Robotics in Introduction to Electrical and Computer Engineering at the Virginia Military Institute

David L. Livingston, James C. Squire
Virginia Military Institute

Abstract

Increasingly universities are adopting a robotics-centric approach to teach their freshmen Introduction to Electrical Engineering: 23% of this year's top-rated engineering schools with an introductory course incorporate a significant amount of robotics into their curricula. Besides teaching concepts from analog, digital, control, and programming courses, students find robots inherently appealing – an important attribute in this national climate of decreasing engineering enrollment. Published data indicate universities tend to either have students build prepackaged robot kits, which stress programming skills, or less commonly have students design their own from discrete components, which stresses interdisciplinary (e.g. mechanical) design and team collaboration. In this paper we describe an intermediate approach we have taken at the Virginia Military Institute. Our students begin with a pre-built mobile base, and then using discrete parts they breadboard a controller, the sensor arrays, and control electronics. In this manner we concentrate on core electrical engineering topics: basic analog and digital circuitry, computer architecture, and machine-level programming, while providing some controlled opportunities for students to make design choices and experiment with the open-architecture system.

I. Introduction

There is a clear national trend towards the adoption of robotics as an aid to teaching undergraduate electrical engineering courses in general, and introductory courses in particular. In 1990, less than 1% of the ASEE conference abstracts dealt with robotics in undergraduate education; this rose to 10% in 2000 and 12% in 2001. Today, 23% of the top-rated electrical engineering schools [1] with introductory courses either are entirely robotics-centric or else use them in a major block of instruction, versus 0% in 1990. This emphasis on using robotics as a learning tool for introductory courses extends to other disciplines as well, such as in aerospace engineering [2], mechanical engineering [3], computer engineering [4], and even in pre-engineering high school courses [5].

There are several reasons for the increasing popularity of robotics in introductory courses. Undeniably freshmen find them fascinating; questionnaires distributed following our introductory course are laced with comments such as "loved building the modules [that ultimately produced] a robot," "this is why I became an EE major," and the more succinct "cool robot." Students also desire to share their interest with non-engineering peers and parents, and find that unlike other more abstract classes it is straightforward to communicate what they are learning in a robotics-centric curriculum. We frequently have students request to show their visiting parents the robotics lab; I have never had a similar request to open the controls lab! Instructors like using robots in introductory courses because with one device they can discuss many major electrical engineering subdisciplines (analog, digital, controls, programming, computer architecture), provide an introduction to the most important test instruments (DMM, oscilloscope, logic probe) and construction techniques (soldered/solderless breadboards, use of test points, removable wiring headers), and also address EC2000 criteria such as teamwork and interdisciplinary collaboration that are difficult to teach in a traditional introductory course.

Two central approaches to teaching robotics-centric introductory courses

The many disciplines involved in robot-building make it challenging to create a reasonable balance among subject areas, and to simply find time to address everything in a single-semester course. In particular, even simple mechanical bases and drivetrains can take significant time to design and fabricate. While developing the Introduction to Electrical and Computer Engineering course at VMI, we discovered that there are two basic approaches universities employ to surmount this problem, and the choice of this approach deeply impacts the manner in which the entire course is taught. Forty high-ranked electrical engineering schools were surveyed [1]. Two-thirds of those programs with undergraduate robotics-centric programs use commercially-available robotics kits. This approach permits a carefully-organized modularized method of teaching that prevents less-skilled students from lagging behind. It is possible to find kits with a variety of interesting sensors that can spark the imagination, and little supervision is required while building the kit. Because the mechanical engineering problems have been pre-solved, this approach also allows concentration on the electrical engineering concepts. Unfortunately, the electrical hardware problems have also been pre-solved, which makes it more difficult to integrate design experiences and by extension does not foster intimacy with debugging instruments. Several universities use the Graymark Model 603A Programmable Robot which is relatively inexpensive ($50 each, and usually built by teams of 2-3 students) and can be used with an excellent text [6] developed by Carnegie Mellon or with an online course developed by the City University of New York [7]. Unfortunately, long-term availability of kits are not guaranteed.

A fundamentally different "roll-your-own" approach is used by the remaining third of universities, and requires students to design every component of their team's robot. This emphasis on design encourages the deep understanding that comes with making and debugging mistakes, and confers the pride associated with creating a unique product. Larger teams of 6-8 students are typically used with this method, which fosters teamwork and development of project management competence [8] in addition to core engineering skills. The larger teams are required to prevent onerous time requirements, but this division of labor discourages all members from learning equally. Unskilled project managers increase the likelihood that less-capable teams fall seriously behind. Also, time spent developing the mechanical base takes time away from electrical engineering topics, although some universities have mitigated this by using modular building blocks such as Lego® or Fischer-Technik® bricks [9].

At VMI we have developed an intermediate approach. We use a custom mechanical base designed specifically for the course and reused each year (Figure 1). The robot is functionally divided into week-long teaching blocks culminating in a small task (e.g. design a 27 Hz clock for the digital state-controller using a CMOS 555 timer) which the students must design, build, debug, and assemble into their robot. This maintains a constant emphasis on design while the modular manner of instruction prevents teams from falling behind, eliminates concerns over future availability of kit bases while not requiring students to spend large amounts of time to design their own, and provides students the latitude to solve many problems for themselves while introducing other problems that students are advised cannot be adequately resolved until future courses are taken. In these cases, the future courses are identified by name and semester which helps familiarize the students with the entire four-year engineering curriculum.

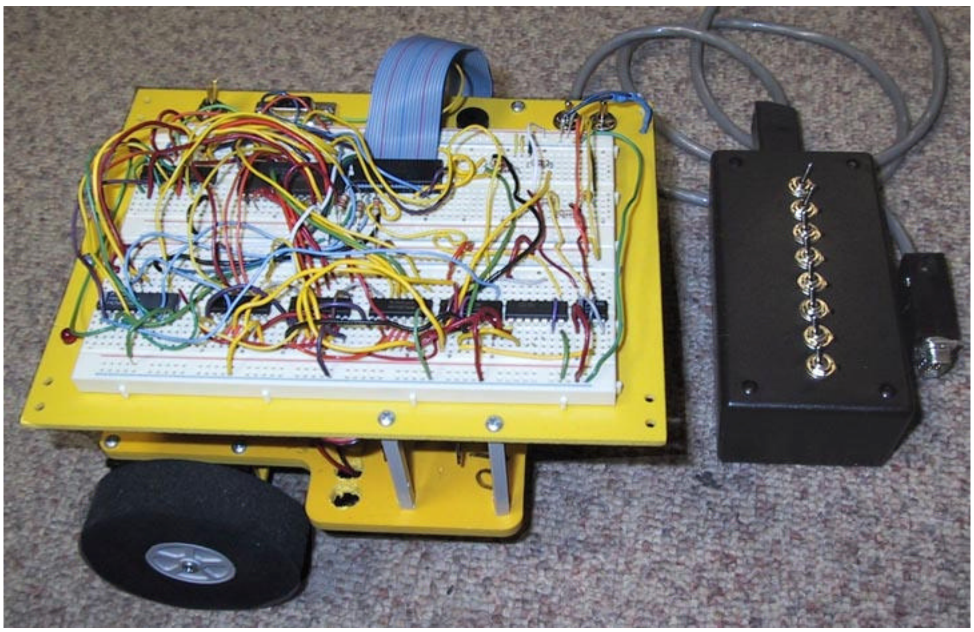

Figure 1: The custom robot base used at VMI. Students add soldered PC boards that they assemble (e.g. an H-bridge motor controller and contact sensors) to the frame, and build the digital logic on the supplied solderless protoboard. The teaching pendent used for programming is shown to the right.

II. Course Implementation

EE 101, Introduction to Electrical Engineering, is a two credit-hour course - one lecture hour and one lab hour - presented over 14 weeks. There is no text; all material is presented using lecture and lab notes. There are no tests or final exams. Student evaluation is performed via individual homework assignments, team lab assignments, and a team project.

The laboratory has six stations each consisting of a computer, an oscilloscope, a bench-top digital multimeter, a hand-held digital multimeter, a logic probe, a 32-channel logic analyzer, and an analog/digital electronics trainer. Two separate stations with soldering irons, mechanical tools, vices, etc., are set up for project assembly. There are also twelve computer workstations for general purpose computing tasks. The lab is open during the day and evenings and is monitored for security in the evenings. There is no structured academic assistance other than during class time.

The explicit objectives of EE 101 are to provide a broad exposure of electrical and computer engineering topics to freshman ECE students and to help those students develop interests in some of the practical aspects of the ECE curriculum. Many of today's students entering the ECE program have little experience with the various facets of electrical and computer engineering. They haven't "diddled" with electronics or programmed computers as their predecessors have. Thus, they lack the practical experience that leads to the "cool, so that's why" moments when presented theory explains why a device or system acts the way it does. The current version of EE 101 was designed to provide them with this missing piece in their backgrounds. Its focus is on the *use* of discrete and integrated analog and digital circuits without significant attention to the theoretical details that are presented in successive courses. Along the way, there is a brief introduction to computer tools such as schematic capture and spreadsheets as well as discussions of professional issues such as ethics and licensing.

The primary vehicle for attaining the objectives of EE 101 is the mobile robot shown in Figure 1. Class lectures and subsequent lab exercises have been designed to introduce subsystems of the robot controller. Students learn about a subsystem in the lecture, perform a lab experiment on the subsystem in the laboratory, and then later incorporate the subsystem into the robot controller. This procedure is based on the work by Carley and Khosla [6]. Whereas they use a commercial robot kit, the EE 101 robot uses a custom base inspired by the Lynxmotion Carpet Rover 1. An H bridge was chosen to drive the motors rather than pulse-width modulated servomotors for reasons of simplicity and so that the base can be used for other fundamentals courses. A platform attaches to the base which includes a solderless breadboard, one power switch, two general purpose switches, four momentary microswitches, two LEDs, one buzzer, and one DB-9 connector. The heart, or more accurately the brain, of the robot is the controller. It was designed around the concept of microprogrammed control, in that control states are stored in SRAM and are "played-back" via a simple counter-based sequencer.

To operate the robot, students connect a pendant – consisting of seven toggle switches in a plastic box – to the robot via a cable and DB-9 connectors. The robot is then placed in "program mode." As switches are operated, two things happen: one, the switch combinations cause appropriate robot actions such as turn-on left motor, and two, the combinations are stored in the SRAM. After programming the robot behavior, the pendant is removed and the robot is placed in "run mode." At this point, the robot behaves in an apparently autonomous manner, recalling the behaviors that were programmed into it.

The controller is implemented using discrete components, small- and medium-scale logic devices, and an 8K x 8 SRAM. Discrete devices are used rather than highly-integrated devices such as microcontrollers because discrete devices are more "tangible," i.e., less abstract and are therefore easier to introduce to the novice ECE student.

The project is easily partitioned into blocks which can be theoretically described in lectures and practically explored in lab exercises. Details including notes, labs, and controller schematics can be found at http://academics.vmi.edu/ee/ee 101/ee 101.html (note the spaces after both ee's).

III. Results and Analysis

Students appeared more alert and enthusiastic in the introduction to electrical engineering course that used a robotics-centric approach than in past years that used a more traditional pedagogical method with unrelated labs (e.g. a class on Kirchoff's Voltage Law followed by a lab in which students constructed a resistive network and compared experimentally-measured with theoretic results). We sought to quantify changes in the educational experience using student survey data that measured both enjoyment (Figure 2) and student-perceived course utility (Figure 3). The surveys were conducted shortly after the completion of the course and were anonymous. Error bars measure the standard error of the mean, and significance was tested using an unpaired two-tailed equal-variance Student-t criteria. All differences were shown to be significant at $p \leq 0.05$ except the applied-to-theoretic rating ($p=0.08$).

Students reported the robotics-centric method was more fun, yet paradoxically also more difficult and time-intensive than students who took the traditional introductory course. We estimate the actual hours required to be approximately the same for both courses and suspect that the student perception arises because the design laboratories demanded more time spent in the higher categories of Bloom's Taxonomy of Educational Objectives than the cookbook-style labs.

Students reported a heightened sense of relevance of the robotics course to their professional lives, both in industry and academia (Figure 3). They also felt that the robotics-oriented course was more theoretic and less applied than students who took the traditional introductory course, a conclusion that professors who have taught both find clearly erroneous. We believe this artifact is the result of prior expectations of the students. Since this is their first engineering course and is taken in their first semester, students in the traditional courses expect it to be difficult and possibly calculus-based, and are relieved to discover that only 10^{th} grade algebra is required to understand the concepts. Students who take the robotics course, however, arrive with expectations of putting together a robot kit and are surprised to discover that much of their time is spent understanding abstract concepts and discovering the difficulty in solving under-constrained design problems.

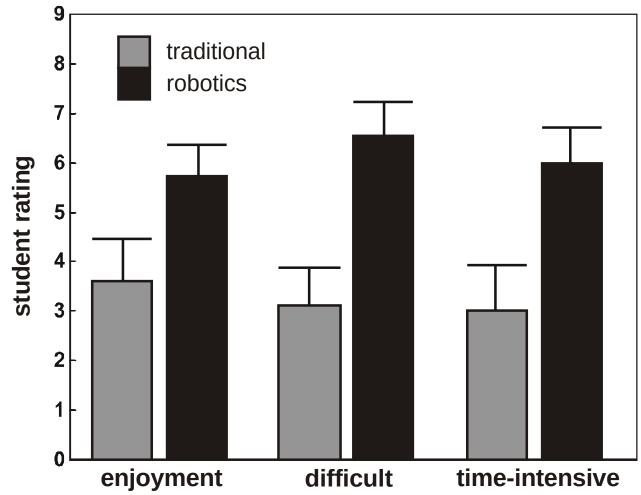

Figure 2: Student self-evaluations of enjoyment, difficulty, and time requirements of *Introduction to Electrical Engineering*, both before and after making the course robot-centric.

Students showed a statistically-significant bias towards preferring the robotics-oriented course (p=0.05), and although this was reflected in a lower first-semester dropout rate the statistical correlation is not as strong (p=0.23). A weaker correlation is expected since perception of the introduction to engineering course is only one factor in students' decision to change majors or leave the school. We have observed common confounding variables include performance in the calculus sequence, financial, and home issues; other universities report similar findings [10].

We believe the increased student engagement is caused by the fact that the robotics-base curriculum addresses a wide variety of student learning styles. One of the most common categorization of learning styles is defined in references 11, 12, 13 and recognizes a dichotomy between learners that are primarily sensory vs. intuitive, visual vs. verbal, active vs. reflective, and sequential vs. global. Sensory learners naturally respond well to the laboratory portion of the course, while the intuitors delight in figuring out how the modules presented can be extended into more complex systems. Visual learners integrate concepts well while viewing the parts, schematics, and plots in the classroom and labs, however since we do not yet have a primary text verbal learners must rely primarily on classroom lectures, and class/laboratory notes. Since 80% of students are visual learners but 90-95% of traditional course content is verbal/text-based [14] this is an improvement although a single cohesive course text would help the minority of verbal learners. Laboratory construction work balances the design homework and project reports for active and reflective learners. The vast majority of students are sequential [14], and their learning style naturally agrees with the modular nature of class instruction. Global learners can view the overall schematics and plans from the start of the course; although they do not know enough to process this information yet, the weekly modular nature of the course prevents them from falling seriously behind and prods them towards that "eureka" moment when they suddenly understand how the elements combine.

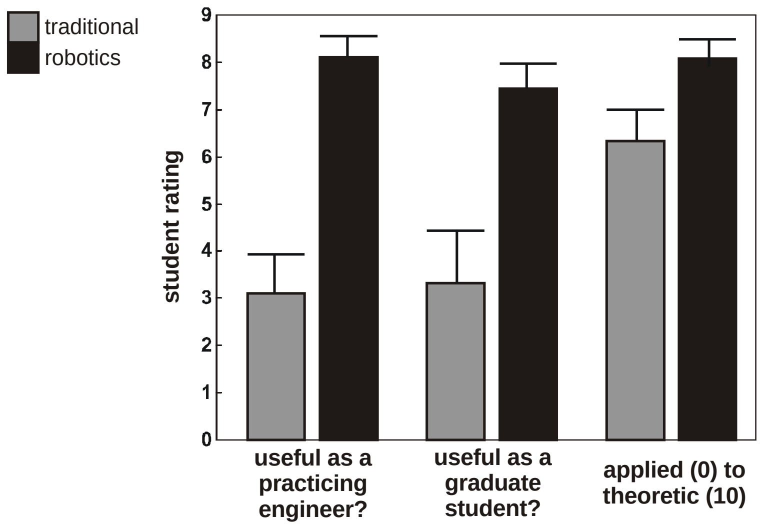

Figure 3: Students felt the robotic-centric course was both more useful to them as practicing engineers and more useful to them as graduate students. Surprisingly they felt the course was very theoretic, even more so than the students who had enrolled in the traditional introductory course. Since the students have no experience with other engineering courses for comparison, this may reflect surprise at the mathematical rigor underpinning the design of what appears to be a simple device.

Students have voted both via surveys and increased department retention (trending towards significance at $p=0.09$) to keep the robotics-based curriculum over traditional labs, however since only two classes have taken the course it is still too early in the students' academic careers to determine whether this preference translates into increased subject mastery. The previous year's class has shown a slight average improvement in their performance in Circuits I, however the improvement did not reach statistical significance, and by Circuits II their performance was indistinguishable from previous years' classes. If the early difference is real it will become statistically significant with greater numbers of students, and we plan to report these findings in the future.

IV. Future plans for course

As with any course, EE 101 is continuously evolving. One major goal is to strengthen it as the base of a spiral curriculum. To accomplish this, upper-class ECE courses will introduce relevant topics as solutions to problems or limitations encountered with the ECE 101 robot. For example, in electronics, a pulse-width modulator project can be designed to implement speed control and in microprocessors, a microcontroller can be interfaced to replace the discrete controller. The current course primarily addresses digital circuitry and lacks coverage of analog electronics. This deficiency can be overcome by adding analog-based sensors to the robot.

V. Conclusion

Student response to the robotics-based curriculum has been overwhelmingly positive: "I've learned a lot about EE since August!" is a frequent comment in the year-end reviews. Although it is still too early to determine if student perception objectively translates into increased mastery of the material, preliminary data is encouraging. Faculty teaching upper-class courses plan to leverage this enthusiasm by introducing selected material as solutions to problems encountered in the introductory course, and we are planning several modifications to the robot to make these transitions more natural. These modifications are easy to implement since we use a custom mechanical base, which unlike using prepackaged kits, also eliminates concerns of future availability while permitting focus to remain on core electrical engineering skills.

Although the VMI EE 101 robot with its custom platform and student-designed electronics is unique, our positive experience using robotics to teach introductory courses is clearly not, and we expect to see the national trend of adoption of Freshman EE robotics-based courses to continue.

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DAVID L. LIVINGSTON
Colonel David Livingston is a Professor of Electrical Engineering at Virginia Military Institute. He has also been employed as a computer engineer for IBM Endicott Labs and was on the faculty at Old Dominion University and Virginia Western Community College. Dr. Livingston received the B.S.E., M.E. and Ph.D. degrees in Electrical Engineering at Old Dominion University. He is a licensed professional engineer in the Commonwealth of Virginia and is a senior member of IEEE and a member of ASEE, HKN, and Skeptics Society.

JAMES C. SQUIRE
Major James Squire is an Assistant Professor of Electrical Engineering at the Virginia Military Institute. Dr. Squire received a B.S. in Electrical Engineering from the United States Military Academy in West Point, NY and his M.S. and Ph.D. in Electrical Engineering/Bioengineering from the Massachusetts Institute of Technology. He is a licensed Professional Engineer in the Commonwealth of Massachusetts, and a member of ASEE and IEEE.