
AC 2012-4021: HANDS-ON, DISCOVERY, CRITICAL THINKING, AND FRESHMAN ENGINEERING

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Hands-on, discovery, critical thinking, and freshman engineering: A systems level approach to learning and discovery

Abstract

One of the most difficult tasks for teaching freshman engineering classes is to fill the gap between the high school experience and the paradigm of adjusting to the open, dynamic, exciting, and ever growing university environment. In a freshman engineering class, we also need to get the students to advance in the areas of critical thinking, engineering fundamentals, computer programming, and basics of engineering principle and design, and hands-on laboratories. All of the above also have to be presented in a context that is not overwhelming, is basically not too threatening, and will help students be ready for the years to come in the engineering discipline. There have been many great efforts as well as practical and conceptual approaches on what, how, and why to do the freshman engineering classes to be more productive and effective. In this work, we try to focus on the systems level approach and helping students to understand how to connect their computers to sensors and equipment for data acquisition.

This paper presents a framework that is applicable in the laboratory development and approach.

Introduction

The challenge of teaching freshman engineering classes has always been one of the most interesting aspects of engineering education in the last decade¹⁻⁶. Traditionally these classes have been the way into engineering thinking and problem solving. The problems that the engineering education community is facing is how to make these classes more interesting, expand students' thinking process, bring in a more systems level thinking, and help students appreciate what is engineering all at the same time. The above challenges together with the typical characteristics, behavior, and attitudes of the new students actually increase the importance of the freshman experience as shaping steps in for the future engineering.

The most effective classes at this level have been the ones that would help students understand how they learn, what engineering is all about, bring basics of math and science to action for them, and allowing them to play and learn. In particular, many programs are starting the design experience and process at the freshman level.

The concept that we follow for our class is not fundamentally different. We would like to create a hands-on and fun-to-learn environment that has the challenging nature of engineering, open mindedness that enhances students' learning and allows them to expand their perspective, and provide a platform to make mistakes, learn, discover and build⁴. However, the most important of them all is how to help students think differently and change most of their rigidly defined perspectives. We need to make an environment that would encourage experimentation, allow them to make mistakes, and let them grow to be innovative at the same time.

We introduce the Arduino-MATLAB experience in response to the shift in mentality of prospective undergraduate students. The increase in open-source rapid prototyping tools coupled with great online support has made it much easier and cheaper for the general public to take on electronics design challenges as a hobby. This has, in effect, caused a shift in the general interest and expectation freshman students in electrical engineering have. As in many hobby projects, students may expect to have labs which are very active oriented and instructional. This provides an increased sense of accomplishment, an excitement for the topic at hand, and a hunger to do more. It is our goal to design an environment for students to practice effective learning technique while also targeting their interest and excitement.

Lab Design

The lab was designed to incorporate the use of hardware, software, and design concepts in 11 labs over a 15 week semester. In general, each lab involved aspects of interactive, discovery activities and some decision making processes. It was found that this system appealed to a broad range of students with different learning styles. The specific topics covered in lab include systems level thinking and a basic understanding of MATLAB, circuit theory and design, the Arduino development platform, and systems design.

The goal of this lab is to create an active learning environment in which professional computation and analysis tools coupled with simple, easy to use, and affordable data acquisition hardware can be used to easily obtain and interpret data. By pursuing the issue of data acquisition as the goal of our activities, important engineering issues can be addressed while keeping students interested, involved, engaged, and excited about learning. This approach reveals topics that include signal processing, electronics design and implementation, programming, high level systems design, and embedded systems design through critical thinking, creativity, innovation, and discovery. The design of this lab is illustrated in Figure 1 below.

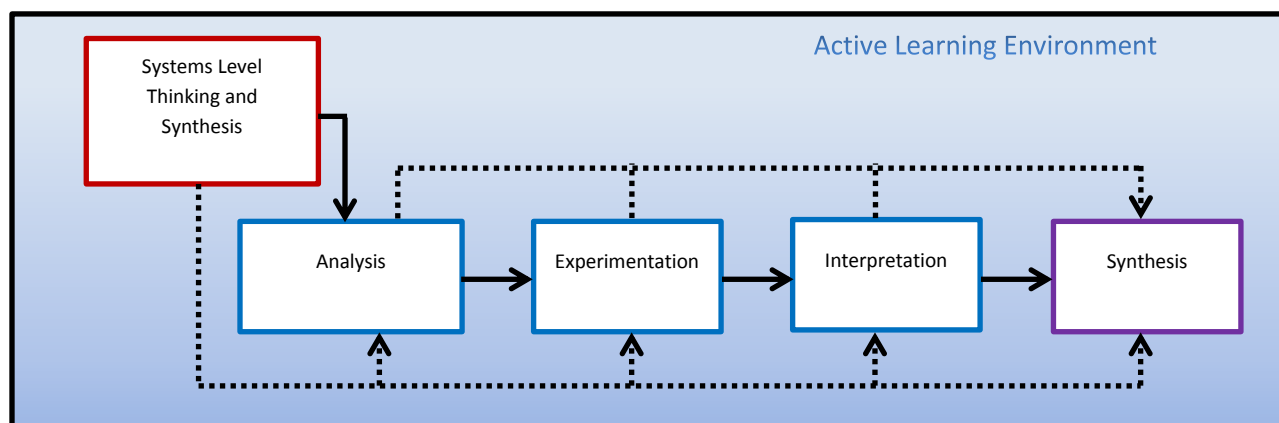


Figure 1: General block diagram of lab design

This diagram shows how each concept is developed (bold arrows) and integrated (dashed arrows) into the lab. Systems level thinking is the main theme and serves as the foundation learning mechanism that supports and feeds the other concepts, as shown. In general, our approach follows with concepts of analysis, experimentation, interpretation, and synthesis, with the assumption that any application can be applied to this system. In this proposal, data acquisition is suggested as an application, as illustrated in Figure 2.

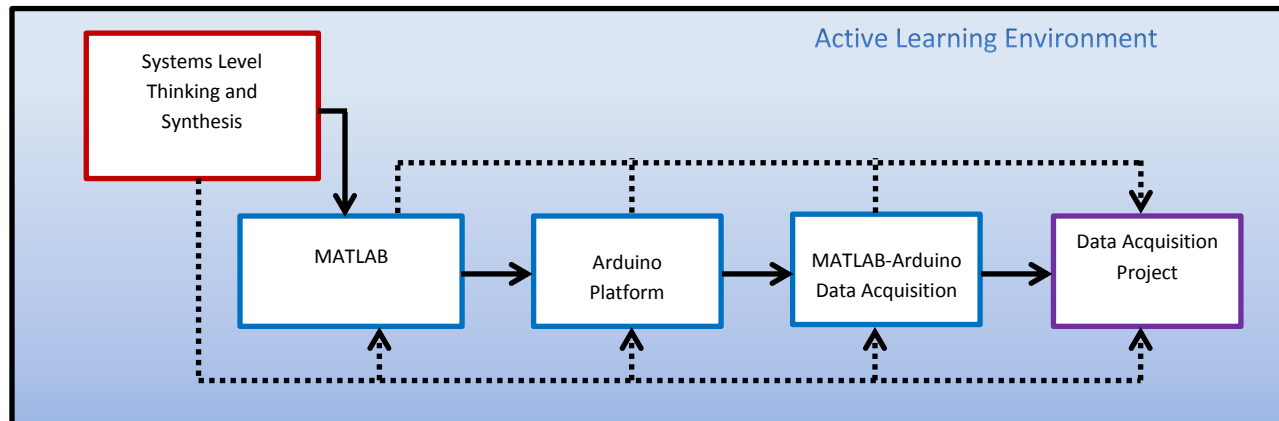


Figure 2: Suggested application - data acquisition platform

Systems level thinking is introduced first as a set of creative discovery and invention labs. We then provide a powerful set of computational tools, in this case MATLAB. Using this in conjunction with topics discussed in lecture, students learn to define and manipulate data to discover interesting information. Following MATLAB we introduce simple, easy to use data acquisition hardware, in this case the Arduino. Students learn pseudo-embedded systems design that is fundamentally important, but not overbearing in detail. We then combine our knowledge of the computational software and data acquisition hardware to present a powerful, easy to use, and affordable data acquisition platform. After students are comfortable with this platform, a team-based project is presented that students work together to combine all concepts from previous labs to complete.

Systems Level Thinking

It can be easy for the details involved with the proposed platforms to become overwhelming for first year students. To set a sound foundation for systematically solving these detail-oriented problems, we began by introducing the concept of systems-level thinking. Thinking on a systems-level, in this context, means to approach a problem and be able to identify a solution involving only the most essential components of the process. In this way, it is easier to see the big picture and break down each component into subcomponents that are simpler to manage. We introduced this concept with activities that explore every-day electronic devices.

Common, low-cost devices that are simple to operate were chosen as the focus of the systems-level thinking activities. Students would make general observations about the device, then disassemble it, discover how it works, and in some cases reverse engineer it. It was stressed that previous knowledge of electrical components was not required which made it easier for students to write a systems level diagram.

Specifically, labs involved the use of a solar powered garden lamp and a disposable camera as the focus of the systems-level thinking activities. For example, when discovering the disposable camera, the majority of students would identify three main components: the battery, the circuit board, and the flash. It was then generally found that the battery supplies power to the circuit board, which, when triggered, ignites the flash. This high level description brings light to the concept of systems-level thinking, helping students understand complicated devices systematically. Many students were able to take it further and describe the circuit board, attempting to reverse-engineer a schematic. In doing these activities during the first couple labs, we can integrate systems-level thinking as the foundation for systematic problem solving and discovery.

Computation and Analysis

When introducing gadgets to any engineering class, the rule that governs the activity is change. All gadgets and all tools will soon be obsolete and replaced with new exciting tools and gadgets. Consequently, it is advantageous to understand a system level approach to automation of data acquisition. The basic knowledge base to do that includes familiarity to programming. Therefore, it is important for engineering students to have experience in programming environments. These environments could be either for high level systems (e.g. controlling or managing subsystems), or for low systems (e.g. designing microcontroller-based devices). In this lab, we have implemented both environments with emphasis on high level systems for computation, analysis, and automation.

Different programming environments were considered and experimented with (e.g. C, Visual Basic, etc.). However, it was found that MATLAB was most effective. The MATLAB environment was attractive because of its forgiving nature with respect to erroneous syntax, variable definition, and memory allocation, and also is provided with great online support that students can easily utilize. Finally, it was very easy to connect to external hardware with the provided serial communication support.

Within the MATLAB environment, topics covered in detail were the following:

1. Scripting, MATLAB basics
2. Arrays
3. Plotting
4. Loops

5. Conditional Statements
6. Serial Communication

The basics of MATLAB were covered briefly, and simple computation operators were explored. Then, students created and manipulated arrays and also explored the plotting capabilities of MATLAB. This was important because it was the heart of managing acquired data. Loops and conditional statements were then introduced with the purpose of learning how to manipulate and make decisions based on large amounts of data very quickly. Here, the concept of automation was brought to light. Lastly, students learned how to communicate with the Arduino using MATLAB's serial port control libraries. It was found that the topics covered were sufficient to do useful data acquisition based projects.

Experimentation

A frequent comment among professionals is that recently graduated employees lack a solid set of practical skills to match their theoretical ones. Generally, it is left to the student to seek practical experience through extracurricular student groups or undergraduate research. Even then, the quality and extent to their experiences may be limited. This has been addressed in other lab-based courses, but the lack of a continuum of practical engineering throughout students' college careers can render the attempts ineffective. It is most important to provide students a set of practical skills during their first year to target their excitement and interest and inspire them to do more on their own. In our approach, we propose a practical platform in which students can learn these skills not only in the classroom under the direction of an instructor, but also in the comfort of their home or with their peers. In this way, it is possible for students to create the continuum of practical engineering for themselves, utilizing the resources, experiences, and lab-based courses from the University to guide them in the process.

The focus of the experimentation portion of this lab was on electronic data acquisition. This was designed for students to learn basic circuit theory, what data acquisition means, and how to utilize embedded systems to accomplish this. In addition, all components used in the labs are affordable and easily accessed by students. If so desired, they could purchase the devices and components themselves (either online or through the department) and perform the same experiments at home. At the end of this lab, students will have acquired the necessary skills to very quickly generate a system that can readily acquire sensor data from a simple circuit through the use of analog to digital conversion.

Specifically, the embedded system chosen for this platform was the Arduino environment. There are many different development platforms available (such as the LaunchPad by Texas Instruments, the MyDAQ by National Instruments, or, more recently, the Raspberry Pi) but the Arduino has been widely accepted as the open-source development board of choice. In addition, it has gained recent acknowledgement among professionals⁶. Simple circuits using linear sensors

were designed, discussed, and used by the Arduino to acquire data. Finally, nonlinear elements (such as LED's, rectifier diodes, and transistors) were also discussed and implemented as well.

Interpretation

Following analysis and experimentation in this platform is the interpretation of data. Here, students combine practical skills from experimentation and theoretical skills from analysis to design a larger, more powerful system. Specifically, this means that students connect the data acquisition hardware, the Arduino, to the computation and analysis software, MATLAB, to start what we call the Arduino-MATLAB experience.

Students have now learned that the Arduino can very quickly and easily be programmed to obtain data, but it has not been discussed how to use this data extensively. In addition, it also has not yet been discussed how to test the validity of the obtained data. Through the use of the serial communication support provided by MATLAB in addition to an Arduino program written by the MATLAB team, the capabilities of the Arduino were able to be controlled by MATLAB with ease. This enabled students to quickly obtain data, store it, plot it, and attempt to interpret the results. The topic discussed most often was the analog to digital conversion and how the experimentally measured values related to the values stored by MATLAB.

Synthesis

In the final weeks of the lab, students are to create, to synthesize, a unique project using the resources and methods learned in past labs. This has shown to be appealing to students because it is team-oriented, the design has an interesting purpose, “real world” challenges are faced, and students have the opportunity to express creative problem-solving skills. Specifically, they were able to utilize the knowledge, experience, and technical skills gained from previous labs to develop a laser communication system that incorporates the use of data acquisition, circuit theory and practice, embedded system design and control, and system-level design and analysis. This is illustrated in Figure 3 below.

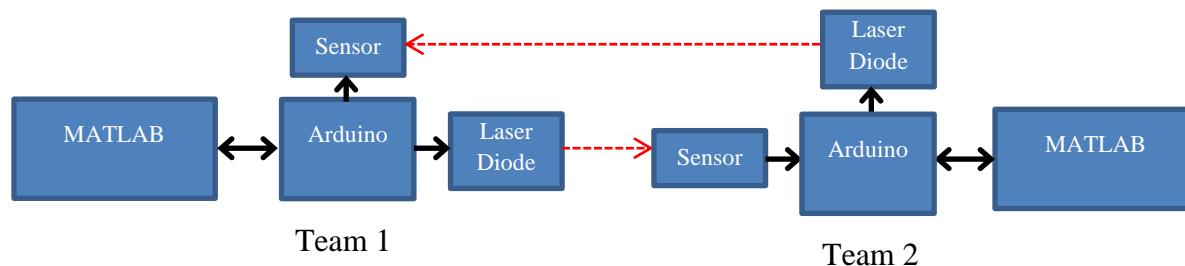


Figure 3: Synthesis project

Student Experience Evaluation

In evaluating the student experience, we based our assessment on opinionated surveys given throughout the semester, judgments of character and personality types in addition to their performance in the lab and 'bubble sheet' questionnaires.

It was found through these questionnaires that approximately 76% of students found the use of Arduinos both fun and interesting. Their comments suggest that the integration of the Arduino platform with MATLAB in addition to the incorporation of circuits proved to be challenging. In addition, opinionated surveys indicate that the reward of accomplishing these tasks was well worth the battle.

From student interviews, it was apparent that the greatest challenges in these labs were in managing all the detail. Many students began having trouble with understanding how to handle errors in code when they have been taught very little about the Arduino environment. Students would be frustrated at points that were unintentional, and their learning would be hindered unnecessarily. This would lead to a loss of motivation. We attempted to manage these issues and try to help students directly, ensuring systematic learning is still taking place. As the frequency of these small learning hurdles escalated, it was clear that we needed more creative and new approaches.

To maintain the balance of reasonable simplicity yet engaging in meaningful and challenging complexity, we introduced supplemental videos. These videos addressed common problems students had during lab that would lead to an unnecessary road block in their learning. Each video would also contain a reminder of the 'bigger picture' so that students could justify for themselves why they are doing the labs, and what direction the labs were taking. Traditionally, labs were designed such that students could realize the bigger picture themselves. We argue that this would create an unforgettable memory and would be more valuable. However, with the increased complexity of the devices used in addition to the greater amount of topics covered, it is very easy for students to stray and lose their sense of purpose during lab.

We gained positive student feedback regarding these videos. It was found that students were ambitious about using the Arduinos so they would purchase them themselves and also download student versions of MATLAB. The videos were very useful because they could work on their own and use the videos as a good review of topics they may have forgotten. We noticed that after a few weeks of these videos, student interest escalated and several additional projects (not defined in the labs) were pursued. As an example, one lab required the use of the Arduino to blink a phrase in Morse code using an LED. Many students found it fun to design a program to handle a user input, define all letters of the alphabet in Morse code, and chat using the their written programs. This was a very satisfying unexpected result.

Conclusion

A new methodology for engaging freshman in engineering was introduced using popular rapid prototyping tools, powerful engineering computation and analysis software, and systematic discovery and exploration through the concept of systems-level thinking. Lastly, an environment was designed and implemented for students to engage and be active with learning while targeting their interest and excitement.

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Testimonials

“I really enjoyed every lab. I don't remember a time that I dreaded going lab it was always a lot of fun and a good learning environment.” – MB Student1

“I thought the labs were very helpful to learn the basics of MATLAB and programming altogether because the same ideas are incorporated in different programming languages. At the end was the most useful because we learned how electrical engineering is related.” – AS student 2

“The Arduino was the best part because it showed how complex things can get and the power behind them. Arduino gave me a good understanding of the areas of expansion and ways to manipulate data that can be brought in with the Arduino.” – AS student 3