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A PROJECT-MOTIVATED APPROACH TO AN ELECTRONICS CURRICULUM

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ABSTRACT

Based on the observation of our students learning electronics in the course of their independent research experiences, the introductory electronics program at Creighton University has been revised to provide a similar contextual setting. From the beginning of the course, the students are involved with the type of instrumentation they will encounter in upper-division laboratories, in research laboratories, and in industrial settings. Two sets of equipment are utilized. The first set is used for learning the basic fundamentals and building blocks of electronic devices. The second set is used for student projects. Experience in a goal-oriented project environment enables students both to learn more effectively and to make significant research contributions at a much earlier stage.

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By graduation, typically 75% of Creighton University's physics majors have been involved in undergraduate research, often over a period of several years. Research areas available to Creighton physics students include experimental solid state physics, high-energy experimental nuclear and particle physics, and medical physics. The authors of this paper are involved in high energy nuclear physics research.

OBSERVATIONS

Six undergraduate students worked with us in high energy nuclear physics research in the summer of 1994. The initial project was the construction of a prototype spot-focusing Cerenkov detector designed at Los Alamos National Laboratory for the NA44 experiment at the European Center for Particle Physics (CERN) in Geneva, Switzerland (Fields et al., 1994). This device can focus light from particles traveling at a given speed to a spot, enabling the identification of particles of different speeds. As background work, one student researched the theory of Cerenkov radiation (light emitted when a charged particle travels through a medium at a speed greater than the speed of light in that medium), while two assisted in the collection of data at the NA44 experiment at CERN. Four Creighton students machined the mounting frames and a light-tight enclosure for the detector under the supervision of the physics machine shop staff. This was the students' first experience with shop equipment; they put in hours well beyond those required and expressed satisfaction with having something concrete to show at the end of each day. One student carried the parts to CERN where she assembled the detector and tested it in a proton beam in collaboration with staff scientists from Los Alamos. She and another student later spent their week-long fall break at Los Alamos National Laboratory working on data analysis and setting up a computer program library at Creighton University via the Internet. During the 1994-1995 academic year three students studied mirror shape, transition radiation contributions, and the light output of the radiator used in the Cerenkov detector.

We have observed that students with little or no previous knowledge of a research area finish a project with a good understanding of many of its details. This transformation occurs with little, if any, formal course work in the area.

DISCUSSION

Recently we have begun to analyze the success of these research projects as teaching tools. Research as a guide for laboratory instruction is a strategy that has been employed in certain specialized environments (Ivany et al., 1968; King, 1966; Robinson, 1978; Shaffer et al., 1992). We find that students in a research environment learn quickly when presented with concrete, goal-oriented tasks. An attainable goal provides strong motivation to master the skills necessary for its accomplishment. In particular, we observed students rapidly acquiring expertise in machining, optics, and electromagnetic theory during the course of the Cerenkov detector project. Although these skills and concepts were assimilated peripherally, as means to accomplishing the goal of building a working Cerenkov detector, they were learned well.

The role of the laboratory in the physics curriculum has been addressed by numerous authors (Arons, 1993; Fuller et al., 1977; Michels, 1961; Reif et al., 1979). Our experience with undergraduate research projects prompted us to explore ways of restructuring the physics teaching environment to take advantage of the efficient learning we have come to associate with research. After seeing how effectively our students acquired skills when they were motivated by an explicit goal-oriented project, we became confident that all our students could benefit from such experience. We also expect that further experience of this type will make our students more effective researchers.

Electronics was selected for restructuring for several reasons. First, the material easily lends itself to being learned as means to another goal. Second, electronics is the foundation for all of our upper-division laboratories, and for experimental research. Finally, the subject matter can be easily tailored to particular student research interests; student experiences in electronics can then lead directly into research projects.

In the restructured electronics course the students are initially introduced to basic, discrete electronics components. After the third week, the focus changes from the details of operation at the level of electrons, diodes, and transistors, to the level of functional building blocks and systems. Projects are introduced to model the research experiences which have proved to be motivating to our students. The scope of these projects encompasses more than just electronics; the electronics is learned in a broader framework. The use of these projects enables the students to master the topics in electronics to which they have been introduced. Projects are tailored to the needs and interests of individuals, and projects of varying complexity are available to accommodate a range of student abilities. As students develop expertise, the teaching style changes from the more traditional lecture/laboratory mode to an approach in which the instructor functions in the role of consultant and facilitator.

To expedite the transition from a traditional electronics curriculum to a project-motivated approach, we introduced an ongoing, communal experiment as a pilot project in the fall of 1993. This collaborative experiment, the study of the electrical activity of a sturdy plant under the influence of various physical stimuli (temperature, touch, light, magnetic field, etc.), provided a context for the application of electronics. Electrodes led to an amplifier connected to a digital storage oscilloscope, and waveforms were stored on a computer. Students began experimenting with the plant and, as they progressed, they substituted and added amplifiers, triggers, oscillators, filters, and digital decision and stimulus units that they had designed and constructed. They were encouraged to find immediate applications of newly-learned electronics topics to their common project.

Based on the success of this initial collaborative experiment, we have generated a non-exhaustive list of other possible projects for students to pursue. They run the gamut from the merely complex to the electronically challenging. Some examples from this list are: investigating various filters and detailed circuit designs, generation of response-dependent stimuli for the plant project, machine language programming of a microprocessor, and exploring digital signal processing. Some of the more sophisticated projects are roughly grouped below into four themes with related equipment listed in parentheses.

The first theme is communication (nine-bit serial network, GPIB, RS232, LabVIEW for Windows). Possible projects within this theme include a detailed study of communication protocols: RS232, General Purpose Interface Bus (GPIB), and Nine-Bit Serial Protocol (NSP).

The second theme is control (nine-bit serial network, LabVIEW for Windows, LabPC+ I/O board, HC11 microcontroller, and MATLAB). Projects within this theme include: system control for the STAR (Solenoidal Tracker At RHIC) experiment at Brookhaven National Laboratory (Gross et al., 1994), microcontrollers and their use in a network, and exploring control concepts using both real and simulated circuits.

The third theme is data acquisition and analysis (Lab PC+ I/O board, digital storage oscilloscope, HC11 microcontroller, LabVIEW, MATLAB, and Electronics Workbench). Projects within this theme include: building a Cerenkov detector for the NA44 experiment at CERN, hardware and software activities involved in positron emission tomography at Creighton University, and acquiring skills in digital signal processing using various software packages.

The fourth theme is system simulation (Electronic Workbench, MATLAB, TUTSIM, Desire, PSpice, and other simulation programs). Possible projects within this theme include advanced circuit, system, and logic simulations.

The restructured course was fully implemented in the fall of 1994. One of the first projects was a microbarometer for the detection of small, short-period oscillations in atmospheric pressure. Voltages were generated in a coil which moved relative to a permanent magnet mounted on a vibrating drum head. Students explored several combinations of barrel, membrane, magnet, and coil. They then designed and assembled an amplifier and used MATLAB to study its output.

Another project completed in 1994 was the activation of a variable-period vertical pendulum seismometer which had been constructed in the physics department's machine shop. Students designed and constructed a suitable amplifier for it and fed its output to an analog-to-digital converter for computer storage and later study. The response of the seismometer to various stimuli was modeled with two analog simulation programs.

Previous studies have suggested a correlation between microseisms, which are small, short-period vibrations in the earth, and similar variations in atmospheric pressure (Eisele, L. J., 1985, private communication). This led to a third project: the simultaneous recording of the outputs of the microbarometer and the seismometer using the GPIB protocol.

Another project was the construction of a lock-in amplifier and a comparison of its operation with that of a previously-purchased lock-in amplifier in the measurement of the magnetic susceptibility of high Tc superconductors.

All of these projects were fully documented by the students; the lock-in amplifier project has already been presented at a departmental seminar.

SUMMARY

Our undergraduate students working on research projects have been observed to learn efficiently in a goal-oriented environment. This experience motivated us to bring this approach into the physics classroom. We chose the electronics course as the starting point for revisions since it lends itself most easily to this setting. The course has been redesigned so that during the second half of the semester students work on goal-oriented projects, culminating in a presentation of their results.

We have prepared numerous projects. These projects are designed to be flexible, to be of varying complexity so that students at all levels can be appropriately challenged, and to provide the students with the opportunity to learn about electronic systems in a contextual setting. Several projects have already been carried out, and student response has been enthusiastic. Students have presented their accomplishments at seminars and professional meetings at the local, regional, and national levels.

More objective measures of student learning are being implemented. Standardized testing of the outcomes of this program should provide a quantitative assessment of the program's effectiveness as well as highlighting the strengths and weaknesses of this approach.

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