Laboratory Development in Power Generation, Conversion and Dissipation

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Abstract
The School of Engineering and Technology at Lake Superior State University is developing an Energy Conversion Laboratory for undergraduate instruction in electrical and mechanical engineering. The laboratory will enhance students' interest in, and understanding of, fundamental energy conversion principles through the use of scaled down systems of industrial processes. The laboratory is being created with grants from industry and the National Science Foundation. The development has included extensive student participation. The paper discusses the project background and educational need for this laboratory. The paper also discusses the laboratory development process along with information on unique instructional equipment that has been designed in the areas of machine control and energy conversion.

Introduction

There is a national need for engineering graduates who are prepared to enter the energy-related industries. This is especially important with increased dependency upon sophisticated computer-based systems, deregulation and the resulting "rolling blackouts" in recent years, and the possibility of major blackouts. National Science Foundation (NSF) and others have long been concerned about the nation's aging technical workforce. The recent NSF report, Science and Engineering Indicators 2000,[1] confirms that "the average age of science and engineering degreed workers will rise," and that the "total number of retirements among college-educated workers in science and engineering will increase dramatically over the next 10 to 15 years." The changing workforce demographics coupled with changes in the energy conversion industry present a challenge for engineering educators to prepare graduates for today's energy-related industries.

There is an on-going concern about decreasing enrollment in electrical power areas, and that the traditional electrical machinery course is outdated.[2] As Leonard Bohmann writes "The traditional Electrical Engineering Energy Conversion course is broken. We need to fix it… The course should be tailored to students who will use the technology as opposed to those who will design it."[3,4] In addition, there is a need for engineering graduates to have strong skills in the thermal-fluids areas and a need to provide both electrical engineering and mechanical engineering students with modern control experiences. Therefore, engineering faculty members face the challenge of providing laboratory learning experiences in these areas that reinforce basic principles while being interesting and motivational.

Background

Lake Superior State University (LSSU) has a unique location in Michigan's Upper Peninsula on the U.S. - Canada border. The University is approximately half a mile from the Saint Mary's River, which separates Sault Ste. Marie, Michigan from its sister city, Sault Ste. Marie Ontario. Students can look out of the laboratory window and see the river, Soo Locks, and one of the three hydroelectric generation plants, which is operated by the U.S. Army Corps of Engineers. Figure 1 is an aerial view of the Soo Locks, center, flanked by Michigan to the left and Ontario to the right. The U.S. Corps of Engineers power plant is partially visible in the lower right. The International Bridge and railroad bridge are also visible in the background.

Figure 1: St. Mary's River

The two other hydroelectric plants are located within two miles of campus. The first, on the Michigan side of the St. Mary's River, is operated by Edison Sault Electric Company. The other is a hydro generation plant across the river in Ontario.

The Edison hydro plant is shown below in Figure 2 spanning the outflow of the power canal into the St. Mary's River. Two of the Edison engineers are graduates of the School of Engineering and Technology and serve on the School's Industrial Advisory Board. A portion of the generation plant also houses an aquatic research laboratory that supports faculty and undergraduate research in the wildlife and fisheries area at the university.

Figure 2: Edison Sault Generation Plant

The School of Engineering and Technology currently has about 300 students, and offers degrees in computer, electrical and mechanical engineering as well as manufacturing engineering technology and engineering management. The engineering programs emphasize understanding of engineering principles and have a niche in robotics and automation. Many graduates find employment in manufacturing related industries. There is a significant overall team spirit among the various engineering programs. The small size of the engineering programs promotes optimizing resources. As a result the school has developed integrated, cross-disciplinary laboratories for instruction[3]. This paper describes the development of an integrated laboratory that will provide student motivation and comprehension in energy related principles. The facility will support electrical and mechanical engineering courses in the area of energy conversion, particularly in thermo-fluid sciences and electromechanical systems.

The remaining paragraphs of the paper discuss the following areas: the ***Educational Goal***; the ***Engineering Courses*** related to the goal; the ***Laboratory Development*** including a description of the process and student involvement; and finally ***Equipment Development***. The last section discusses upgrades to older laboratory stations, and the development of new laboratory stations.

Educational Goal

The overall goal is to enhance students' interest in and understanding of energy conversion systems, particularly in the areas of electro-mechanical systems, thermal-fluid sciences, and modern industrial control processes. The specific objectives that will support that goal are to improve students' understanding of:

- electro-mechanical energy conversion and the use of alternative energy sources;
- mechanical energy conversion in thermal sciences and fluid mechanics;
- data acquisition and data acquisition software; and
- the operation and application of modern energy control technology.

These objectives require the development of new learning experiences in several engineering courses.

Engineering Courses

Addressing the desired goals required changes to the content and laboratory focus of several engineering courses. These changes require the development of new laboratory learning experiences, which will be provided in the new Energy Conversion Laboratory. The course areas that will be enhanced the most by the new laboratory include electrical machines, programmable logic controllers (PLCs), fluid mechanics, thermodynamics and heat transfer. A total of eight courses in the electrical and mechanical engineering programs will make use of the completed laboratory facilities.

The three electrical engineering courses are EE210 Circuit Analysis, EE305 Analog and Digital electronics, and EE330 Electro-Mechanical Systems. All three have a laboratory component, and each will use the upgraded Hampden electrical trainers that will be discussed later in the equipment development section.

- <u>*EE210 Circuit Analysis*</u> is the first electrical circuits course and is required for all engineering majors. The course covers basic dc and ac circuit analysis, and will use the laboratory for three phase circuits.
- <u>*EE305 Analog and Digital Electronics*</u> is a required course for non-electrical engineers. The course covers an overview of analog and digital electronics, but has been refocused to include the basics of electrical machinery and data acquisition.
- <u>*EE330 Electro-Mechanical Systems*</u> is a traditional electrical machines course. It is being modified to integrate more machine controls, motor drives and applications of energy conversion as well as data acquisition and programmable logic controllers.

Five courses in the mechanical engineering curriculum will use the new laboratory. They are ME337 Thermodynamics, ME338 Fluid Mechanics, ME431 Heat Transfer, ME432 Thermal Fluids Laboratory, and RS365 Programmable Logic Controllers.

- <u>*ME337 Thermodynamics, ME338 Fluid Mechanics, ME431 Heat Transfer and ME432 Thermal Fluids Laboratory*</u> are required courses for mechanical engineers and optional for electrical engineers. These courses cover the fundamental aspects of thermodynamics, fluid mechanics, and heat transfer as applied to engineering practice. In these courses an emphasis is placed on the development of solutions to thermal-fluid engineering problems using case studies. The laboratory will integrate data acquisition and energy conversion in fluids and heat transfer.

- <u>*RS365 Programmable Logic Controllers*</u> is a required course for some mechanical engineers, and frequently taken as an elective by various engineering students. The RS365 course emphasizes the development of PLC solutions for machine control problems. The course will use new PLC laboratory equipment that has been developed by the faculty and staff laboratory engineers. The same type of PLC and operator interface that is used in RS365 will be integrated into the new thermal-fluids trainers.

Laboratory Development: Process

The laboratory has been developed over a multi-year period using university funding along with grants from Consumers Energy Foundation and the National Science Foundation. The development was initiated with concept planning for the new laboratory. This planning then led to facility changes in the laboratory, upgrading existing equipment and new equipment development as shown in Figure 3.

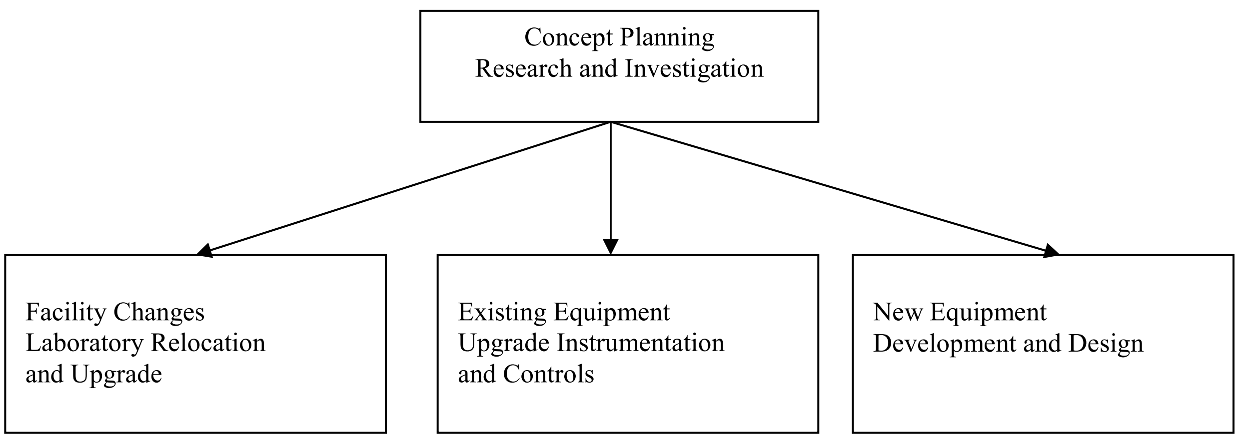

Figure 3: Laboratory Development Plan

The concept planning involved investigation and evaluation of the existing facilities, the desired focus of the laboratory and types of learning experiences, and the necessary equipment to support those learning experiences. Some possible options such as fuel cells and wind power were investigated, but at this point, these have not been incorporated into the laboratory.

Development required relocating an existing computer laboratory, and then preparing the vacant area to serve as the home for the new energy conversion laboratory. This phase included determining the function and form of the new computer laboratory, and laying out the facility upgrades along with logistics of the move. This phase also included developing a proposed layout for the new energy conversion laboratory.

The concept-planning phase identified existing laboratory equipment that could support the vision and learning experiences of the new laboratory. The engineering department had some existing equipment in the electrical machinery and PLC areas, but it needed upgrading with modern instrumentation and controls. The details of the upgrades are discussed later in the equipment development section.

Finally, the initial planning also identified new learning experiences that the new laboratory would need to support. These experiences required the acquisition and development of new laboratory equipment. New equipment was particularly needed in the thermal-fluids area. However, there was also a desire to have the new equipment serve both electrical and mechanical areas and support cross-discipline energy conversion activities. As a result of the planning process new instructional trainers are being developed that are scaled-down versions of real industrial processes.

Laboratory Development: Student Participation
Undergraduate students have participated in the development of several engineering laboratories and laboratory equipment through undergraduate research and senior design projects. The School of Engineering and Technology has a well-organized Senior Design Project program in place.[5,6] Students can complete their senior design experience by choosing from among three possible paths: 1) traditional industrial-based, design-and-build projects; 2) co-op employment projects; or 3) research-based projects. The Senior Projects Faculty Board manages the entire senior design experience including the courses, projects and student teams. The School is expanding the research options available to students by committing university funding to perform internal projects and securing external funding. A prior NSF – ILI program (NSF-DUE-9751372) that developed a $130,000 multi-purpose Integrated Systems Engineering Laboratory[7,8] was largely implemented by Senior Project teams over two years. The students, under the direction of the grant's principle investigator, were involved in the lab layout, selection of equipment, and assisting in preliminary curriculum development.

Students have been extensively involved in the development of the new energy conversion laboratory. Two student design teams and an undergraduate research team provided the major student contribution. Additional student involvement has included those who have been awarded NSF CSEM scholarships and desired to participate with a faculty mentor on the laboratory development.

As stated previously, the engineering programs at LSSU offer students the opportunity to do independent study and undergraduate research for credit. A small team of junior students did investigative work into the possible use of wind power and fuel cells for the thermal-fluids laboratory. This included giving a presentation to the math and engineering faculty that summarized their findings. At this time this technology has not been included in the laboratory.

Student Design Team DOTE
Design Options Technology and Equipment (DOTE) senior design team consisted of four members: one electrical engineering student, two mechanical engineering students, and one environmental engineering technology student. The new laboratory occupies a room that was previously a computer laboratory that was moved to another location. Team DOTE's involvement started with determining the design of the new computer laboratory. They surveyed faculty and students to obtain usage and layout information to guide their design for the relocated computer laboratory. The team developed the floor plan for the new computer facility, planned

the details of moving the computer laboratory, and also worked through necessities to upgrade electrical and data lines.

Team DOTE also did preliminary work on the new energy conversion laboratory. They investigated various types of energy conversion processes that could be utilized in this laboratory setting. Finally, they initiated work on upgrading some of the existing laboratory equipment that is used to teach electrical machines.

Student Design Team ECS

Engineering Conversion Systems (ECS) is the second senior design team to work on the laboratory development. This team has one electrical engineering and five mechanical engineering students. ECS has completed the upgrade of the electrical machines that team DOTE started. Team ECS and the engineering department faculty have been establishing a new direction for the laboratory away from solar cell and wind power technology and toward water powered systems.

The primary task of team ECS has been to develop, design and construct a laboratory instructional trainer. This trainer will be used primarily in thermal-fluids instruction to support laboratory experiences such as turbine/pump efficiencies and conduction/convection heat transfer studies. This trainer will also support the electrical and PLC courses, particularly in the areas of computer-based instrumentation and process control. This trainer will model the water-driven generator plants that students can see in the distance when they look out the laboratory window. In addition, the heat dissipation process of the trainer will model the dynamic braking process in railroad locomotives; another aspect of the Sault area that can be seen from the lab. This unit is described in detail in the equipment development section of the paper.

Equipment Development

This section will outline an upgrade to older laboratory equipment in the electrical machinery area, and the development of new laboratory equipment for programmable logic controllers, thermodynamics, heat transfer, and fluid dynamics.

Older Laboratory Equipment: Electrical Machinery Trainer

Several electrical engineering courses will use the new laboratory. The engineering department

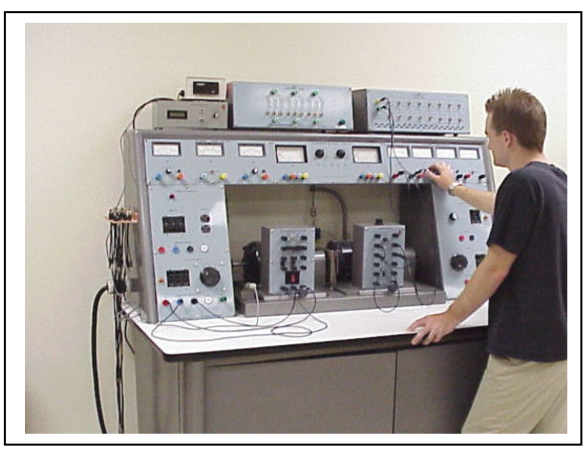

Figure 4: Electric Machines Trainer

currently uses several Hampden electrical trainers and machines like the one that is shown in Figure 4. However, the instrumentation on the electrical bench is analog and cannot be easily interfaced to a computer.

The trainer's instrumentation has been upgraded from analog to digital for use in the new laboratory. The old trainer had three panels across the top (left to right) that included the following devices: ac voltage and current meters, wattmeters, and dc voltage and current meters. The existing panels were replaced by making new front panels and wiring in new digital meters. Some of the trainers will also have the data acquisition capability to enhance the dynamic testing of electrical machines. Allen Bradley SLC500 PLCs interfaces will be developed for machine control to supplement PLC instruction in EE330 Electro-Mechanical Systems.

New Laboratory Equipment: Part Checker System

The RS365 Programmable Logic Controllers course provides students with opportunities to develop PLC solutions for machine control applications. The course uses Allen Bradley Micro Logix PLCs on small trainers. The course also has scaled down versions of machine control applications. One such applications trainer is the Parts Checker shown below in Figure 5 that utilizes the Allen Bradley SLC500 PLCs and PanelView operator interfaces. Encoders and

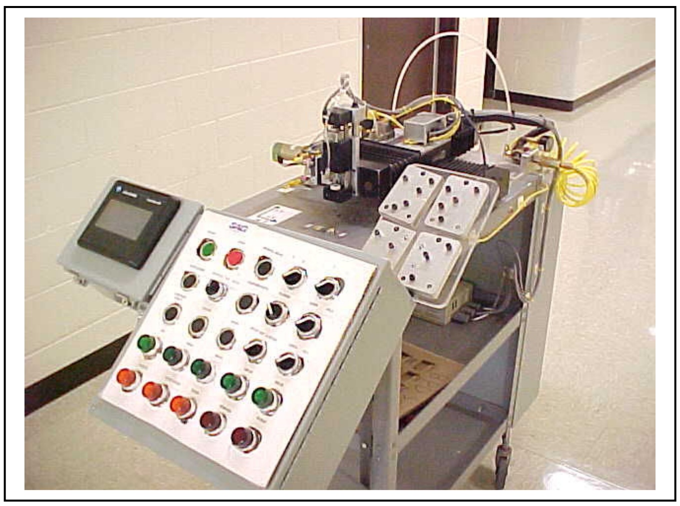

Figure 5**:** PLC Parts Checker

linear variable displacement transducers have also been incorporated to provide the students with experience in high-speed digital and analog input signals. Students write code for automatic checking of the location and height of a feature on a part. The students also program and design the layout for the operator interface. Finally they conduct a design review that explains how the operator interface meets the system specifications.

New Laboratory Equipment: Energy Conversion Trainer

A significant portion of the work-in-progress on the new laboratory is the development of a new energy conversion trainer. The senior design team ECS is developing this trainer with the authors of this paper representing the faculty advisor and industrial customer for the team.[9] The trainer will have significant flexibility that will allow it to be used in all of the engineering courses discussed earlier. The trainer will replicate mechanical, electrical and heat energy conversion as shown below in Figure 6.

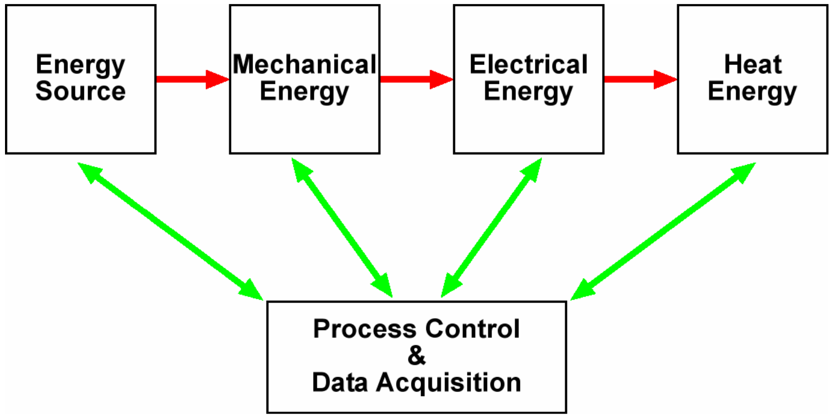

Figure 6: Energy Conversion Process

The trainer unit that is being developed by team ECS is modeled after typical industrial systems. The power generation subsystem follows a scaled model of a hydroelectric plant. The heat dissipation subsystem or electrical load is modeled after the regenerative braking system found in diesel-electric locomotives. The PLC controls the power generation system and load interface as is typical in hydroelectric plants. A block diagram of the unit is shown below in Figure 7.

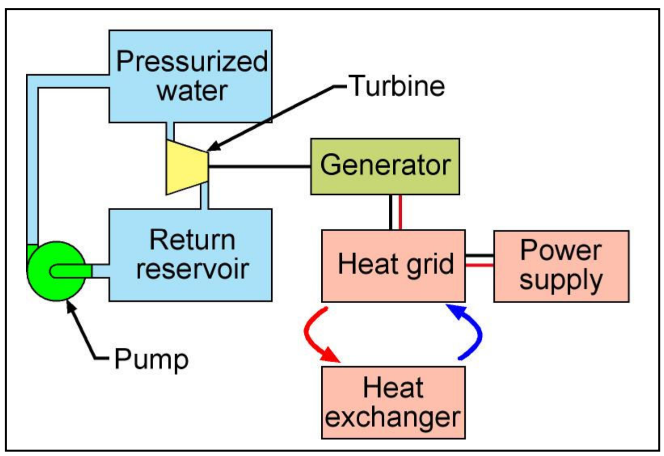

Figure 7: Layout of Energy Conversion Trainer (courtesy of team ECS)

A concept drawing of the laboratory trainer system is shown in Figure 8. A description of the equipment incorporated in the lab station is contained in the following paragraphs.

Overview of System

A pressurized water tank supplies water to drive the turbine, which in turn drives an electric generator. The electric energy is dissipated in electric resistive heaters. The heaters can also be powered by a separate power supply that does not require using the turbine and generator. The heaters are mounted in a copper block with cooling fins that utilize natural and forced convection heat transfer. Appropriate instrumentation in the form of digital meters and data acquisition will be available on the trainer. The PLC (not shown in the drawing) will provide overall system control and allow the instructor and students to select the type of experiment that is to be conducted.

The intent is to allow various instructors to run tests with the turbine, generator, return pump or heaters. Thus the design of the trainer will allow the instructor and students to operate the complete integrated system, or to separately operate the power generation subsystem, the individual mechanical components, or the heating subsystems. The system will be completed and functional at the end of the spring 2004 semester.

ENERGY CONVERSION SYSTEMS
LABORATORY TRAINER

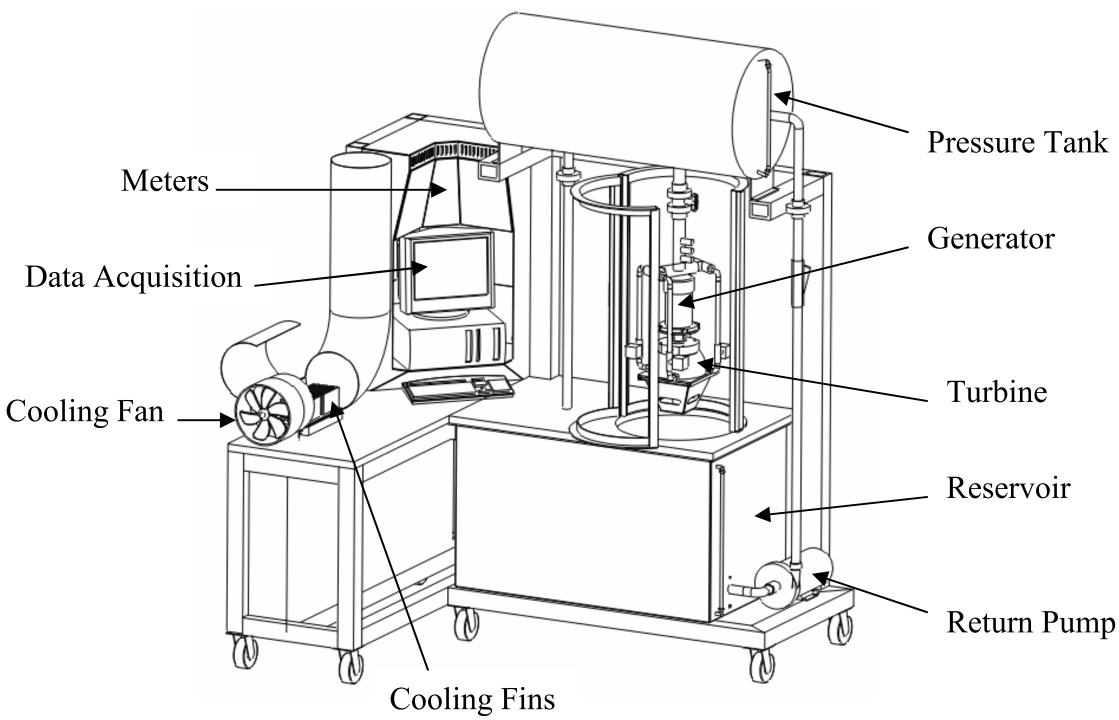

Figure 8: Trainer Concept Drawing (courtesy of team ECS)

Specific System Components
A Harris Pelton wheel turbine will be used in the laboratory trainer. This particular turbine is popular for household use where an individual can develop electrical power for remote applications provided a water source is available. The turbine is capable of operating with multiple nozzles and as well as various size nozzles. The operator will have the ability to select the tank pressure, number of nozzles, and nozzle size through the PLC operator interface. Currently, very little information is available on the engineering characteristics and specifications for low-flow rates. The designer has expressed an interest in student research results to aid future development of the turbine.

A load cell is incorporated between the turbine and generator for torque measurement. This coupled with rpm, current, and voltage data will enable the students to perform power and efficiency analyses. These variables will be recorded both on meters and through data acquisition software.

The heating subsystem utilizes four resistive heaters connected in parallel. The operator will have the ability to select the number of heaters used in an experiment through the PLC interface. The PLC will monitor the heater temperature through four thermocouples and will also have overall control if the temperature exceeds a preset limit. The cooling fins will have sixteen thermocouples arranged in a rectangular grid to record temperatures at the base and tip of the fin. The thermocouples will also allow measurement of the upstream and downstream fin temperatures. Fin temperatures are recorded in the data acquisition system but are not used for control.

Summary

Undergraduate engineering education needs to provide students with solid instruction in related engineering principles, but that instruction also needs to be motivational and tied to real industrial processes. Developing relevant, motivational laboratory equipment is a design process that can include undergraduate students. Students, who are also stakeholders in the new laboratory design, can participate in the laboratory design process, and their voice can enrich the new laboratory equipment and the learning experiences.

The paper has presented a work-in-progress of a new integrated engineering laboratory that will support instruction in both electrical and mechanical engineering. The laboratory will develop new instructional laboratory equipment that can be used by instructors in various engineering courses in the electro-mechanical systems and thermo-fluids areas. This laboratory development has been supported with funds from industry and the National Science Foundation, and the development process has the design and development efforts of several faculty and students in multiple disciplines.

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Student Team DOTE: Joe Miskiw, Brian Wyllys, Brandon Woodworth
Student Team ECS: Matthew Fitchett, Lester Jensen, Vesa Luomaranta,
Andy Rynearson, Gary Vansickle, Grant Wood

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