Int. J. Appl. Engng Ed. Vol. 7, No. 1, pp. 35-39, 1991
Printed in Great Britain.

0742-0269/91 $3.00+0.00

Integrating Design Projects in Electrical Engineering Curriculum: Case Study in an Undergraduate Computer Engineering Laboratory*

H. L. OWEN†‡
School of Electrical Engineering, Georgia Institute of Technology Atlanta, Georgia 30332, U.S.A.

An undergraduate computer engineering laboratory that supports a one-quarter hardware and software design class is described in this paper. This course is a senior capstone design elective in the Georgia Institute of Technology electrical engineering program, the class is also taken by many students in both computer engineering and computer science. The approach described in this paper allows 50 students each quarter to apply their cumulative education in design problems. Technological advances coupled with large class sizes and increasing instructional loads require the use of new approaches in order to teach students engineering design skills as defined by independent accreditation reviewers. This newly developed class was implemented by the author to assist in meeting the 'design oriented capstone class' requirements included in engineering curriculum accreditation review specifications.

• INTRODUCTION

RAPIDLY changing technology in electrical engineering has resulted in the generation of many new classes [1–7]. As these new classes are added to a curriculum, they are directly affected by the accreditation review process. Such a review process, conducted by an outside source, determines if a given curriculum meets published standards. In such standardization criteria, education in engineering design is specified. An example of such a specification is the following excerpt [8] from the Accreditation Board for Engineering and Technology accreditation requirements:

> Engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing, and evaluation. The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of alternative solutions, feasibility considerations, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics, and social impact.

Several classes have been recently created to include some design experience [9,12]. A laboratory and its associated classroom instruction which was created to meet the above stated 'engineering design' requirements is presented in this paper.

Coursework and Examination Methodology

The classroom instruction begins by providing the basic background necessary to place students in a position to design a personal computer based hardware and software 'product'. This is accomplished by covering the computer architecture of the IBM Personal Computer (PC) family, the PC family busses and their signals, address decode circuitry, and input/output hardware and software design. At this point, which is typically the third week of the quarter, students have enough specific knowledge on PCs to begin their own designs in the accompanying laboratory assignments. The course topics continue with event timing, interrupts, direct memory access, and timing analysis of hardware and software designs. Finally systems design issues such as the operating system and memory design are covered.

The class requires extensive use of the C programming language. Several computer languages

* Paper accepted 12 June 1990.
† Dr Owen is Assistant Professor.
‡ Current address: c/o Thomas Hagemeister, Standard Electrick Lorenz AG, Mail Station US/EMB2 Lorenzstrasse 10, D-7000 Stuttgart 40, Germany.

were considered for use throughout the class, it was determined that C was by far the preferred choice due to the single bitwise Boolean operators and shift operators available in C. Additionally, industry use of this language in design of computer based products indicates C is an excellent choice for this particular application.

The text selected for this course is *Interfacing To The IBM Personal Computer* by Lewis C. Eggebrecht [13], and is supplemented with class notes which will soon be published as a book *Interfacing Hardware and Software With PCs*. Additionally since the C programming language is used in conjunction with the hardware designed in the class, the reference text *The Waite Group's C PRIMER PLUS* by Michell Waite, Steven Prata, and Donald Martin [14] is also recommended.

In a design oriented class it is necessary to administer exams which are relevant to design methodologies. The approach used in this learning environment has been to issue 1 and ½ hour exams which ask for the design of a 'product' in such a manner that the students ability to initiate the design process is benchmarked. Previous questions given on exams have included designing data collection systems via analog to digital interfaces, design of neural network circuits which are random memory access based, and design of discrete digital input and output circuits. Exams are not graded based upon completeness but instead are graded to measure the students abilities to weed through the false starts inevitable in any design practice, filter out the necessary information, and initiate a successful design approach.

Laboratory Assignments

Five laboratory assignments are given during the first five weeks of the eleven week quarter to bring the students to the level that they may complete the final design project. The first three lab assignments are the same each time the class is taught, the later labs are changed to prevent students from using work from previous quarters. Students are required to work individually on the laboratory assignments so that each student may individually experience the design process. Typical laboratory assignments for this course are as follows:

(1) Connect a four bit counter to the computer clock source and display the computer outputs on a logic analyzer.
(2) Execute a C computer program and display the computer bus cycles generated by this program on a logic analyzer.
(3) Construct a provided circuit and write a C program to manipulate the hardware.
(4) Complete a small scale design project involving both hardware and software design to meet announced design specifications.
(5) Complete a medium scale design project that involves more complex computer issues such as interrupts and or direct memory access.
(6) The last assignment is a large scale design project requiring creative and innovative design in order to meet design specifications.

The first lab is oriented toward familiarizing the students with the logic analyzers, oscilloscopes and logic probe debugging tools available in the lab. The second lab reinforces the use of debug tools by requiring a C program to be written to generate specific computer bus cycles which are then recorded on the logic analyzers. The integration of software and hardware concepts is begun in the second week of the class and continues as a main theme throughout. The third lab assignment requires the construction of a provided circuit and the writing of a C program to exercise the hardware. The fourth lab is assigned the fourth week of the quarter. The students are assigned a simple design problem. One example of such a problem is to design a programmable signal generator which outputs various waveforms at several different frequencies. This project requires the student to design both the hardware and the software to accomplish the design objectives. The fifth lab assignment is typically a more difficult design problem which requires understanding of more complex software issues such as interrupts and direct memory access, therefore requiring system understanding of the PC. A typical problem assignment is to design a memory resident program that continues to handle interrupts and or direct memory access transfers while carrying out other computer programs.

Laboratory

The laboratory consists of 10 workstations each of which has an IBM PC XT, a logic analyzer (HP1651B), an oscilloscope (Tektronix 2225), a printer, a TTL logic probe, and a PC bus signal extractor. This PC bus signal extractor, which consists of circuitry to buffer and fuse the internal signals of the PC, allows the class to be offered in a pragmatic manner. A diagram of a typical work station is shown in Fig. 1. In determining a laboratory setup, one constraint was the ability of students to be able to work in short lab appearances with the necessary computer and test equipment and yet the students needed the ability to physically carry their creations out of the lab environment to do additional debug and design modifications at home. The ability to in essence open up the computer and allow the circuitry to be placed inside the computer while still allowing students to remove their circuits from the lab allowed this class to be offered.

The lab was implemented in a way to allow students to accomplish useful work both inside and outside of the lab. Students are allowed to sign out the needed integrated circuits on a library card type inventory system and may prototype their designs up while at home. Upon entering the laboratory a vacant lab station may be chosen and by jumpering between 15 and 62 PC bus signal connections the

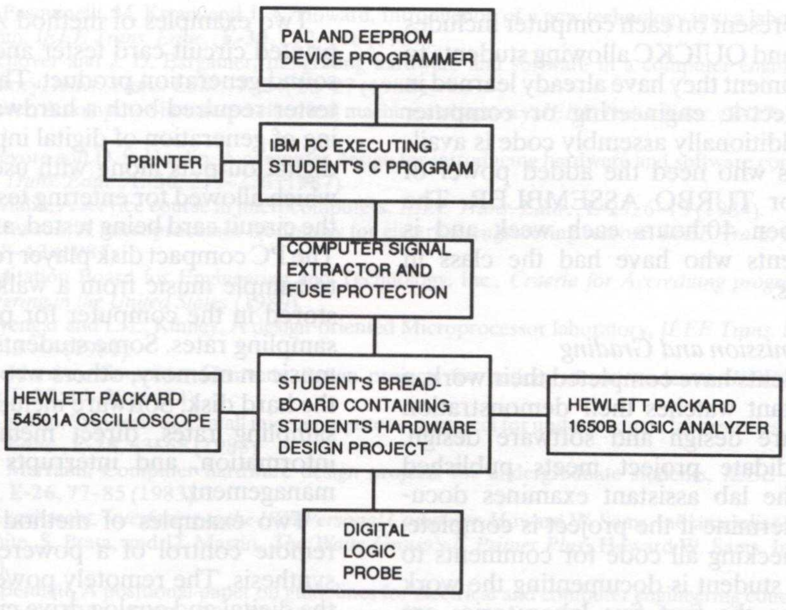

Fig. 1. Typical laboratory workstation.

student may begin test and debug using the computer and associated test equipment. Students use a protoboard to construct their prototype design circuitry, allowing for easy modification and protability during the design process. In the event of a student wanting to construct a more permanent version of their design project, they may use one commercially purchased expansion chassis along with a printed circuit card version of their project. Both of these methodologies for connecting student hardware to a computer are shown in Fig. 2.

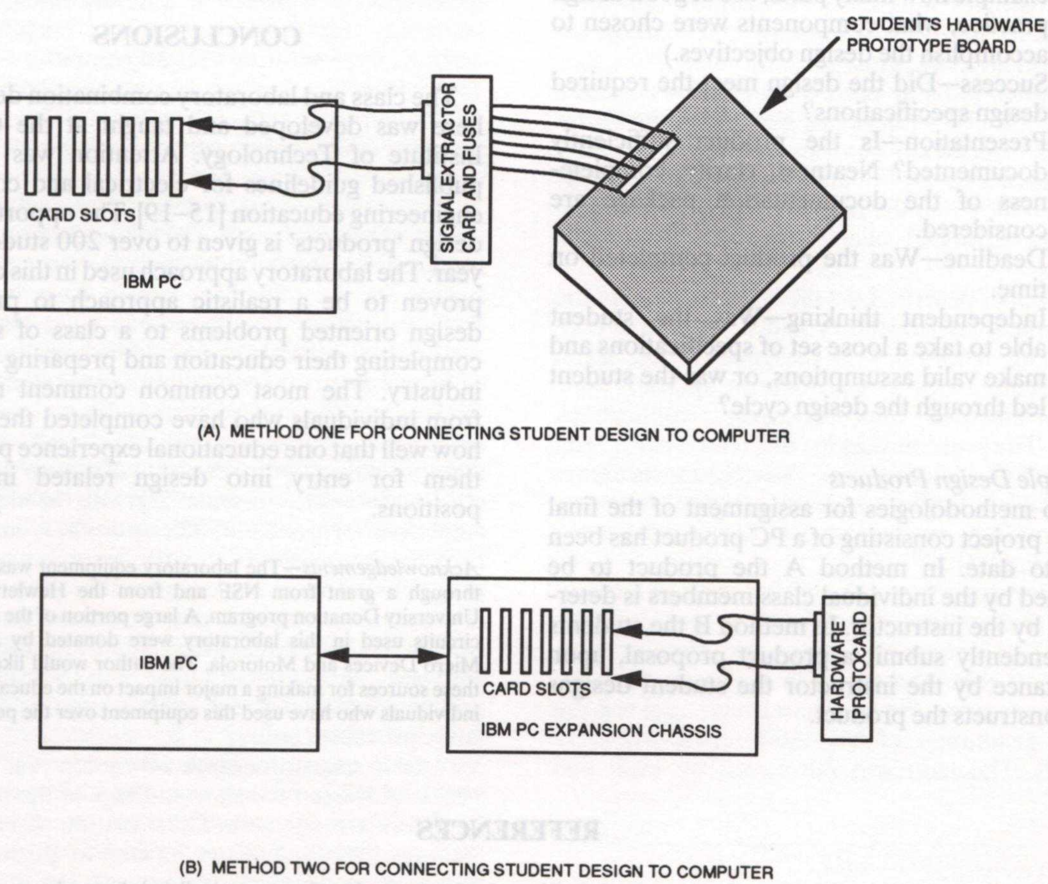

Fig. 2. Methodology for connecting student hardware to computer.

The software present on each computer includes both TURBOC and QUICKC allowing students to use the C environment they have already learned in any previous electric engineering or computer science class. Additionally assembly code is available for students who need the added power of either MASM or TURBO ASSEMBLER. The laboratory is open 40 hours each week and is staffed by students who have had the class in previous quarters.

Laboratory Submission and Grading

When the students have completed their work, a laboratory assistant watches their demonstration of their hardware design and software design. When the candidate project meets published specifications, the lab assistant examines documentation to determine if the project is complete. This includes checking all code for comments to determine if the student is documenting the work sufficiently. Since the first five laboratories are intended to bring the students design skills up to a level where a realistic design problem may be solved, the first five designs are graded on a satisfactory or unsatisfactory basis. The final design project which typically consists of 40% of the students grade is graded on a different basis.

The final design project is graded based upon the following criterion.

(1) Creativity—How 'good' is the design? (For example how many parts, use of good design practice, what components were chosen to accomplish the design objectives.)
(2) Success—Did the design meet the required design specifications?
(3) Presentation—Is the product sufficiently documented? Neatness, clarity, completeness of the documentation package are considered.
(4) Deadline—Was the product completed on time.
(5) Independent thinking—Was the student able to take a loose set of specifications and make valid assumptions, or was the student led through the design cycle?

Example Design Products

Two methodologies for assignment of the final design project consisting of a PC product has been used to date. In method A the product to be designed by the individual class members is determined by the instructor. In method B the students independently submit a product proposal, upon acceptance by the instructor the student designs and constructs the product.

Two examples of method A products include a printed circuit card tester and a PC compact disk sound generation product. The printer circuit card tester required both a hardware platform consisting of generation of digital inputs and sampling of digital outputs along with user interface software which allowed for entering test patterns, exercising the circuit card being tested, and analysis of results. The PC compact disk player required the hardware to sample music from a walkman, the music was stored in the computer for play back at different sampling rates. Some students placed the digitized music in memory, others wrote the information to the hard disk. Software included the control of the sampling rates, direct memory transfer of the information, and interrupts to handle memory management.

Two examples of method B products include remote control of a powered vehicle and voice synthesis. The remotely powered vehicle required the digital and analog drive circuitry to control the vehicle. Software commands were issued by voice command using a voice recognition chip which is commercially available. The speech synthesis product used a commercially available speech synthesizer with words stored in memory, the student used computer direct access memory functions to transfer the information from the memory to the speech synthesizer.

CONCLUSIONS

The class and laboratory combination described here was developed and taught at the Georgia Institute of Technology. Attention was paid to published guidelines for electrical and computer engineering education [15–19]. The opportunity to design 'products' is given to over 200 students per year. The laboratory approach used in this class has proven to be a realistic approach to providing design oriented problems to a class of students completing their education and preparing to enter industry. The most common comment received from individuals who have completed the class is how well that one educational experience prepared them for entry into design related industrial positions.

Acknowledgements—The laboratory equipment was provided through a grant from NSF and from the Hewlett Packard University Donation program. A large portion of the integrated circuits used in this laboratory were donated by Advanced Micro Devices and Motorola. The author would like to thank these sources for making a major impact on the education of the individuals who have used this equipment over the past year.

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