AC 2012-4428: ENERGY DEMOS: CLASS PROJECT VERSUS COMMERCIAL EQUIPMENT

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Energy Demos: Class Project versus Commercial Equipment

Abstract

Renewable Energy Education is a hot topic and many institutions are trying to make up ground and address the educational issues which have led to many courses being added to curricula which require new lab equipment. Companies have responded by providing state-of-the-art educational equipment and pre-designed lab manuals. Due to varied economic circumstances, many instructors must develop their own equipment and lab manuals. While it has been well documented that humans learn better through a combination of hearing, seeing, and hands-on experience, there is little research on whether student/instructor designed and built equipment is more or less advantageous than commercial equipment. As a prelude to developing our own renewable energy lab equipment and developing our own lab exercises, this paper looks at qualitative data from students in existing courses and discusses the details of developing the experience-based lab class, describes the labs and their structure, discusses some of the pros and cons of each system with respect to pedagogy, time, and cost, in the course and curriculum.

Background

An important component of addressing the global energy challenges of the future will involve public understanding and acceptance of new and emerging energy technologies as safe and reliable sources for transportation fuels, energy storage, and power generation. Creating a highly educated workforce with experiences in renewable energy and life cycle thinking will contribute to overcoming the energy challenges and increasing the public awareness of the challenges and opportunities are essential components in bringing about the transition[1]. However, developing new curricula and purchasing new lab equipment is time consuming and costly so we need to collect as many variables as possible to determine the proper path forward.

The learning environment is described by Anderson as an "interpersonal relationship …between students and teachers …and the subject matter and method of learning"[2]. Modern scientific and engineering education emphasizes inquiry, discovery, creativity, and generalization. Laboratory design attempts to fulfill those objectives. Hofstein and Lunetta describe 'open-ended' laboratory exercises that enhance creative thinking by students[3]. They argue that research has shown that these inquiry-based laboratories in which "information in a carefully organized way (hierarchical explanation of problem but no detailed instructions) …stimulating students to think independently" … develop high-level skills more successfully than conventional noninquiry-based, or scripted, laboratories.[2] Further studies indicate that student perception of the classroom environment is related to cognitive, affective and behavior measure of learning, and that students involved in inquire-type activities found the classroom environment more satisfying than the noninquiry-based classes.[3]

Engineering Technology (ET) is a hands-on technical profession that requires knowledge of mathematics and physical sciences obtained through education and practical experience. Engineering Technology education is aimed at preparing graduates to develop and implement technology innovation; evidenced by the nearly 60% of classes that include laboratory content. Laboratory exercises are designed to simulate manufacturing process and product design problems and, as such, are particularly important to the student's education.

ET Laboratory Class Structure

The laboratory experience offers the ET student his or her best opportunity to apply coursework to application. Laboratory experiments are designed to provide the student a physical representation of an engineering problem; providing four learning opportunities[4]:

- Cognitive learning – integrating theory and experience
- Inquiry methodology – hypothesis forming, experimental design methods, and analysis
- Vocational aims – familiarizing the student with current practice and technology
- Development of personal skills – teamwork, communications, and technical reporting

In his discussion of lab objectives, Edwards notes that "applications provide a relationship between the material in lectures and how it might be used in industry…Worked examples only go so far because they get no feel for the numbers… and through labs students get a feel for what the numbers mean."[4] Labs that coincide with the lecture schedule usually produce the best cognitive learning results, but the quality of the lab session design is the most significant factor. Thus, the design of the lab becomes critically important to the success of the student outcome. Acknowledging this, the instructor has two choices; design his or her own lab session, or purchase lab designs from commercial outlets.

The following are examples of these lab choices, and the course descriptions they were applied to.

Instructor-developed Lab: Introduction to Control Systems

This course provides the third-year engineering technology student with a study of industrial controls including; on-off, open and closed loop control systems, and analog based systems. Major topics include relay controls, programmable logic controllers (PLC), human-machine interfaces (HMI) and system networking.

The lab materials include PLCs, networked computers, voltmeters, power supplies, pre-wired input and output devices, and HMIs. Lab instructions for twelve circuits were developed to introduce the PLC programming software, analog input and output signals, dynamic data exchange with Microsoft Excel, industrial network communications, HMI design, and several pre-defined control problems such as a paint booth system, soft drink dispenser, and stoplight operation.

Each lab includes a description of the circuit operation and objective, a listing of the file structure that needs to be created for the program, and the lab materials needed to assemble the inputs and outputs. The lab tasks the student with writing a program to solve the control circuit objective, connecting the input and output components, testing the program, performing necessary measurements, and to demonstrate the control circuit to the instructor. Labs include programs and HMI terminals to operate systems such as a multi-sprayer paint booth and conveyor system, soft drink mixing and dispensing, stoplight control, batch furnace control, PID tuning, and dynamic data interchange with MS Excel.

Instructor-developed Lab: Electrical Power & Controls

This course provides an introduction to transformers, induction motors, and single-phase and three-phase power systems, motor control devices, programmable logic controllers, PLC input and output devices, and PLC communications to third year students.

The power portion of the labs utilize small components (such as motors, relays, transformers, etc.) that students assemble based on instructor provided schematics. The eight power labs explicitly detail the design and testing procedures as well as the reflection that should occur. These labs are all hands-on and require physical interaction with the components.

The course provides both instructor developed labs and commercially available labs. The instructor developed labs use physical, hands-on equipment and the commercial labs use simulator software that provides realistic images of physical equipment and their operation. The control labs are considerably different, in addition to providing both simulation and physical (hands-on) wiring and connecting opportunities, they are much less structured and provide open-ended guidelines rather than step-by-step procedures because the safety concerns associated with the power labs are much lower for controls. Due to equipment availability there is only one physical lab devoted to the PLC content, as opposed to four simulations discussed later. The hands-on lab requires students to physically connect a PLC to several output lights on a four-way traffic light, see Figure 1. The students are give a pin-out table and timing specifications and must wire, communicate with the PLC, and write a program to meet the specifications.

North/South Traffic Lights	Local:2:O.Data.4	Red
	Local:2:O.Data.5	Amber
	Local:2:O.Data.6	Green
	Local:2:O.Data.1	Amber Left Turn
	Local:2:O.Data.2	Green Left Turn
East/West Traffic Lights	Local:2:O.Data.12	Red
	Local:2:O.Data.13	Amber
	Local:2:O.Data.14	Green
	Local:2:O.Data.9	Amber Left Turn
	Local:2:O.Data.10	Green Left Turn

Figure 1: Physical PLC Lab

Commercially-available Lab: Fluid Power

This course provides the second-year engineering technology student with an introduction to fluid power systems. It is a study of incompressible and compressible fluid statics and dynamics as applied to industrial hydraulic and pneumatic circuits and controls. Major topics include fluids, pumps, control valves, motors, cylinders and piping systems.

The lab materials include a commercially-available hydraulic trainer in which standard industrial hydraulic components are mounted on a panel, and can be interconnected to demonstrate a wide variety of basic hydraulic functions and circuits. Lab instructions for ten circuits are included with the trainer and demonstrate controls for reciprocating cylinders, hydraulic motor speed control, regenerative cylinder control, sequencing operations, traverse and feed circuits, and cylinder flow control circuits. Pressure gages are included to analyze circuit operation.

Most of the labs include a schematic of the circuit, a description of its operation, and listing of the components needed to complete the design. The lab tasks the student with connecting the components according to the schematic, testing the circuit, performing pressure measurements, demonstrating the circuit to the instructor, and answering three to five questions about the circuit operation. The final lab was developed by the instructor. This lab stated a hydraulic system requirement and specifications, and asked the student to design and construct a solution using only the components available on the trainer. No instructions were given, and no schematics were supplied.

Commercially-available Lab: Electrical Power & Controls

The course, as described above, provides both instructor developed labs and commercially available labs. The instructor developed labs use physical, hands-on equipment and the commercial labs use simulator software that provides realistic images of physical equipment and their operation. The control labs are considerably different, in addition to providing both simulation and physical (hands-on) wiring and connecting opportunities, they are much less structured and provide open-ended guidelines rather than step-by-step procedures. Four simulated labs where developed around LogixPro™ Simulation software. The first of four simulated labs provides and introduction to input and output devices and the programming environment, see Figure 2. A detailed lab is provided to help students adapt to the new programming language and the simulation's graphical user interface (GUI).

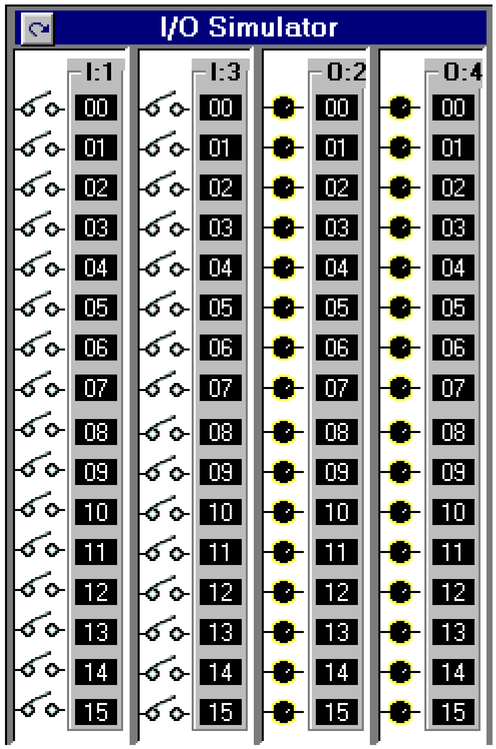

Figure 2: 1st Lab, I/O Simulation GUI

The second, third, and fourth labs are more open ended with three different levels of criteria that reflect A, B, and C level work. The second lab simulates a garage door application, see Figure 3, the third simulates a silo/filling operation, see Figure 4, and the fourth lab simulates a batch mixing application, see Figure 5. The simulation program has many realistic features and simulates likely safety and programming errors, for instance if the silo filling valve is left open it will flood the conveyor and set off alarms. The graphics are antiquated by today's gaming standards but quite adequate for the important aspects of the learning environment.

Figure 3: 2nd Lab, Garage Door Simulation GUI

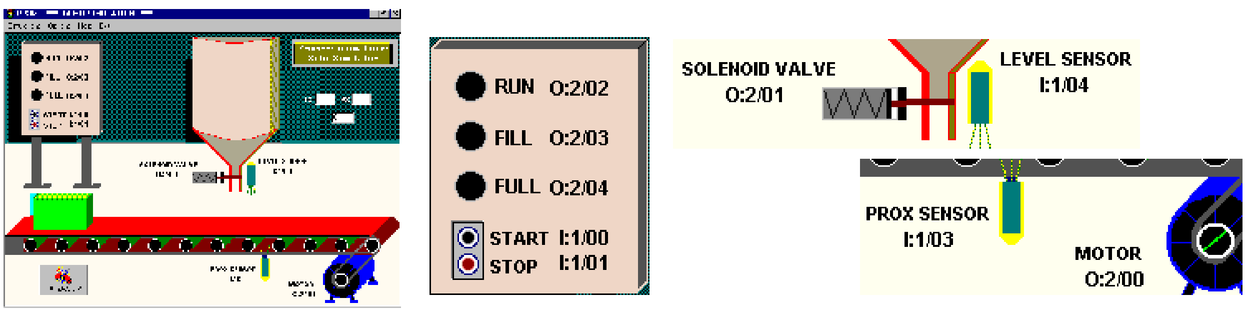

Figure 4: 3rd Lab, Filling Simulation GUI

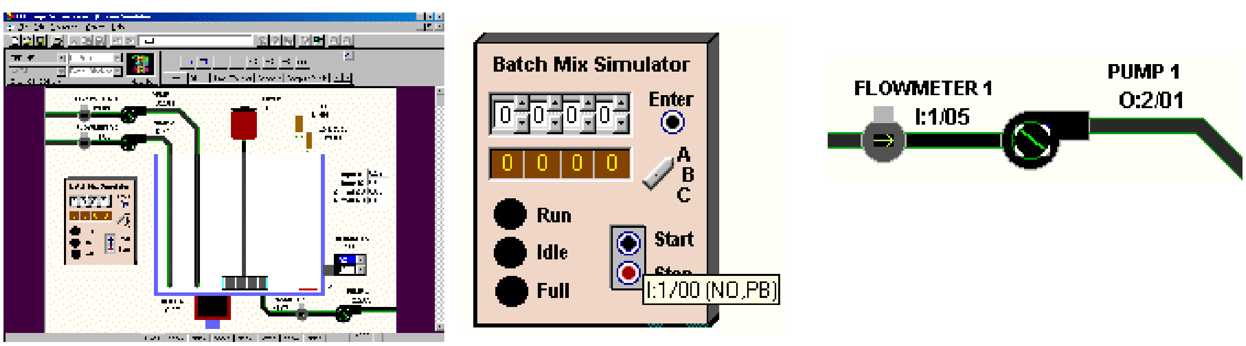

Figure 5: 4th Lab, Batch Mixing Simulation GUI

<u>Results: Introduction to Control Systems and Fluid Power</u>

Surveys were conducted with 33 students enrolled in the Control Systems course, and 42 students in Fluid Power over a two-year period. Ten questions were designed to score the level of successful student experience with lab content; 1 indicating a poor experience and 5 an excellent experience. Additionally, questions were asked to draw out student thought regarding the laboratory materials, time allowed to perform the lab, the learning experience, and instructor performance.

Student scoring of the labs for Control Systems and Fluid Power did not indicate any significant difference between instructor-developed or commercially available laboratories. In both cases, scores were positively skewed, and followed nearly identical median and mode responses to each of the questions. Together, they indicate no difference between the two types of labs.

Table 1: Student Evaluations

	INTRO TO CONTROL SYSTEMS			FLUID POWER		
	Mean	Median	Mode	Mean	Median	Mode
Laboratory work reinforced material in class/course objectives.	3.46	4	4	3.52	3.6	4
Appropriate tools were available to do the laboratory exercises.	3.38	4	4	3.3	3.5	4
Laboratory equipment functioned adequately.	3.02	3.3	3	3.17	3.3	4
The laboratory instructor provided clear instructions on how to participate in laboratory activities.	3.41	3.3	3	3.36	3.3	3
The laboratory instructor provided sufficient help to assist students during the laboratory periods.	3.48	4	4	3.53	3.5	4
The laboratory instructor provided clear safety guidelines.	3.65	4	4	3.66	3.9	4
The laboratory instructor provided timely feedback.	3.67	4	4	3.54	3.6	4
The amount of laboratory work required was appropriate.	3.47	4	4	3.57	3.8	4
Overall, I learned a great deal from the laboratory work.	3.57	4	4	3.32	3.5	4
Overall, this laboratory instructor was effective at teaching this course.	3.67	4	4	3.49	3.5	4

However, student comments revealed something quite unexpected. In both cases students voiced a strong affinity toward lab exercises that were unstructured. These unstructured lab assignments that simply stated a system requirement were preferred to those that included the sequence of steps necessary to complete the lab. Some examples from the unstructured Control Systems labs included:

- "Probably one of the better labs I've had with the amount of equipment and programs used, and all worked very well all year"
- "It's always nice to be able to feel a sense of accomplishment about fully completing a lab rather than having to rush out something not completely working."

The Fluid lab comments showed significant contrast between the 'canned' structured labs and the unstructured final lab:

- "The labs in this class were excellent and fun. They helped us to really learn the material and the last lab where we were given a set of objectives and told to find a way to make it work allowed us to sit and actually think about everything we learned and show that we know the material."
- "I did not learn a lot from the labs until the last we performed…"
- "The labs were great, very informative; it would be nice to do more labs like the final lab."

- "The unstructured lab was a lot of fun, because we got to come up with the design on our own."

Results: Electrical Power & Controls

In prior years, only the simulation software was used. This year a survey was given to determine the student's opinion about the physical lab with respect to the simulations. The questions on the survey were: "Which teaching method did you like better, the simulated labs or the physical lab? Why?" The results are shown in Table 2.

Table 2: Electrical Power & Control Opinion Survey Results

Simulated	Neutral	Physical	Explanation: transcription of student comments, clarifications in ()
		1	The stop light (physical) lab using actual hardware was sufficient enough in my opinion. It was a good emphasis on selecting the correct PLC on a network and it gave a better feeling for physical wiring and operation.
	1		I think both the simulation and physical hardware are important. The simulations allow the class to solve problems that would be impossible to use real hardware for in the lab and the actual PLC's are necessary for an overview of how hardware is actually implemented.
	1		I think both experiences were important. The simulation is easier to do because of the equipment required to do the lab, but the real thing is also important because that is what we would actually do in real life.
1			Prefer simulations with instructions on what to do.
	1		I liked both the simulated and the real logic labs. Maybe you could make a 50-50 split between the two.
1			I think the Logic Pro (simulated) was somewhat more beneficial. However, it was one more program to learn in a short period of time. Never really had a chance to get good with either program.
		1	I prefer the real world application (physical).
		1	The Logic Pro software (simulated) worked well for simulating the programming, however it was very glitchy. It was really nice to work with the real PLC's. I know this might be hard to accomplish with a class.

Conclusions

There was a positive and dramatic resonance with students and the unstructured lab format. Students felt that this lab format was interesting, challenging, and at the same time, fun. The students like having multiple options available. After completing these labs they were very confident that they could perform this type of engineering work in an industrial environment. Lecture concepts were crystallized into working knowledge, and confidence rose. This student response was unexpected, but has been well documented in educational research.

Comparing cost for class projects versus commercial, except for the Physical PLC versus LogixPro™ Simulator, showed that the commercial equipment (includes parts, labor, shipping, pre-made labs) was approximately ten times more expensive than parts for the class project units (labor was free, no shipping, labs developed in class). The commercial equipment was usually available within six weeks, while the class project units required 1-2 semesters to design and build.

Overall, students seem better served by instructor developed, open, design-build, labs. However, we have concerns with how previous designs (stored in lab and used for some experiments) would impact the quality of education by potentially diminishing design creativity with subsequent course offerings.

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