Experiential Education – At Classroom, Lab or Home

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Abstract: It is no surprise that everyone finds activities, demos and hands-ons more engaging, as compared to lectures, problem sheets and step-by-step lab exercises. And students are no exception to this! Yet, hands on learning activities have very little role in a typical classroom scenario.Most of the classes continuously deliver theoretical concepts without quickly showing the relevance of the concepts in a real world scenario. The students have to wait for weeks or months to see / try what they were taught in class. And even when they do get to the lab, in many cases, the equipment/software are not flexible enough to make the lab very exciting. As a result, a big number of students do not understand the relevance of the concepts learnt in class to real world engineering. Many of them may also lose interest in engineering, as what they make in most labs may not be very exciting. This problem is potentially more serious now-a-days, because, the things that students use outside academia, like phones, laptops, apps, games etc. have a very interactive user experience, by which the user quickly figures out how to use the equipment/app. The younger generation has come to expect of the same interactive experience when it comes to learning concepts as well.

Wouldn't it be great:
- if there were flexible instruments which the students can bring to class and take home?
- if students could try out concepts in class immediately after they are taught?
- if students are excited enough to tinker, explore and reflect on concepts on their own?

This paper discusses, with examples and case studies of how, doing engineering anywhere (classroom, lab or home) and that too with real world signals, enhances the understanding and retention of concepts and gets the students excited about engineering.

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1. How are concepts taught today in most engineering courses?

In many of today's curricula, theory and laboratory are two separate set of sessions. The theory sessions tend to impart the knowledge mostly via black board/presentation slides. The assignments for the theory sessions are also mainly oriented towards written problem solving or may go a step further by incorporating simulations. The laboratory typically happens weeks or months later and it contains step-by-step exercises not necessarily directly correlated to the concepts taught in class.

While this may have been a very practical approach to teach engineering 15 years ago, can it be done in a better way in today's world? What has changed over the past 15 years?

Table 1. A comparison of technological and social trends 15 years ago, vis-à-vis today.

15 years ago	Today
Computers were a centralized resource in universities. They were big, fixed and wall powered.	Every engineering student has a laptop. These laptops are portable, battery powered and powerful.
Laboratory instruments were bigger, costlier and not portable. It was impossible to imagine each student having his own signal generator and oscilloscope on his classroom desk.	Low cost, pocket sized, USB powered, computer based Data Acquisition systems like NI myDAQ, AnalogDiscovery, PicoScope etc. are available.
Even if they had these instruments, they were not easily programmable through computers – which means, only fixed signals can be generated.	These instruments are computer based – which means, you can completely customize what these instruments generate, analyze and control.
Embedded systems were	You can get a Raspberry-Pi (900

much less powerful and costly.	Mhz Quad-core) for as low as 35$
Embedded systems were difficult to program	Arduino - Embedded systems as easy as it can get!!
High level programming languages were less powerful, especially for engineers.	High level languages like Python, LabVIEW, MATLAB, and Simulink can be used for virtually any application.
Sensors and actuators were difficult to source and costly. Many of them also needed to be imported. The idea of 'every student works with these components' was far from reality.	Extensive online stores (Indian) where you can source components for cheap and quick: http://robokits.co.in/ http://www.rhydolabz.com and many more
Content for learning engineering concepts was mainly text books, computer animations etc.	There is so much quality content on the internet for any engineering concept that we can think of.

But are we really leveraging these trends to enhance classroom teaching?

2. Is there an alternative approach?

In context of these emerging technological and social trends, the idea of this paper is to propose that, today, it is very much possible to bring experiential learning into classroom to enhance classroom teaching. The result of this could be envisaged as follows:

- ***Students try out the concepts immediately after they are taught,*** in the class with real world signals – This establishes relevance of the concepts taught, to a real world engineering scenario enhancing their comprehension and retention.
- ***Home assignments can be experimental and not just written!*** For example, in order to teach the concept of 3dB bandwidth, you can ask the students to plot the gain of an amplifier as frequency varies and bring it to class the next day.
- ***Students become confident to work with real signals***, real sensors and actuators. They do engineering more often than they just read engineering.

In the remaining section of this paper, some example topics and courses are picked up to show the contrast between how the topic is dealt in conventional manner vis-à-vis, 'in-class experiential learning' manner.

Topic 1: System Modeling using Transfer Functions (Signals & Systems):

Conventionally, in Signals & Systems course, the students are taught Laplace transform, LTI systems, impulse response, transfer functions etc in a very abstract manner. There are hardly any real systems that are dealt with in this course. Because of this, the students fail to understand the relevance of the concepts that are taught in class to real world signals & systems.

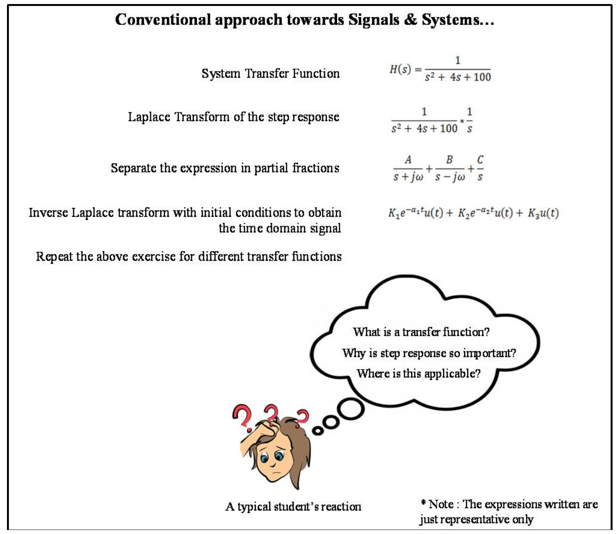

Fig 2: Conventional approach towards Signals & Systems

Alternatively, an 'in-class experiential learning' approach would look as follows:
- The instructor teaches the concept of step input and how to calculate the step response of system
- Using pocket sized computer based DAQ instruments mentioned above; students apply step voltage input to a small but real system, like a DC motor and plot the motor velocity with time. The same plot can also be done for an amplifier to show how the same analysis techniques be used for systems as different as a DC motor and an amplifier.
- This kind of exercise establishes the relevance & importance of step response using a real system, as soon as the concept is taught.

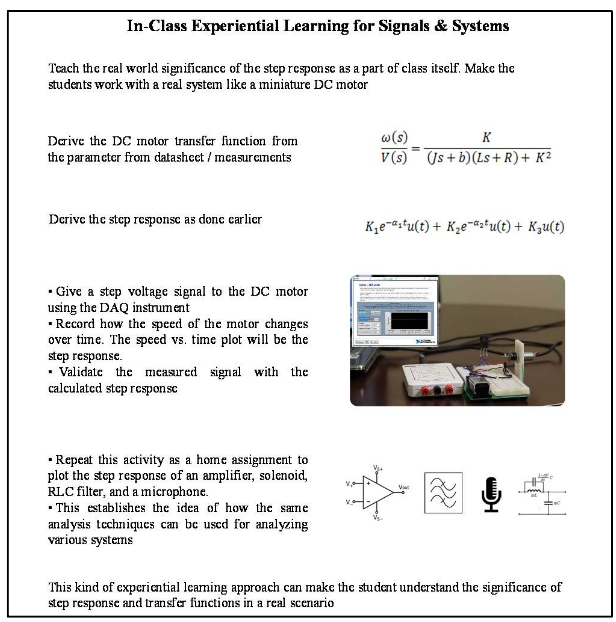

Fig 3: In-Class Experiential Learning for Signals & Systems

Topic 2: Digital Modulation & Demodulation Schemes (Digital Communication)

Conventionally, Analog & Digital Communications has been another topic where most of the topics covered are heavily based in abstract mathematical concepts. While it is very important for the student to understand the math rigorously, it is also equally important that the student implements real communication, so that he understands the relevance of the concepts taught in class and gets excited about communications.

Alternatively, the 'in-class experiential learning' approach for this could be as follows:

- The instructor teaches the concept of digital modulation schemes and demodulation techniques.
- The students define the modulation scheme in the software like LabVIEW/MATLAB and use the USB connected DAQ instrument to generate this custom signal. This signal is transmitted to another student's DAQ instrument over two wires.
- The second student implements the demodulation technique in software to decode the text message sent by the first student.
- This exercise can be implemented partly in class and also as a home assignment given to the students. This kind of exercise would help students understand the relevance of the modulation schemes learnt in class to a real scenario of wired communication like ADSL, Coaxial cable communication etc.

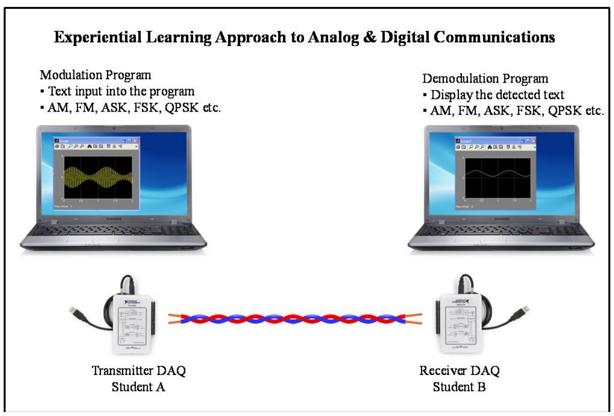

Fig 4: Experiential Learning approach to Analog & Digital Communications

Topic 3: Basic Electronic Circuits:

Conventional approach to teaching basic circuits again, isolates what is done in classroom, laboratory and home into separate sessions and assignments. For example, a student cannot verify and understand I-V characteristics of a MOSFET immediately in class. He has to wait for the lab session, possibly for weeks or months. Neither can he perform these experiments at his home because he lacks those expensive instruments. Even in the laboratory, with the equipment usually being shared among 3 students and with a prescribed set of steps to perform, many of the students do not get the time to tinker around with circuits & components as much as they want to.

Alternatively, the 'in-class experiential learning' approach could be as follows:

- Using the low cost, portable DAQ instruments, the students take the instruments to home along with them and tinker around with circuits and components at their own pace.
- The students can explore questions related to basic circuits and components right after they are taught, in an experimental manner. For example
    - o What is the input impedance of a MOSFET?
    - o What does bandwidth of an amplifier mean?
    - o What happens if you do a direct voltage control over an LED?
    - o What happens if you give a square wave input to a transformer?
    - o What happens to the power supply voltage when heavy load is connected?
- Having the instruments always with them, encourages the interested students to come up with many interesting circuits and mini projects.

Topic 4: Analog & Digital Signal Processing:

Signal Processing is another course that is usually taught in a very theoretical-only approach. A few samples of experiential learning activities for Analog & Digital Signal Processing course could be seen below:
- Sampling theorem & Signal reconstruction: The significance of sampling theorem will be best understood by dealing with real signals. The activity could be as follows:
    - o Student A generates a custom band limited signal using his DAQ instrument.
    - o The signal generated by the student A is sent over two wires to the DAQ of student B.
    - o Student B will sample this signal at barely sufficient sampling frequency. He will then use the reconstruction algorithm to reconstruct the signal.
    - o This activity first proves to the student that even though the sampled signal does not look quite like the actual signal, it is still possible to recover it if you follow Nyquist rule.
    - o This approach also removes the misconception that most people have about Nyquist sampling theorem. Many engineers do not associate necessary rigor to the Nyquist sampling theorem. For example, if one were to ask a pointed question to an engineer - 'If you sample a 100 Hz signal at 220 Samples/s, can you reconstruct the signal perfectly? While the answer is 'yes you can', many of them would start thinking if it is a yes or a no. Some of them answer that it may be necessary to sample the signal at 5-10 times the maximum frequency for best results, which is incorrect.
- Frequency Response of a Filter/System: The relevance of 3dB bandwidth to a real scenario can be best understood by

actually pushing a real system to its 3dB bandwidth. The activity below uses a simple audio system to show how 3dB bandwidth is an important measure for any system.

- o Using the DAQ instrument , student A generates an audio signal of a specific frequency, say 100 Hz through a loud speaker
- o The student B records the audio signal using the DAQ instrument and finds the peak-to-peak amplitude of the recorded signal.
- o The student A varies the frequency from 100 Hz to 20 kHz and both of them observe the variation of the amplitude as the frequency varies.

Topic 5: Control Systems:

DAQ instruments are very much used already in many of the Control Systems labs. All that is needed is to bring miniature & low cost versions of the plant models into the classroom.

- Classic DC motor speed control

- o The student uses the DAQ instrument to generate PWM pulses which are then given to a motor
- o The feedback from the motor is taken in using the DAQ instrument
- o The student implements various control schemes in LabVIEW / Simulink and understands the concepts.

The above examples are just to illustrate how computer based DAQ instruments along with a high level scientific computing language like LabVIEW / MATLAB be used for bringing real systems / applications into classroom. Of course, the applications are not limited to these and the teachers could actively invest time in coming up with more ways of how they can use these tools to enhance students' comprehension and also excite the engineer within them.

4. A Few Sample Case Studies:

Many teachers around the world have embraced this concept of doing engineering with real world signals to teach the students better. A few examples have been given below:

Designing Hands-On Wireless Communication Lab:

Challenge: Moving beyond theory and simulation to expose entry-level wireless communications students to real signals for hands-on laboratory learning.

Solution: Using the NI software-defined radio platform to give students opportunities to apply hands-on wireless communications concepts in the lab as part of the sophomore-level EE 49 Building Networked Systems course at Stanford University.

Result: *"The course evaluations for our class were fantastic. Students rated the class 4.94/5.0, likely making it one of the highest ratings among all classes in the School of Engineering at Stanford."* – Prof. Sachin Katti, Stanford University.

Integrated Approach to Learning Electric Circuits:

Challenge: Circuits and microelectronics courses traditionally separate laboratory projects and homework; however, integrating physical measurements into homework assignments can help students appreciate that textbook theory really does apply to the real world. It also helps them experience the limits of mathematical models..

The Solution: Developing a three-way solution method as a weekly laboratory activity based on NI hardware, software, and courseware to enhance students understanding of theory and let them experiment multiple scenarios on their own.

Result: *Student questions shifted from the typical, "How do I do this step?" to a more confident request for help: "Something must be wrong with my analytical work because my simulation and measurement results agree with each other!"* – Prof. Ed Doering, Rose-Hulman Institute of Technology

Teaching Electronics to Product Design Undergraduates:

Challenge: Making electronics and programming interesting, motivational and relevant for designers.

Solution: *Using LabVIEW and myDAQ to develop a radically different electronics course that was interesting, motivational and relevant for product designers. We found that myDAQ, with adjoined custom protoboard, offered an ideal platform for practical learning and promoted experimentation* - David Keeling, The School of Mechanical Engineering, University of Leeds

5. Conclusions

This paper discusses how an approach of being able to merge 'doing engineering' in classroom, lab and home enhances the student's comprehension and retention of engineering concepts at the same time making engineering education more exciting for the students. Five example topics are shown in this paper, to contrast how the proposed approach compares with typical approach of teaching topics like, Signals & Systems, Digital Signal Processing, Control Systems, Communication Systems etc.

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