopes and function generators** – they can follow instructions and do all the labs, but they have very little idea, almost none, of what they are actually doing; even if they get 100% on the lab. It's like driving a car. They can get from place to place, with no concept whatsoever of how the engine works. This is definitely an area where they 'fake it'.

- **AC current** – they understand it differs from DC and maybe even have some concept that it "alternates," but that's the end. Most would likely say that something that plugs in is AC and something on a battery is DC. And they would have to stop for a few second to think about electronics that plug in. Are they just charging a battery or actually running on AC? What does "running on" mean? With things plugging into car batteries or walls these days, they are a bit more familiar with the concept, but how or why it is necessary to change from AC to DC or back again (from a scientific perspective) would be a mystery for most students.
- **Figuring out if a light bulb will get dimmer or brighter as voltage, current, resistance changes.** They can calculate circuit diagrams all day long and also figure out what will differ between series and parallel, but no one does a good job of explaining to students what all that means in a tangible way. All the following questions would stump many students, "if a bulb designed for 220 V and rated for 60 W is given 110V instead, what would happen?" or "what happens if you put a 100W bulb into a lamp that says 40W bulb max?" or "The resistance of a 25 watt bulb is ______that of a 100 watt bulb, if both run on the same voltage" or "A household circuit rated at 120 Volts is protected by a fuse rated at 15 amps. What is the maximum number of 100 watt light bulbs which can be lit simultaneously in parallel in this circuit without blowing the fuse?"
- **Digital** – OK, they understand digital = electronics or data or computer or something to that effect; but some students would struggle to come up with the word "analog" and event those who came up with it would likely struggle to say what that means, or how/why we would want or need to convert.

Her guidance was astoundingly accurate. For every topic she said students could learn quickly if given a short overview, they did it whether or not they saw the review in class or using an online video. In a very recent experiment, students only saw a quick review of terminology and then had to do a practical calculation of the current limits for resistors in their parts kits. They were able to do it but took about twice the time as the students in the Fall, who had the video in addition to the quick terminology review. They had to find the power limits on the spec sheets for the resistors and apply what they knew about Ohm's Law, power and current. The experiments and online problem sets covered all of the topics from high school, whether or not most students there are really expected to learn them (i.e. whether or not they appeared on standardized tests). Every student was able to do basic paper and pencil analysis and build and simulate simple circuits that involved all of the topics. They used LT-Spice for circuit analysis and Analog Discovery for most of their measurements, signals and DC power. They also often used multi-meters and, from time-to-time, used more traditional standard desktop instruments.

In the second third of the course, the key goal was to prepare the students for their core ECE courses. Circuits was the primary focus because it is the next course in sequence, but some topics from signals and digital logic were also included. This continued in the last third with the addition of some simple design projects. For the latter, the goal was to have the students identify something they wished to accomplish with their circuits, search online for a circuit that does nearly what they want and then modify the design they found to do their specific task. They also had to operate their circuit in two distinctly different sets of conditions. All were able to accomplish this. In addition, Matlab analysis of data and control of experiments was addressed throughout the second and third parts of the course.

What went wrong and where can the course be improved? First, because the course materials were being developed or highly modified while this pilot class proceeded, there never was a complete set of practice problems for the students to look at throughout the term. Both daily short think-pair-share questions and online problem sets are now fully available starting at the second class meeting of the term. The goal of these problems is to develop competency in the basic algebra of circuits and the tools of experimentation and simulation. Too many students were still making some simple calculation errors as they did their end-of-term projects during the fall. Some content is also being added in the spring that could not be covered in the fall because of the time it took to experiment with delivery methods. Anecdotal reports from students taking the introductory course in circuits in the spring indicate that they are very comfortable in spite of the fact that they never did a lot of detailed circuit analysis. The focus was on big ideas like input and output impedance and not necessarily on topics like KVL and KCL.

Conclusions

Experiences reported on here demonstrate that it is possible to both transfer a well-developed, blended course at least to a colleague who fully understands the value of hands-on learning that incorporates all of the aspects of what an electrical and/or computer engineer does. Little has to be changed in the course as long as the instructor understands the new role they are playing that includes little or no formal lecturing. It also helps that the new instructor has experience with studio instruction. Transferring what is learned in one course to a completely new group of students with almost not common background but greater interest in the subject is also possible as long as the learning experience is personalized. There is still a long way to go to find the best use of experiment centric pedagogy, but there can be little doubt that experimentation must play a core role in the education of engineers.

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