The Impact of Ownership on Student Performance and Attitudes in a Microcontroller-based Robot Laboratory

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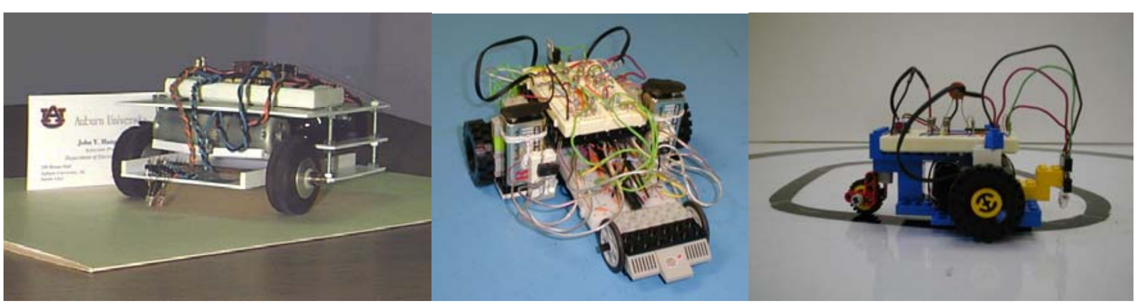
Abstract

Autonomous robots have become extremely popular in undergraduate curricula. Used at every level from cross-discipline freshman experiences to capstone designs, these projects can incorporate almost all aspects of electrical engineering into a single project. At Auburn University, the PICKIT® programmer/evaluation board from Microchip Technology Corporation ($35.00) has been incorporated into our junior-level robot laboratory. Every student team (two members per team) purchases their own PICKIT®, gaining the capability to program, debug and evaluate the MCU either at home via their PC or in the laboratory room. In this work, student surveys and their lab performance are used to rate the impact of this ownership on both laboratory performance and career perspectives.

Introduction

Autonomous robots have become extremely popular with the general public and in undergraduate curricula. Used at every level from cross-discipline freshman experiences [Ahlgren, 1, Schurnacher, 13, Tonkay, 14] to junior-level laboratories [Martin, 9, Mrad, 11, Knight, 8] to capstone designs [Archibald, 3, Ahmad, 2, Crisman, 4], robotics can incorporated almost all aspects of electrical engineering into a single project. The junior level robot laboratory at Auburn University began as mechanical kits with custom electronics built of discrete components [Hung, 6]. Next, kits were replaced with LEGO motors and blocks, adding mechanical design to the project [Hung, 7]. In third generation robots discrete electronics have, with the exception of motor drives and optical sensors, been replaced with an 8-pin PIC® microcontroller. This evolution is depicted in Figure 1.

The appeal of a robot lab is its breadth. Properly structured, it can incorporate all ABET criteria. There is, however, another criterion critical for soon-to-be-seniors: a change in self-perception from student to engineer. In this work, the effectiveness of ownership on both laboratory performance and career perspectives is investigated.



(a) (b) (c)

Figure 1. The evolution of the Auburn University autonomous robot from (a) a mail order kit, circa 1998, (b) to LEGO motors and block, circa 2000, to (c) a microcontroller-based embedded system, circa 2002.

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Ownership at Auburn

Origins

In 1997, the electrical engineering department at Auburn University made a drastic change in the undergraduate laboratory structure [Roppel, 12]. Old course-specific laboratories were replaced with four stand-alone laboratories – two in the sophomore and two in the junior year. A cornerstone of the policy is student ownership of electronics hardware: particularly of inexpensive tools, IC's, wiring and breadboards. Through an arrangement with an on-campus laboratory supply store students may purchase the required hardware at discounted prices.

A Higher Level of Ownership – The PICKIT Eval Board/Programmer

Despite its appeal, the original ownership structure had a major shortcoming. Students could take their hardware home, but, having no diagnostic equipment there, they could not test and verify. Based on studies of courses that incorporate at-home digital hardware experiments, it was believed that adding inexpensive verification tools is the best solution to the problem [Dillard, 5]. In particular, an inexpensive programmer/evaluation board ($35.00) has been incorporated into the robot laboratory. The board, shown in Figure 2, is the PICKIT® from Microchip Technology Corporation [Microchip Technology, 10]. Every student team (two members per team) purchases their own PICKIT®, gaining the capability to program, debug and evaluate their MCU code and embedded system either at home or in the laboratory room.

Creating a Bid-Driven Prototyping Contract

Students take the robot lab in the second semester of their junior year. As these students will soon be job searching, a change in perspective from student to engineer is vital. To encourage this shift in thinking, the robot laboratory has been restructured to mimic the relationship between a company (the instructor) seeking proposals for prototype robotic and bidders (student teams of two) vying for the contract.

Each company has been asked to submit a prototype autonomous robot for an automated warehouse. Their robot must demonstrate that it can follow a prescribed through a virtual warehouse path of orthogonal "streets and avenues", as shown in Figure 3. At the Destination Download Station (DDS) the exact path is transmitted serially to the robot where it is stored in EEPROM. Table 1 lists the 2-bit code corresponding to travel plans at each intersection. After download, the robot is ready to negotiate the warehouse.

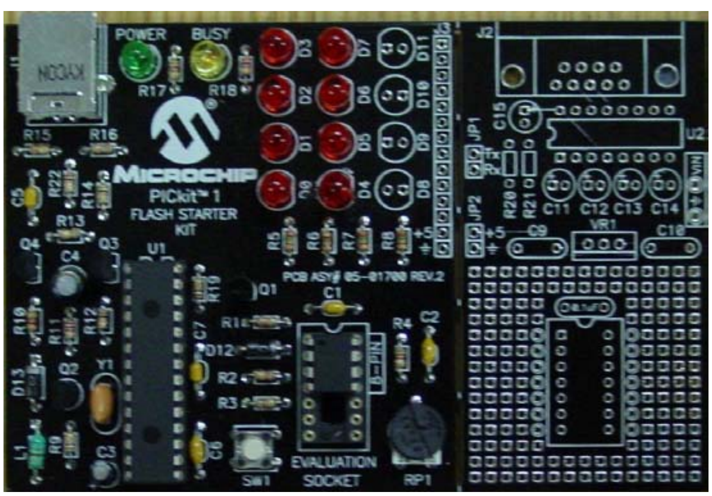

Figure 2. The PICKIT® programmer/evaluation board from Microchip Technology Corporation. The unpopulated area on the right is a serial port interface with PCB wiring for RS-232 protocols.

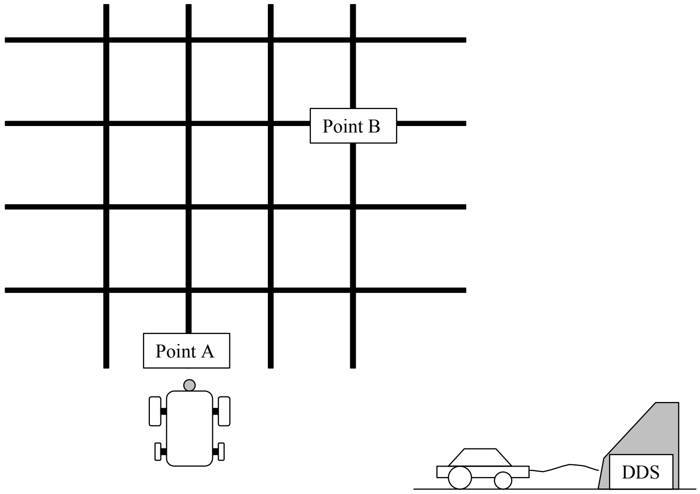

Figure 3. A conceptual diagram of the warehouse grid the robot must negotiate and Destination Download Station where intersection codes are transmitted serially to the MCU EEPROM for non-volatile storage.

Table 1. 2-bit Intersection Codes

Code	Instruction
0 0	Stop
0 1	Turn right
1 0	Turn left
1 1	Go straight

Small Business Emulation

Students form teams of two and operate as a small business creating a prototype robot to meet the instructor's specifications. To emphasize the business environment, each "company" creates a business name and letterhead. Two written progress reports are submitted during the semester with cover letters on the letterhead. An oral presentation at the end of the semester is also format as the final prototype submission. References to academic entities such as Auburn University, the instructor, lab assistants, grading policy, etc., are not allowed. Email correspondence is written in the same spirit.

For the educational aspects of the laboratory, introducing motor drives, optical sensors, microcontroller details and so on, the instructor acts as "interactive technical support", providing technical details, implementation options and references to other resources. However, the lecture environment is avoided as much as possible. Laboratory assistants are in the laboratory room three hours each week to offer advice and to verify Milestone demonstrations. While these machinations are admittedly artificial, it was found that adhering to them strictly greatly enhances their effectiveness at distancing students from a "classroom mentality" towards a "creative design mentality" where verifying ***THEIR OWN*** designs drives their effort and resolve.

Milestones, Design of Experiments and Project Management

A major issue for this new lab structure is maintaining the desired entrepreneurial spirit while teaching embedded system concepts. To accomplish this, Milestones were used as opposed to traditional assignments. For fall semester 2003, the Milestones in Table 2 were used. Each Milestone is designed to teach either programming skills such as interrupt management, I/O interfacing, analog-to-digital converter performance, serial transfer protocols, EEPROM storage and PWM coding; or hardware design and implementation for sensors and motor drives. Meeting the Milestones provides the code and subcircuits needed to implement the final design.

Glaring and intentional omissions from the Milestone requirements are the intermediate code snippets and the experimental verification protocol that would make meeting a new Milestone each week easier. For example, Milestone 1 requires reading a button status on an input pin and driving four output pins appropriately. This Milestone should be divided into three coding pieces: output driving, button polling, and debounce. Each code snippet can be verified before being combined to yield the final code. While the instructor preaches the benefits of this approach, the actual design of the experiments leading to meeting each Milestone is left to the student team.

To introduce students to realistic project management and timeline predictions, each team completes and submits the Milestone Timeline listed in Table 3. Each Milestone has a two-week window for demonstrating performance. Points are awarded with emphasis on meeting the deadline more so than on scheduling the demonstration early in the window. Teams that aggressively schedule early demonstrations but cannot meet them are not rewarded for their ambition. Such a practice in industry would frustrate supervisors since they cannot rely on their subordinate's predictions when mapping larger schedules. Similarly, teams that schedule late demonstrations and complete them excessively early are also exhibiting poor project management. The same supervisor now has a long-term timeline that is being unnecessarily delayed by over-conservative estimates from subordinates.

Table 2. The Milestone Table

Milestone Topic	Milestone Demonstration
I/O Management	Read an input pin to turn on LED's 1 to 4 successively
Interrupts	Use the interrupt input pin on the PIC to toggle a single LED
Optics	Design an IR optic system capable of distinguishing black electrical tape from the floor
ADC	Write code for ADC using the PICKIT potentiometer and LED's for I/O
Motor drive	Demonstrate the motor drive you plan to use for your robot
PWM	Demonstrate a 3-level PWM output using the ADC to read an input signal
EEPROM	Demonstrate that you can write to and read from the EEPROM
Serial Comm.	Write code to download intersection codes from the DDS and store in EEPROM
Track tape	Show that your robot can track accurately on straight lines
Intersections	Negotiate each of the intersection commands: STOP, GO, RIGHT and LEFT
Full Demo	Download path at DDS and complete entire path without error

Table 3. The Milestone Matrix

Set Date	Demo Date	Points	Set Date	Demo Date	Points
Week A	Week A or earlier	3	Week B	Week B or earlier	2.5
	Week B	2		Week C	1
	Week C	1		Later	0.5
	Later	0.5	Week C	Week C	1.5
				Later	0.5

Assessments

Two surveys have been used for assessing the success of PICKIT ownership and the Milestones on impacting student's perspectives of their careers.

Preparedness

The questions below address the student's preparedness for an embedded systems robot design. Responses are numerical ranging from 1 to 5 with 1 designating strong disagreement and 5 denoting strong agreement.

> Listed below are several preparatory areas that can be beneficial in this course. Your exposure might have been through coursework, hobby activities, or work experience. Using a 1 – 5 scale please rate your experience level.
>
> 1. Assembly language
>
> 2. High-level languages (C, Basic, Fortran, Ada, etc.)
>
> 3. Programmable Applications (Excel, Access, MATLAB, etc.)
>
> Rate on a scale of 1 (no experience) to 5 (well versed) your background in:
>
> 4. Constructing circuits from preexisting diagrams.
>
> 5. Constructing your own designs.

Responses to questions 1 to 3 show a preference for high-level languages like C, Basic and MATLAB over assembly language. While this is not surprising, it is disappointing in that all MCU programming for the robot is done in assembly. In question 1, only 1 out of 10 respondents rated their skills at 4 or 5 while half rated themselves at less than 3.

In questions 4 and 5, students reported a higher level of comfort when constructing circuits from preexisting diagrams (mean of 4.45 out of 5) as compared to their own designs (3.25 out of 5). This was expected, but the differential mean of 1.2 was lower than expected, indicating that the design content of the four-lab sequence is having the desired impact.

Awareness

A selection of short response and essay questions address the student's opinions on their careers and how their academic pursuits are helping them meet their goals.

6. I cannot see any connection between my coursework and my career.

7. I have no clear idea of the daily activities of engineers.

8. I know what branch of electrical engineering I want to pursue in my career.

9. I often think about my career and how I can prepare for it.

10. I have a clear idea of the skills I must master to have the career I want.

11. I know which classes in my curriculum will provide the skills I need.

12. My studying is geared more for my GPA than my understanding of the material.

Responses to these questions were particularly encouraging. The mean response to question 6, which assesses the academic-career connection, was 2.43 with most responses at 1 and 2 (a single 4 raised the mean). The mean response to question 7, knowledge of what engineers actually do, was 2.00 with no responses above 3. In questions 8 – 11, only 10% of respondents' average response was less than 4.0, indicating that a career plan is in effect. Question 12, the motivation for studying, showed a strong and even split between GPA and mastery of material. Given the emphasis job recruiters and graduate schools place on GPA, it is difficult to fault that perspective. However, we recommend that instructors revisit their class assignments, particularly homeworks and projects, to see if a synergy between mastery and GPA can be obtained and demonstrated to the student.

The Impact of Ownership

Questions 13 to 22 assess the impact of ownership over a two-year, four-semester laboratory sequence, with focus on the PICKIT® system.

13. Over the past 4 labs, I have, for the most part, enjoyed designing my own circuits.

14. My lab experiences have been less about engineering skills and more about completing assignments.

15. How has our laboratory structure helped prepare you for entering your job market?

16. Engineers "build stuff". Students attracted to engineering generally like to "build stuff" too. Do you fit that mold? Given your disposition, what is you opinion of our ownership-oriented lab program?

17. Question 14 is the crux of the entire laboratory sequence. If your response was a 3 or above, please offer suggestions on what can be done to correct this situation.

18. Because I own my hardware, I have thought of some independent projects I would like to build.

19. I have built some projects outside of the laboratories using my hardware.

20. Ownership has affected my thinking from "student preparing for tests" to an "engineer in training".

21. Owning a programmer and a MCU, I have thought of applications I would like to build on my own.

22. I plan to use my PICKIT® system in either my senior design or extracurricular projects.

Responses to question 13 show a high level of satisfaction with the design content of the laboratories: mean of 3.71 with a single low score of 2. Given that laboratories can be very time intensive per credit hour awarded, this outcome is comforting. For question 14, there is strong parallelism and correlation to question 12. Respondents who pursue a GPA tend to view labs as assignments while students working toward mastery see the laboratory as a chance to experiment and verify.

In question 15, students found the emphasis on teamwork and oral/written communication skills (50% of all respondents) to be the best career preparation component of the laboratory structure. Each of these respondents have plans for engineering managements and already recognize the importance of these skills. Student responses to question 16 were overwhelmingly supportive of the ownership oriented lab structure. In particular, owning the PICKIT® system was highly recommended since they could verify code and hardware at home.

Question 17 generated a wide range of responses from better equipment to more credit hours per lab. The most common complaint was a poor connection between the exercises in the early labs and real-world scenarios. This supports our original proposal that a laboratory driven by Milestones and structured around a commercial endeavor, even if contrived, can be a superior laboratory format.

The impact of 2 years of ownership on extracurricular projects is gauged in questions 18 – 22. A mean score of 3.43 on question 18 coupled with a mean of 1.14 on question 19 indicate that students have some ideas for projects but no one is actually building them. Focusing on the PICKIT® and the robot lab structure, the mean response to question 21was 3.57. While this is an improvement over the 3.43 score for question 18, this issue will be addressed by introducing students to the extensive list of application notes and projects on the Microchip webpage. The mean response to question 20 was a disappointing 3.29 with a low score of 2 and a high of 5. However, as discussed in questions 8 – 11, the vast majority of the students already have a career plan in effect, which may account for the low score in question 20.

Finally, responses to question 22 spanned the full range from 1 to 5 with a mean of 3.43. All students scoring 4 – 5 explicitly mentioned that they like having their own programmer at home for these activities, while students scoring less than 3 generally showed no interest in embedded systems at all.

Conclusions

A microcontroller-based autonomous robot laboratory for junior-level electrical engineering students has been restructured around the availability of the PICKIT® programmer/evaluation board from Microchip Technology Corporation. The new structure emphasizes project management, design of experiments, and creativity of design by shifting the traditional instructor/student roles to those of grantee/contractor in a robot prototype bid contest. Based on student surveys and interviews, this emulation of a small business arrangement has made them appreciate the nature of organizing a multi-task project and has given them confidence that these skills will translate to the workplace.

These new roles also support a change from assignments where deadlines set by the instructor to Milestones whose demonstration dates are chosen by the contractors. While the Milestones are chosen to help students accumulate the knowledge, code and hardware needed to complete the entire project, each Milestone is complex enough to require subdivision into easily testable code snippets and subcircuits. These “design of experiment” issues are left to the students to consider. Early in the semester, students tended to jump directly from the Milestone description to complete code with disastrous results – particularly inefficient coding and poor use of MCU resources. As the semester progresses, and Milestones become more demanding, students are much more motivated to use a methodical approach based on subsystem verification.

On a broader scale, the impact of Auburn’s two-year laboratory sequence was evaluated. During these four laboratories, students accumulate low cost components, breadboards, meters, etc. as they perform experiments week to week. Since students construct their own circuits for lab, there is tremendous latitude for design content. Surveys show that students understand the advantage of such a laboratory structure and feel that it will benefit them when interviewing and on the job. However, students are doing very few extracurricular projects now with the parts they have collected. This will be addressed by emphasizing the extensive set of application notes and project descriptions on the Microchip website and other URLs.

The same surveys indicate that ownership as it currently exists in the laboratory structure has made some impression on the students' career awareness, but the impact is not substantial. The data indicate that these junior-level students are already very career conscientious. Future studies will gauge the impact of the PICKIT® in a sophomore level class on assembly programming. Since these younger students will generally be less career focused, the impact of owning a microcontroller and programmer may be more fairly evaluated.

Based on the full scope of this work, it is recommended that undergraduate laboratories rely on ownership of inexpensive equipment and components to provide design content that is ***AS STRONGLY RELATED TO REAL-WORLD APPLICATIONS AS POSSIBLE***. For laboratories that can be formatted as a single major project (or no more than two smaller projects), a milestone-driven approach that stresses project management is also recommended.

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