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A "COMMON PRACTICE" APPROACH TO ATTRACT AND RETAIN ENGINEERING STUDENTS

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ABSTRACT

Hands-on, design oriented experiences have been shown to attract students to enter engineering programs by increasing their awareness of engineering as a profession. To expose pre-college students to a broad spectrum of "common" engineering practices, the University of Texas at Tyler, aided by funding from the National Science Foundation, developed hardware and activities using the process control industry as a theme. The topic area covers many engineering disciplines and systems, including HVAC related processes. This paper describes a proof of concept system developed to attract and retain engineering students. Both the apparatus and exercises used for K-12 outreach activities are presented; primarily focusing on the HVAC applications. Examples from open house activities, summer camps and a site visit, along with student and parent survey data, are presented. An overview of how the system has been extended to enhance the undergraduate engineering curriculum is also included.

INTRODUCTION

Attracting and inspiring students to enter the engineering profession continues to receive a high level of attention. Pre-college preparation and a realistic understanding of what constitutes the engineering profession are key factors in attracting and retaining students in engineering programs. The minimum level of mathematics and science coursework does not adequately prepare students to directly enter an engineering program without remediation and, as a whole, secondary school students are not sufficiently motivated or prepared in science and mathematics to meet the challenges of the 21st century [1]. Programs such as FIRST [2] and Botball [3] have grown as a response to the challenge. Space exploration programs have also been successful at stimulating interest in engineering careers. While each of these programs have been successful at stimulating interest, robotics and space exploration are highly specialized and selective employment industries. They do not focus on a broader range of common engineering practice.

In order to increase the completion rate of graduate engineers, a strategy was developed to make common practices appealing to prospective engineering students. In an effort to inspire more students to adequately prepare themselves for university-level engineering programs, the University of Texas at Tyler, in partnership with the National Science Foundation, has developed an integrated approach to attract and retain engineering students using the multidisciplinary field of process controls as the topical focus. The approach combines a specially developed system of hardware components with an array of activities to achieve an increase in the quantity and quality of prospective engineering students. The Process Control Breadboard (PCB) is a proof-of-concept system that serves as a demonstration tool and a hands-on design, build, and test platform. Although the PCB system is fully capable of providing university-level design capability [4,5], this paper will focus on using the system to synthesize HVAC related systems in K-12 outreach activities. Middle-school-aged students have been specifically targeted in an effort to positively impact pre-college math and science preparation.

THE BREADBOARD SYSTEM

The design, build, and test of industry-relevant thermal-fluid systems in an academic environment are frequently hindered by the costs involved in system realization. While many trainer-based systems exist, selection and configuration design of these systems are completed by the manufacturers, effectively negating any academic value as design education tools. Removing the need for single use components and skilled trades fabrication, while maintaining an educational design experience, presented a challenge. The Process Control Breadboard evolved to meet this challenge [5-10]. Component groups include the backplane, valves, heat generators or exchangers, sensors, vessels, pumps, and connectors. The components were selected and configured so that systems could be assembled and disassembled quickly, with few tools and low force, using quick-connect devices. This allowed younger students to create their own systems with little instruction or physical assistance.

The backplane is the fundamental element and is the support structure and connection system for the breadboard. Each backplane contains 22 equipotential circuits, piping manifolds with five access points in each circuit, located on a uniformly spaced grid. The circuits are configured in column format, with two separate rows of circuits. Back–to–back pairs of backplanes were attached onto rolling frames for portability. This allows a set of backplanes to have mobility for offsite system demonstrations and for easy storage in a multiuse laboratory setting.

Various manually and pneumatically actuated valves were configured for direct attachment to the backplane for fluid flow control. The valves selected represent smaller versions of components typically found in full-scale process systems. Each size and type of valve has unique characteristics, so selection and configuration of valve elements influence system performance. This provides a context for design activity.

Heat exchange elements include water heaters, steam generators, and tube-based heat exchangers. These elements provide sources of controllable process media. Shell-and-tube heat exchangers rigidly connect directly to the backplane, while other elements connect using flexible hose assemblies.

Sensor components interface with the breadboard system to complete the control loop. Sensor groups are available to measure flow rate, temperature, and pressure. Most of the sensors provide both electronic and human-readable displays, making them suitable for either manual or fully automatic control systems. For any specific property of interest, there are various sensor elements available that differ in range, technology, and interface capabilities. Figure 1 is a composite photograph illustrating a variety of components attached to the breadboard backplane.

To complement the hardware, the CAD solid models initially created for fabrication purposes were adapted so that the 3-D CAD environment can be used to visualize a proposed system. By accessing a library of CAD subassembly models, virtual duplicates of component configurations existing in the actual laboratory environment may be realized. Multiview layout drawings, complete with a bill of materials, can be produced, so that specific systems are designed before receiving the components for assembly. A Web-based catalog of the parts [11] includes basic descriptions, operational characteristics, and component costs, so that informed decisions regarding selection and configuration of systems may be made. A comprehensive description of the components and associated vendors may be found on the website.

Figure 1. A variety of breadboard compatible valve (butterfly, globe, and pneumatically actuated), heat exchanger (single and multiple pass), and flow sensor (paddlewheel, turbine, and orifice plate) assemblies.

Although this is not a complete description of the laboratory and computer-based system components, it provides a basic understanding of the system's capability and operation. With this overview completed, we now describe how the Process Control Breadboard system was used to engage students in real-world engineering experiences.

HVAC RELATED PROCESS SYSTEMS

While process control systems are most commonly associated with petrochemical related industries, the PCB system was not designed for actual chemical reactivity. The simulation of chemical process reactions required the use of imagination and role playing. The focus has been on the control of temperatures, pressures and flow rates of water acting as hypothetical chemical constituents. On a broader scale, the approach used has attempted to identify a wide variety of thermal-fluid systems as being process systems. This broader definition includes food processing, potable water processing, and HVAC systems as controllable processes. Although DX system simulations are not possible using the PCB system, small-scale chilled water and hydronic heating systems are easily achieved. By adapting hydronic kickspace heaters, small-scale coils with air handlers have been created. While hot water or steam would be the "typical" working fluid, chilled water systems can be simulated using an ice-filled tank as the chiller. Pumps, valves, and sensors for temperature and flow create small-scale HVAC systems in a classroom or laboratory environment. Although small in size, system performance is measurable, with a cooling capability of approximately 700 BTU/hr. for a single coil-air handler combination. Heating systems have not been attempted since most K-12 activities have occurred during warm weather months.. The chilled water air conditioning systems have been presented as examples of process systems commonly designed by engineers in East Texas and around the world.

Two different venues and delivery techniques have been used with middle school students: hands-on demonstrations at a rural middle school and summer day camps held at the UT-Tyler campus. Detailed descriptions of those activities are presented in the following sections.

HANDS-ON DEMONSTRATIONS AT RURAL MIDDLE SCHOOL

At the request of the 8th grade mathematics teacher, a subset of the available components was transported to the middle school in Bullard Texas, a small rural community south of Tyler. The purpose was to provide hands-on demonstrations of the Process Control Breadboard, and to illustrate how a chilled water air conditioning system operates. Due to the limited amount of wet space available, the demonstrations were conducted in an externally assessable, general storage area.

Approximately 110 8th grade math students, comprising six sections of algebra and pre-algebra classes, were involved in the demonstration. For each class section, a small-scale, chilled water system was assembled and operated by the middle school students, with only moderate assistance from undergraduate engineering students. Following a brief explanation of the chilled water air conditioning process, and to incorporate mathematics into the presentation, we conducted a "search for Q," the rate of heat removal from the space. A steady-state approximation for the heat transfer rate of this type of system can be determined from the following equation:

$$dq/dt = 500 \cdot gpm \cdot \Delta T \qquad \text{Equation (1)}$$

Where dq/dt is the heat transfer rate in BTU/hr, gpm is the flow rate in gallons/minute, ΔT is the Fahrenheit temperature difference of the fluid across the heat exchanger, and the 500 is a conversion coefficient with units BTU-minutes/(hr-Fahrenheit). For the purposes of a simplified explanation, dq/dt became Q. By introducing this simplified formula, the importance of mathematics in an engineering context was demonstrated.

The system used a bag of ice submerged in a tank of water to simulate a chiller. The water was pumped from the tank through a system of valves, jumpers, a water-to-air heat exchanger, and a variable area flow meter before returning to the simulated chiller. The water-to-air heat exchanger was equipped with a forced air fan and produced cool air; resembling an air conditioner. Condensation on the coil was also observed during the operation of the system. Figures 2 and 3 show middle school students, assisted by an undergraduate engineering student, assembling and operating the small-scale systems.

Figure 2. A middle school student attaching a control valve for a small-scale air conditioning system with the assistance of an undergraduate engineering student.

Figure 3. A middle school student operating a small-scale air conditioning system and gathering heat transfer rate data.

Following system assembly, the objective was to adjust the flow rate to reach a maximum "Q." The effects of adding a second coil/air handler component in parallel to the original were also investigated. To provide a sense of scale, air conditioning capacity determined for the simulated system was compared to the capacity of typical residential units.

At the conclusion of each class session the systems were disassembled in order to prepare for the incoming class. This allowed each class to have the opportunity for a hands-on experience.

SUMMER DAY CAMP EXPERIENCES

The summer day camp activities using the Process Control Breadboard System included an introduction to the valves, sensors, and heat exchangers used with the Breadboard. A brief lecture explaining the fundamental concepts behind the activity was provided to the participants before the actual hands-on experience. The participants qualitatively determined the characteristics of the different types of valves, were exposed to temperature, pressure, and flow instrumentation, and then had to design thermal-fluid systems that not only became increasingly difficult as the camp progressed, but also illustrated a fundamental concept of the equipment used, such as a flowmeter or heat exchanger. The systems were first designed using CAD solid models to generate an assembly drawing and a bill of materials. The participants were provided only the parts on the bill of materials, and then they constructed and tested their systems. For safety reasons, all electrical and steam equipment was set up by the camp staff.

The summer camp activities that did not use the PCB system included a tour of a local water treatment facility, a lunch presentation from a project manager of a local petroleum company, and a brief demonstration of some of the more appealing aspects of engineering, such as robotics and automation. The tour of the water treatment facility allowed the participants to see larger versions of valves and instrumentation they were using with their breadboard systems. The lunch presentation from the project manager showed that with high-dollar refineries and plants, the necessity of engineering design before construction was very important. The robotics and automation demonstration revealed to many of the participants the truth behind robots, breaking the science-fiction expectation of intelligent machines.

A small percentage of the participants were very excited about the activities of the camp, and their systems generally performed very well. One noteworthy occurrence was during the simple mixing activity: the participants were to mix a hot source of water with a cold source of water to achieve a desired temperature and flow rate. Most participants, including the staff, manually throttled a valve on each input stream until the desired results were obtained (which also demonstrated some basic system control concepts.) One team placed a valve before the outlet to set the flow rate, and then adjusted the previously mentioned valves on the input streams to get the required temperature.

Some of the participants had a hard time understanding some of the underlying concepts. While some were still able to construct a working system through a trial-and-error methodology, others had extreme difficulty with most activities. Generally, the participants that were 12 years old or only a few months into being 13 years old had the most difficult time, implying that 13 years old is the age for engineering [7].

Table 1 summarizes the numerical results for selected questions from the 55 summer camp participants completing the camp. A five-point scale was used where higher values indicated favorable responses. The questions have been paraphrased for brevity. It should be noted that the average response was over 4 for the remaining seven numerically evaluated questions, with standard deviations ranging from 0.559 to 0.886, except as shown in Table 1.

Table 1. Summary of the Summer Camp Activity Assessment Survey.

Question	Mean	Standard Deviation
The mental challenge of the CAD activity	4.48	0.909
Your awareness of how math, science and engineering relate	4.83	0.412
Affected your interest in engineering	3.80	1.101
Rate the "fun factor"	3.91	0.747

One additional student was unable to complete the camp session and did not complete a survey. Demographically, twenty-three percent of the camp participants indicated that they were either female or a minority race and participants came from a variety of public, private, urban, rural, and home-schooled environments. Each participant came to the camp with preconceptions about engineering, and by the end of the camp, most came to understand that engineering can be an interesting and fun activity, albeit heavily based in math and science.

OTHER OUTREACH ACTIVITIES

In addition to the previously mentioned activities targeted specifically at middle-school-aged students, high school students have been able to experience a brief, hands-on design-build-test exercise during open house activities held on the UT-Tyler campus. Tour groups of approximately 16-20 students were guided through several exhibits, demonstrations and hands-on activities. During the approximately 30-minute time frame allowed for the activity, the groups selected components, built and tested small-scale mixing systems. Their objective was to achieve and maintain a specific temperature by mixing hot and cold fluid sources. The exercise was posed as a chemical mixing problem. An acceptable temperature range was specified, along with an "ideal" temperature to achieve the best mixture. Hypothetical consequences were associated with producing mixtures that were outside of the prescribed temperature limits: too cold would produce an unusable mixture and "waste" raw materials; too hot would initiate an explosive reaction. Due to the interconnectivity of the systems, all of the teams experienced random disturbances which usually caused the systems to exceed the specified limits. Although these mixing systems are analogous to tub valves and conceptually simple, the participants found the control problem to be challenging when placed in the hypothetical context.

Table 2 summarizes feedback obtained from the participants at the end of the open house exercise. These numerical results were obtained from 113 participants representing eight different high schools. Students from public, private, urban, and rural schools were represented. A five-point scale was also used for this survey, but a high value was not always the most desirable assessment. The closest linguistic equivalent statement is included with the numerical result to assist with the interpretation. Although no specific demographic data was obtained, approximately one third of the high school participants were female and approximately one third were minority race students.

The largest standard deviation was 1.029 for the fourth question, while all others were less than 0.963. Given the nature of the survey instrument and the limited time available, this type of activity appears to have been successful. Additional anecdotal evidence of success was in the form of positive and encouraging comments provided by the teachers that accompanied the students.

Table 2. Summary of the Process Control Breadboard Open House Activity Survey.

Question	Mean (Linguistic Equivalent)
How would you rate the "hands-on" component of this activity?	4.48 (Mostly Hands-on)
How would you rate the mental difficulty level of this activity?	3.06 (It took some thought)
How would you rate the physical difficulty of this activity?	2.53 (Somewhat easy)
How did this activity affect your awareness of engineering?	3.40 (Learned something new)
How has this activity affected your interest in engineering?	3.96 (Somewhat interested)

CURRICULUM INTEGRATION OVERVIEW

Aspects of the "Common Practice" approach have been integrated into the curriculum at UT-Tyler. By developing activities that complement existing course content and structure, the process control theme has become a thread appearing at each academic level. Targeting courses containing hands-on laboratory or design project activities, the integration has been minimally disruptive.

At the freshman level, the semester-long, team-based design project offered as part of the mechanical engineering CAD-graphics course introduces the process control theme. Student teams design, assemble, and test small-scale systems to meet operational specifications. Students are introduced to heat exchanger basics and directed to information sources to help select other process elements. System performance is de-emphasized, while graphical and oral communication skills are stressed. Project graphics include piping and instrumentation diagrams (P&ID), solid model assemblies of their proposed systems, and layout drawings leading to a parts list and system configuration diagram. Teams are provided a budget and all components, whether for testing or final system use, have costs associated with them. Consultation fees are also charged when outside assistance is sought from a more experienced person; including upper classmen, faculty, and staff.

Written procedures for system assembly, commissioning, and operation are also required. The level of documentation is such that another team, or individual, can successfully assemble and operate the system based solely upon the provided documentation. The use of paid consultants and the production of procedures are common aspects of engineering practice that are frequently de-emphasized in an educational environment, but provide a basis for a real-world experience.

At the sophomore level, an introduction to computer–based data acquisition and control has been incorporated into a structured programming course. Prior to this integration, team-based development of a modular computer program was the project focus. By introducing data acquisition and control of sensor and control elements from the breadboard system, students gain first–hand experience with first-order system response and the lag times associated with relatively slow process systems. Figure 4 is a photograph of the breadboard system used for this initial data acquisition and control experience.

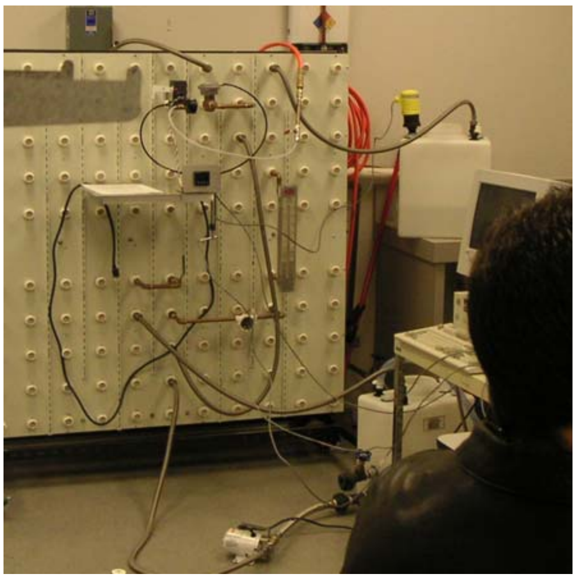

Figure 4. A breadboard configured for a sophomore level data acquisition and control experience.

Junior-level students gain access to process control elements, primarily sensor systems, during the first designated laboratory course in mechanical engineering. The course focuses on measurement uncertainty, measurement systems, and basic sensor technologies. Directly interfacing thermistors, thermocouples, and RTDs to data acquisition systems, determining time constants, and investigating chip-level digital logic circuits are process control related experiences that are included in the course. Paddlewheel and turbine flow meters from the breadboard system are used to investigate digital measurement systems and the circuits required for direct data acquisition interfacing. The junior-level activity focuses on calibration, uncertainty, and interface circuitry, rather than programming related issues.

The follow-up junior laboratory class is a more traditional thermal-fluid systems course. Students gain HVAC related experience from exercises dealing with piping system head losses and heat exchanger characterization. Additional exercises using a DX system heat pump trainer expose students to basic system operations.

For seniors, the content is integrated into an electro-mechanical systems design course. A team-based automatic control system design project includes selection, configuration, and integration of sensors, actuators, and controller elements. An introduction to programmable logic controllers (PLCs) and ladder logic programming is also included as part of the course content. Although the breadboard concept is premised on thermal-fluid systems, the selection and configuration of sensor and control elements is consistent with the course content. Many project designs implement two-position or floating control modes which are typical of HVAC and other large-scale thermal-fluid systems using PLCs with ladder logic programming. The final control elements selected most often are pneumatic control valves, commonly found in hydronic systems. Both normally open and normally closed valves are available for selection and some project solutions have involved synthesizing a three-way valve by combining the functions.

Although most of the process-related activities integrated into the curriculum are not directly HVAC examples, most of these activities strongly support students wanting to pursue a career in the HVAC industry. The integration of these activities has been attempted by substituting context instead of content; making the process minimally disruptive to the existing program outcomes and objectives. This approach has provided students with hands-on activities that provide common engineering practice experiences.

It can be difficult to directly measure the impact of “across the curriculum” enhancements before a set of students has completed the entire program. The introduction of the data acquisition component at the sophomore level only started during Fall 2005. To gage the impact of the approach, an anonymous survey of seniors completing the electro-mechanical systems design course indicated that their experience significantly improved understanding of control problems and increased their confidence to integrate electronics and sensors into real systems. They overwhelmingly agreed that the integrated thematic approach adds significant value to the educational experience and should improve the retention of early program students. Table 3 summarizes these responses. The five-point scale used was worded so that 5 is a significantly positive response, 3 is a neutral response, and 1 was a significantly negative response.

Table 3. Summary of senior-level survey concerning the impact of the Process Control Breadboard System (PCB) on the program design experience.

Question	**Mean**	**Std. Dev.**
Understanding of control problems	4.70	0.483
Increased understanding of sensor/controller/system interfaces	4.60	0.516
Increased confidence level for integrating electronics/sensors	4.80	0.422
Confidence to instrument & control an employer's small/medium scale system	4.20	0.632
Preference for using PCB to simulation for design experience	4.60	0.516
Overall PCB experience value added for design experience and retention	4.90	0.316

CONCLUDING REMARKS

Maintaining a connection to common engineering practice is an important aspect of an engineering education. By adjusting the context associated with design and laboratory courses, a rich curriculum with direct ties to industry can be devised. The addition of thematic content, based on process control systems design and supported by hardware developed to allow quick, hands-on realization of small-scale systems, has enhanced the overall design experience. Outreach activities based on the same theme have also been well received. The combined approach will hopefully result in an increase in engineering graduates.

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