# Undergraduate Engineers for Curriculum and Laboratory Equipment Development

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**Abstract**

Often, engineering departments are faced with the need to update laboratory exercises and equipment. However, adequate funds do not always exist to accomplish these upgrades in a timely manner. Another challenge faced by departments are satisfying Accreditation Board for Engineering and Technology (ABET) requirements for a major design experience within the curriculum. ABET guidelines state, "Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political". Furthermore, specific Program Outcomes require an ability to function on a multi-disciplinary team.

In this paper we will describe how we solved these two challenges by updating our microprocessor laboratory facilities on a limited budget using student engineers. This highly successful program provided state-of-the-art computer engineering laboratory equipment using student designed, fabricated, and tested laboratory equipment. Furthermore, the students were completely responsible for developing all of the supporting courseware such as laboratory assignments for the new equipment.

From the department's point of view, state-of-art, custom laboratory equipment based on the 68HC12 microcontroller was obtained at a lower the cost than commercially available trainers. Furthermore, students were exposed to a real world design problem and all of the inherent related issues such as: working on a design team, interacting with highly skilled technicians, budget constraints, timelines, manufacturability issues, reliability issues, and customer satisfaction.

We will describe how the program was instituted along with potential pitfalls and successes. Most importantly we will provide candid comments from the student engineers on their thoughts toward the utility of the program and what they gained from it.

## Background

The University of Wyoming instituted a new undergraduate Computer Engineering curriculum in Fall 2000 in response to a nation-wide shortage of computer engineers. The hardware design portion of the curriculum consists of traditional course and laboratory work in digital design, embedded controller programming, and advanced digital design. Although this curriculum provides a thorough technical education, other concepts need to be incorporated into the curriculum including: competition, quality design, teamwork, systems design, interdisciplinary projects, and advanced embedded controller concepts.

**Funding Efforts:** In July 2001 one of the co-authors (sfb) submitted a $200K proposal to the National Science Foundation (NSF), Directorate for Education and Human Resources, Division of Undergraduate Education (DUE), entitled "Motivational Robot-Based Undergraduate Computer Engineering Laboratory". This proposal provided a plan to incorporate the vital concepts listed above into the existing curriculum via creation of a comprehensive laboratory experience based on robot technology. Using robots to teach digital design and non-technical concepts in a motivational environment has been used at many institutions [1,2] with great success including Trinity College in Hartford, CT [3,4]; MIT [5], and the US Air Force Academy [6-8].

Later that year, the co-author was notified the proposal had not been selected for funding by the NSF. The proposal had received a very thorough and fair review by the review panel. Both positive and negative feedback was provided on the proposal. The NSF review panel was concerned about the feasibility of using student design and in house fabrication of teaching aids. They considered this a risky undertaking. The co-author carefully reviewed the reviewer's comments and incorporated them into an improved proposal. The proposal was then used to apply for internal college funds, internal university funds, and external foundation funds in an effort to get the project started. In all cases the project was not funded. Early in 2002, the Electrical and Computer Engineering Department provided seed monies to begin the project.

**Project Overview:** The overriding goal of the project was to best prepare University of Wyoming Computer Engineering graduates for the technological work force. To achieve this goal we targeted our first microprocessor course for improvement. This course required updated pedagogy, instructional aids, equipment, software, and laboratory exercises. In effort to save money and provide design experiences for our students, we proposed having students design the prototype teaching aids for the course. Specifically, two undergraduate senior design students, Abbie Wells and Carrie Hernadez, would design a microprocessor laboratory platform for their senior design project. Also, an undergraduate, interdisciplinary design team, consisting of Thomas Schei (electrical engineering) and Joshua Werbelow (mechanical engineering), would design the prototype laboratory robot and accompanying control software. It was also planned to hire undergraduate students to fabricate and test the instructional aids.

**Project Plan:** The plan consisted of two phases designated I and II. The microprocessor course was using an industry standard microprocessor (Motorola 68HC11) that was approximately a decade old and being slowly phased out by its manufacturer. We believed infusion of the course with the concepts described above, a newer processor (68HC12), and using robot technology would greatly improve the course and hence the educational experience of our computer engineering graduates.

To integrate the concepts of competition, quality design, systems design, and interdisciplinary projects into the existing curriculum a dramatic change in the laboratory format was required. We planned on implementing the highly successful robot laboratory concept used by other schools (Trinity College, MIT, and the US Air Force Academy (USAFA)) to provide a highly motivational (fun) laboratory experience to seamlessly incorporate these concepts. We used the USAFA plan as a guide. At USAFA, students learn the fundamentals of microprocessors in a course very similar to EE4390. They also use the 68HC11 as the target microcontroller but have converted over to the 68HC12 microcontroller. However, in the laboratory portion of the course the students are provided a basic robot platform the first day of lab. The basic robot platform is equipped with two motor driven wheels, three sets of infrared emitter/detector pairs and a microcontroller. In the laboratory exercises, the students equip the robot platforms with the capability to sense walls, make decisions to navigate within an unknown maze, and to propel the robot about. Fundamentally, the concepts used and learned in the laboratory exercises at USAFA are virtually identical to those at UW. However, the concepts are taught using a motivational, robot platform. Rather than unrelated laboratory exercises, all exercises provide related functional capabilities for the robot system. At the completion of the course, the robots are placed in an unknown maze. The robots start at the same location within the maze and then proceed through the maze and out an exit door. The robot must sense, navigate, and propel its way through the maze. The winning robot is the one that proceeds through the maze in the shortest amount of time. A penalty is assessed every time the robot bumps into maze walls. The student who wins the competition has their name put on a permanent plaque within the department.

The concepts of competition, quality design, system design, and interdisciplinary projects are inherent within the structure of the course and the maze competition. The maze competition brings out the competitive nature and pride within the students which results in improved project quality. Students also learn the importance of quality software design since poorly executed robot software leaves the robot foundering through the maze and results in a dismal navigation score. The concept of system design is also inherent in the robot project. Each laboratory exercise provides the robot with a new skill. When a new skill is added, its impact on existing skills must be considered as well as incorporating the skill into the existing software system. Finally, the students must consider the mechanical aspects of their robot. A trade-off analysis must be performed on how fast to propel the robot through the maze to minimize navigation time and avoid wall collisions. This requires the students to carefully consider the range of their infrared emitter/detector pairs, the characteristics of the drive motors, and the mechanical characteristics of the robot—an interdisciplinary problem.

**Why not a commercial system?**
We investigated commercially available microprocessor-based trainer systems and commercially available robots. The features we desired were not available. We also thought that we could custom design and fabricate these teaching aids in house at a lower cost.

## Proposed Solution – Phase I

**Prototype development:** To implement the laboratory improvements we divided the project into two phases. The goal of Phase I was to design, fabricate, test, and manufacturer a 68HC12 based teaching platform. The platform would be based on the commercially available 68HC12 A4 evaluation board (EVB).

The EVB was chosen because it is equipped with:

- An RS-232 compatible interface for a host PC,
- A large random access memory (16K) suitable for a laboratory environment, and
- A representative collection of microprocessor-based subsystems. These subsystems include:
    - Asynchronous Serial Communication Interface (SCI),
    - Synchronous Serial Peripheral Interface (SPI),
    - Analog-to-Digital Converter Subsystem (ATD),
    - Timer System (TIM) with input capture, output compare, and pulse accumulation features, and a
    - Powerful, yet flexible Interrupt System.

As previously mentioned, senior design students Abbie Wells and Carrie Hernandez chose this as their project. These students met with the microprocessor course instructors (sfb, jc) to establish requirements for the trainer as well as a list of deliverables for the project. The trainer would consist of a self-contained platform with a resident power supply. The platform would include the "A4" EVB with an attached daughter card. The daughter card would have a dedicated Liquid Crystal Display (LCD), hexadecimal keypad, dual in line package (DIP) switches, light emitting diode displays, and multiple power supply voltages (+/- 5 VDC and +/- 12 VDC). Furthermore, the EVB would be jumpered to the daughter card via ribbon cables. Finally, the daughter card would provide access to the pins on the 68HC12 A4 processor on the EVB card. A conceptual diagram of the training platform is provided in Figure 1.

The student team agreed to design and deliver a prototype platform with six accompanying laboratory exercises. The laboratory exercises would consist of the laboratory student handout and a solution for each laboratory. The six laboratories would be developed in the following areas:

- Introduction to the Teaching Platform and Binary Arithmetic
- Serial Communication Interface
- Analog-to-Digital Converter
- Timer System – Input Capture and Output Compare

- Interrupt System
- Serial Peripheral Interface

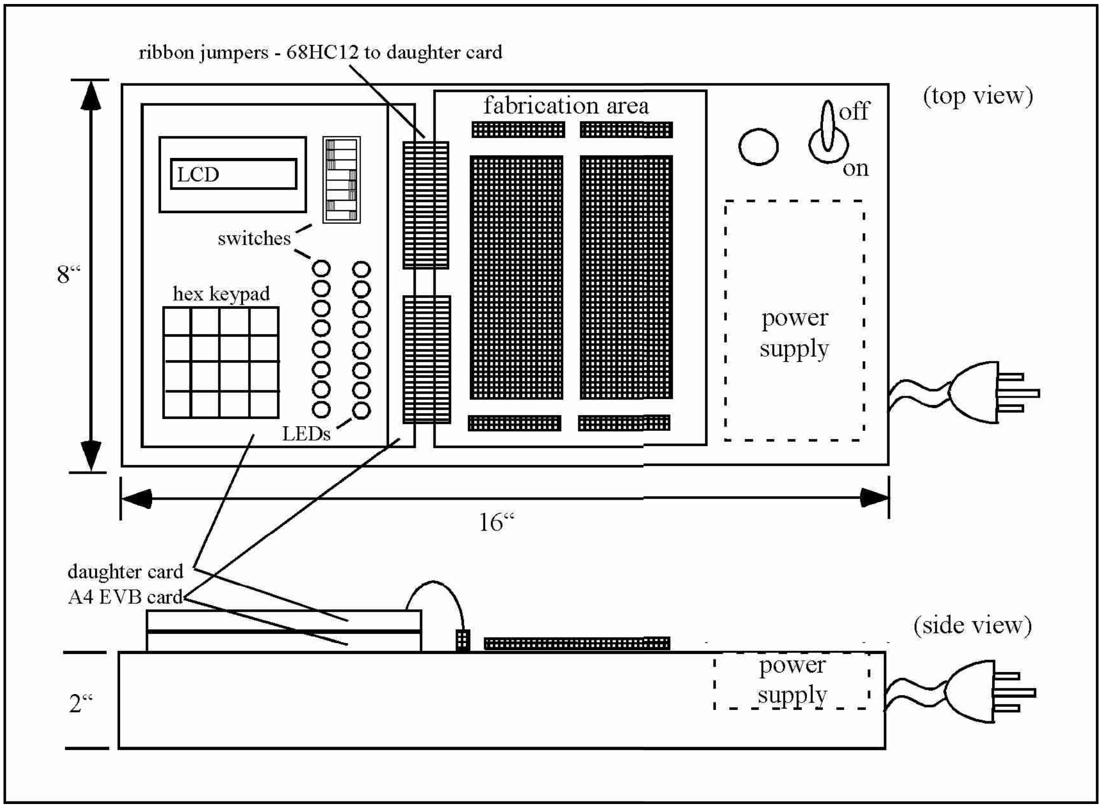


Figure 1. Conceptual Diagram of the 68HC12 Training Platform

A picture of their prototype is provided at Figure 2.

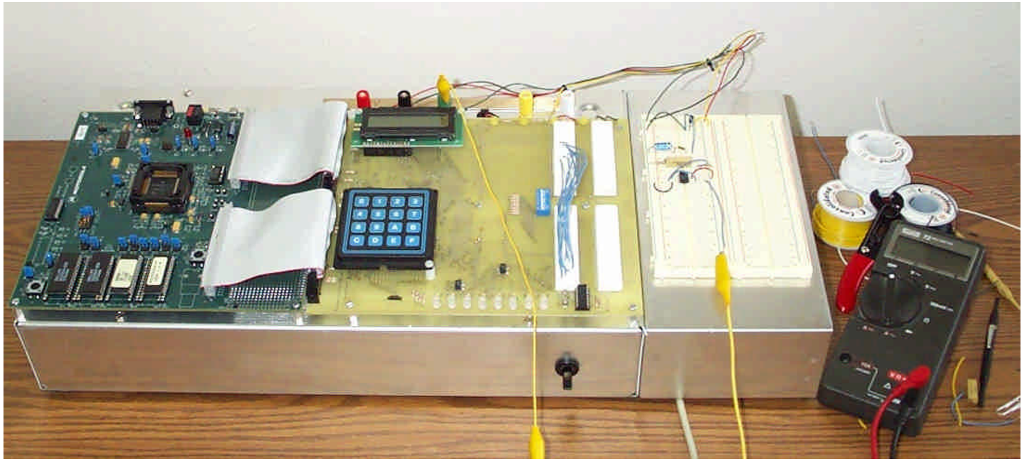

Figure 2. Teaching platform prototype.

The Motorola 68HC12A4EVB card is on the left side of the trainer. The pins of the 68HC12 processor are connected to the daughter card via two 60-pin ribbon connectors. The daughter card hosts a Liquid Crystal Display (LCD), hexadecimal keypad, DIP switches, light-emitting diodes, and four terminal connectors. The terminal connectors (white connectors on right edge of daughter card) provide access to the 68HC12 processor pins. The terminal connectors are connected to the 60 pin jumper cables via printed circuit board traces on the bottom of the daughter card. The "A4" card and the daughter card share a common chassis. The chassis contains a power supply with +/- 5VDC and +/-12 VDC outputs. A prototype area consisting of a protoboard was mounted on a separate chassis. This allows students to fabricate laboratory exercise associated hardware and then connect to the 68HC12.

The student design team completed the project on time. From the faculty's point of view, the students learned to:

- Work in a team environment,
- Work closely with both electronic and mechanical highly-skilled technicians,
- Specify and order parts within a tight budget,
- Construct a prototype including PCB fabrication, soldering, chassis wiring, chassis layout and fabrication, subsystem testing, and integration testing,
- Apply product safety and reliability guidelines, and
- Develop student-oriented curriculum.

Several weeks after completion of the project, the primary author (sfb) sent e-mail to Abbie and Carrie and requested their candid comments about the project. This is what they said.

**From Abbie Wells:**

"The HC12 Teaching Platform project required effort from every member of the team. Without teamwork, a successful platform would not have been possible. Teamwork was required to develop the initial goals and strategies for the Platform. Carrie and I brought a student perspective while Dr. Barrett and Dr. Cupal contributed their years of experience teaching students in a lab setting. Together we developed a plan that resulted in a Platform that in many ways did not resemble the original design conception but was a more complete, better-designed project.

The Teaching Platform project also required flexibility. The design seemed to be constantly changing as new improvements were considered. The changes were then passed on to the shop where the technicians had to implement them into the layout which was already in progress. The technicians were wonderful to work with and always found a way to get our newest changes implemented. Patience was necessary on our part because the technicians were working on several other projects at the same time and could not always get our changes finished as soon as we would have hoped. By working closely with them and Dr. Barrett, we were able to obtain a completed board that with a few minor problems (LED's in backwards and a couple of shorts) which was fully functional after the first build.

Testing the board was probably one of the more difficult portions of the project. We were pressed for time because of when the board was actually built. We also were not always sure what we were seeing was expected behavior or an anomaly because this was the first time either of us were the designers and testers of a board. It was rewarding to see something we had worked on from the beginning actually function.

The project taught me more than just Electrical Engineering skills. I learned about the surprising number of changes a project will go through from conception to completion. Teamwork is important and patience is a virtue when trying to convince technicians that you need your project to have priority. I learned that economics is a class I should have taken. I learned that designing a student lab (equipment or exercises) is not as easy as it may seem. Most of all, I learned that working on a project like this can be fun and rewarding."

**From Carrie Hernandez:**

"When I began working on my senior design project I discovered that this design was going to be unlike any other assignment. First, my part in this project was mostly an individual effort. I planned on just making my component compatible with the rest and that was it. After a few months of planning, the decision was made to combine both my efforts and that of Abbie Wells in order to more efficiently create the HC12 teaching platform. This was the first of many challenges faced in Senior Design.

Creating a design that will be used, not once (and just at a demonstration), but many, many times was particularly challenging. Creating a design that will be "manufactured" at least 15 times is also a challenge. Both of these conditions changed my approach to what I had assumed about design prior to my senior year. The other students in the class really only had to consider their own projects' ability to work, and whatever modifications or choices they made could be as simple or complex as they needed. With every decision on the platform, more than just the immediate future had to be considered. Could students drop books on the platform and have it survive? If I placed the keypad somewhere strange on the board, would that be a complaint heard from students for years to come? Does 50 cents, $1.00 or even $1.50 more per part really matter? All of these questions are really "real world" questions. This design project, unlike all of the assignments done in laboratory and the classroom, simulated what really occurs when working together with a team to meet specifications on a product. I think that this project provided an extremely valuable learning experience for me, and I will never forget it".

## Manufacturing/Implementation:

The prototype teaching platform and accompanying laboratory curriculum was completed in May 2002. It was desired to use the Teaching Platform in the microprocessors course beginning in the Fall 2002 semester. We hired an undergraduate student, Ted Dibble, to perform the fabrication. Ted had just completed the microprocessor course based on the 68HC11 during the Spring 2002 semester. Ted was hired for the project based on his demonstrated work ethic and his enthusiastic approach to challenges.

Again from the faculty point of view, Ted learned many valuable lessons including:

- Fabrication skills including PCB manufacture, drilling, stuffing, soldering, and troubleshooting,
- Chassis fabrication,
- Subsystem integration, testing, and troubleshooting,
- Working with highly skilled machine shop and electrical shop technicians,
- Safety issues,
- Meeting production deadlines, and
- Working around late part deliveries and design changes.

As before, we asked for Ted's comments on the project several weeks after completing the fabrication of the units.

**From Ted Dibble:**

"When Dr. Barrett first outlined the project to me, I was not sure if I had accumulated the technical and engineering knowledge necessary to complete a project so complex. The first day of work, I was given an office, an overview of the project, all the tools and supplies needed in order to complete it, and was told "This is your project Ted, you carry it out how you seem fit". I was alarmed and flattered that I would be given so much responsibility.

Before I worried myself to do death, I sat down in my office and thought about the best way to complete this project. I decided to first read the textbook the student's would be using in the microprocessors class in order to get a feel for what they were learning. Also, I learned the differences between the HC11 and the HC12 (I learned the HC11 the previous semester). Next, I decided to begin testing the first prototype immediately in order to catch any bugs as early as possible. My testing procedure was defined by the laboratory exercises the student's will complete. I worked each laboratory from start to finish to ensure that the students could complete each lab in the allotted time and to gain personal experience with the HC12.

Testing the teaching platforms taught one very important rule: "Don't just test a component once, do it again and again." Before I decided to give the go ahead to the shop technicians to fabricate another PC board, I ran all the labs and discovered a small problem with the keypad. It was a very simple fix but would have caused serious problems with students in the lab.

Dr. Barrett also assigned me the task of writing a lab that used the Serial Communications Interface (SCI). The lab consisted of two parts, each written in assembly language using the ICC12 (ImageCraft) compiler. In the first part, the student outputs a character and views the signal on an oscilloscope. Using a scope, they can see the start/stop bits, the parity bits, and the actual character translated into binary. In the second part, the students will connect their teaching platform to another and transmit an ASCII character to each other. When one lab group receives the character, they decode it and display it on the LED bank. Then the students echoes the same character back and the other lab group outputs the same character to the LED bank.

Interfacing with technicians for this project was a great experience. I needed advice and the expertise of the Engineering Shop and the Electronics shop. The technicians in the Engineering Shop taught me the best way to drill holes in the boxes (i.e. AC plug, fuse, banana plugs) and the best way to mount the PC boards on the box. Most of my work in the engineering shop dealt with a drill press and a nibbler. The technicians in the Electronics Shop taught me how a PC board was created, from start to finish. They taught me how to cut and drill a PC board for feed throughs and components. I also learned how to solder feed throughs and components like resistors and terminal strips to the board. They also showed me the art of making and testing ribbon cables.

Once I had a fully functional design for the Teaching Platform, the shop technicians and I figured out an "assembly line" process for making as many boards as fast as possible. Once technician, Lou, would do the photography, etching, etc. I would cut and drill the board. George, another EE shop technician, would solder and stuff the board and then I would mount, test, and debug the completed boards. Once Lou fabricated a board, George and I could complete about one board a day once we got rolling.

To test a completed board, I simply ran all the lab experiments again. This time I just downloaded the solution into the chip from file instead of working the lab every single time. The only problems I encountered during the testing phase was an occasional solder bridge which I fixed very easily.

I gained a vast amount of knowledge while working on this project. Not only did I learn another processor but also I learned what it was like to be an engineer. I had to organize and manage the project, create a suitable testing procedure, and meet the deadlines. Moreover, I am a few steps ahead of the other students when I take Senior Design because my confidence as an engineer has increased dramatically from completing this project and I know the process for designing and creating printed circuit boards".

**Into the classroom:**

Ted finished the trainers by early August 2002. We began using the trainers in the microprocessor laboratory in early September. Each trainer requires connection to a standard PC host via a serial cable. We purchased the Image Craft ICC12 assembler, compiler, communication software suite for each PC. As of this writing, the first semester of using the Training Platform is approximately complete. Informal, qualitative feedback from students indicate they like using them. It is difficult to provide a comparative analysis since there is no group of students that have used the new trainer and the predecessor instructional aids.

We are working on expanding the basic set of six laboratory exercises written by the students with additional laboratory tasks and new laboratory exercises. Our goal is to have a large library of laboratory exercises to choose from for each offering of the course. We are in the process of adding the following laboratory exercises:

- Adding an RS-232 interface task to the Serial Communications Interface laboratory exercise.
- A motor control laboratory to control the action of a direct current motor using pulse width modulation techniques.
- A motor control laboratory to control the action of a stepper motor.
- A laboratory which measures the gravitational constant using the 68HC12 Timer System. A ball bearing is dropped through a plexiglass tube that has been instrumented with multiple infrared emitter-detector pairs to detect the ball as it passes by. The information gathered can be used to determine the gravitational constant.
- A Global Positioning System (GPS) laboratory. Students will obtain GPS coordinate data from a GPS receiver and display it on a liquid crystal display panel.

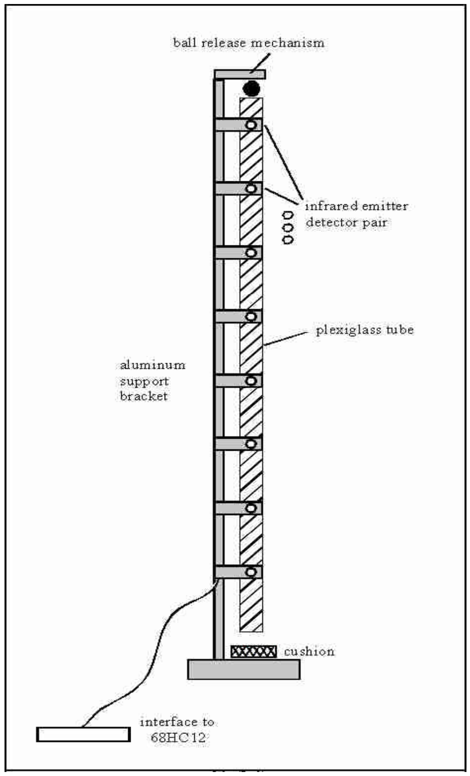


Figure 3. A ball bearing is dropped through a plexiglass tube that has been instrumented to detect the ball passing by.

These new laboratory exercises should be complete by the end of the Spring 2003 semester. Again, undergraduate students will write the laboratory exercise, work the solution, and order any required parts for the exercise.

## Phase II – Implementing the Robot Maze

The goal of Phase II is to implement the use of the robot and the maze in the microprocessor course. A graduate student, Yi Shi, has developed the robot and maze as her thesis topic. The robot has the ability to sense walls and navigate about the maze. Also, the robot has the capability to sense "land mines" in the maze floor. In this case magnets are placed on the bottom of the maze floor out of view of the students. As the robot navigates about the maze it is supposed to detect the presence of a "land mine" and then safely navigate around its position. A Hall Effect sensor is used to detect the presence of the magnet.

Yi Shi completed the microprocessor-based robot navigation system in assembly language. The undergraduate microprocessor course uses both assembly language and C during the semester. Also during her research, Yi Shi discovered the robot encountered certain scenarios where it became "stuck" in the maze.

These findings were passed onto the undergraduate design team of Schei (EE) and Werbelow (ME). Their charter was to design a production model of the robot, incorporate design solutions to issues identified by Yi Shi, and provide an operating system in C. The result of their design effort is provided in Figure 5.

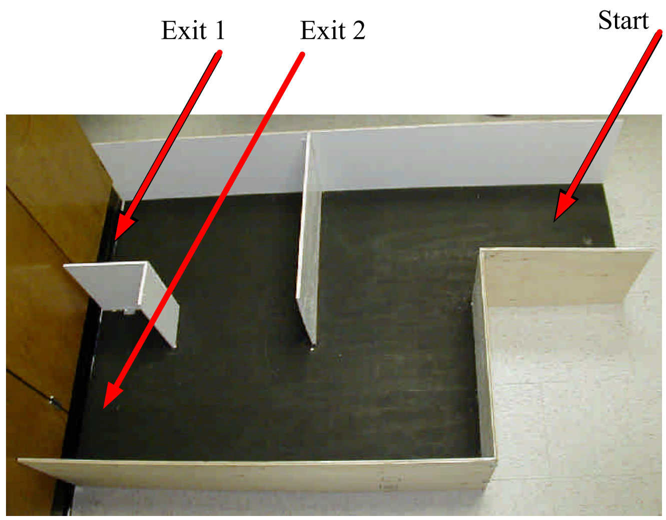


Figure 4. Robot Maze

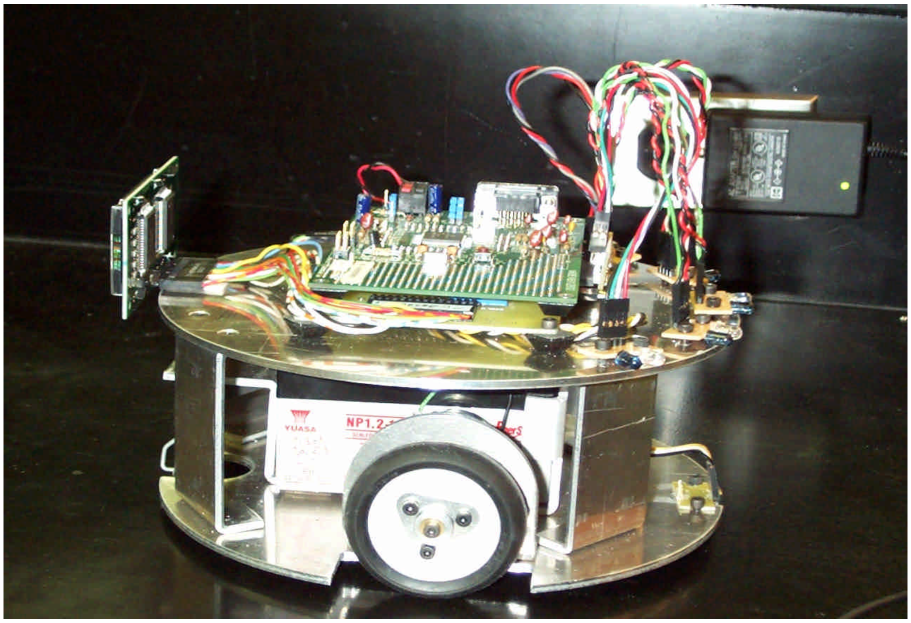

Figure 5. The prototype robot.

**From Tom Schei:**

"The wall following robot project was somewhat difficult from an electrical engineering standpoint. It involved learning how to incorporate mechanical motion with a control algorithm so the robot would avoid walls. Working with a mechanical engineer was helpful in that the robot's body design could be deferred to a person with knowledge about materials, weight, and mechanical design.

Communication was key to the success of this project. We spent hours talking about how to approach the design, where to place the electronics, and how the robot would function. Some communication barriers had to be overcome since both our fields are specialized and we both had to understand how this project was going to come together. Because of our different backgrounds, when we did not communicate efficiently problems arose. For instance, because we each had our own ideas of how our project should look, the infrared sensors were too large for the specifications of the body design so the printed circuit boards had to be resized. Although communication barriers existed and a few revision had to be made, overall we worked well together. A lot of time was devoted to ensuring specifications were met.

To some it all up, the project went fairly well. Due to our work ethic and the numerous conversations that took place during the course of this project we were able to overcome the obstacles we encountered. Although it was an interesting program, I was not impressed with the final results of the teamwork because there were more hassles than benefits."

## Lesson Learned

Throughout the duration of this project, all students involved have learned many valuable lessons. Many of these lessons have already been discussed. A consolidated list is provided here for summary. The opportunity to:

- Work in a team environment,
- Work closely with both electronic and mechanical highly-skilled technicians,
- Specify and order parts within a tight budget,

- Construct a prototype including PCB fabrication, soldering, chassis wiring, chassis layout and fabrication, subsystem testing, and integration testing,
- Apply product safety and reliability guidelines,
- Develop student-oriented curriculum,
- Develop fabrication skills including PCB manufacture, drilling, stuffing, soldering, and troubleshooting,
- Design and fabricate a chassis,
- Perform subsystem integration, testing, and troubleshooting,
- Meeting production deadlines, and
- Work around late part deliveries and design changes.

Aside from these skills the students have gained a tremendous boost in confidence in their ability to perform as a practicing engineer. As faculty we learned it is essential to carefully choose the students to participate in this design exercise. Students must be motivated and excited about the project. The excitement carries over long after the project work is complete. Two of the students that were involved in the design and fabrication of the teaching platform regularly check to see how the platform is working out in the classroom.

One of our initial goals was to save money. So did we save money? No. By the time the teaching platform was complete, the cost of locally fabricating the platform versus commercially purchasing them were quite similar. However, we have custom features tailored to our laboratory program. Also, the experience, boost of confidence, and the lessons learned are priceless.

## Where to from here?

With Phase I complete, and the prototype for Phase II complete, our next goal is to obtain fabrication funds for Phase II. Furthermore, we have been submitting proposals for funding to equip our laboratory with logic analyzers. Within the coming year, we will also begin a second laboratory based course in microprocessors which will cover such topics as memory expansion, timing, real-time operating systems, and other advanced concepts in microcontroller-based systems design. We are also investigating the feasibility of offering the microprocessor course to mechanical engineering students. The required prerequisite material for the course will be offered in optional seminars.

## Summary/Conclusions

In closing, we have declared Phase I a smashing success. We have obtained the desired laboratory equipment and have provided our students with a challenging and meaningful design experience. We highly recommend this approach to other universities and colleges.

If you are interested in any of the developed material, feel free to contact us at steveb@uwyo.edu

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