January 2007

Robotics as the Delivery Vehicle: A contexualized, social, self paced, engineering education for life-long learners

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We present our approach to undergraduate engineering education, "A contexualized, social, self-paced, engineering education for life-long learners" through a look at a new two course introductory sequence for the freshman year. As the centerpiece of these courses, we use a smaller version of our advanced research platform, RHex, to integrate introductory programming material with electrical and systems engineering theory. We move away from the traditional "filing cabinet" test and drill approach (fill minds up with facts and test)as students start to become life-long learners, creators, and innovators through exposure to research level problems. The initial assessments of our approach have been very positive. Treating students as junior-researchers and exposing them to cutting edge robotics yielded a 98% attendance rate, 95% of students choosing to take a optional follow-on course, and 90% saying they would recommend the course to another student. We describe as well our students' development of leadership and communications skills through a required ervice-learning component.Working with high-schoolers from the School District of Philadelphia the undergraduates in the course in turn teach material similar to what they have learned in class

Comments

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***Abstract*— We present our approach to undergraduate engineering education, "A contexualized, social, self-paced, engineering education for life-long learners" through a look at a new two course introductory sequence for the freshman year. As the centerpiece of these courses, we use a smaller version of our advanced research platform, RHex, to integrate introductory programming material with electrical and systems engineering theory. We move away from the traditional "filing cabinet" test and drill approach (fill minds up with facts and test) as students start to become life-long learners, creators, and innovators through exposure to research level problems. The initial assessments of our approach have been very positive. Treating students as junior-researchers and exposing them to cutting edge robotics yielded a 98% attendance rate, 95% of students choosing to take a optional follow-on course, and 90% saying they would recommend the course to another student. We describe as well our students' development of leadership and communications skills through a required service-learning component. Working with high-schoolers from the School District of Philadelphia the undergraduates in the course in turn teach material similar to what they have learned in class.**

I. Introduction

Recent reports detail the failures of the United States education system in attracting, educating and developing engineers for the 21st century. In order to understand the scope of the problem one needs to go no further than to look at the data. The number of American high-school students that are planning to enter college engineering is decreasing [1] while at the same time internationally students are entering engineering and science with increased numbers [2]. Exacerbating the problem, teachers are often not qualified to teach high school math and science [3]. These facts come in spite of an increasing awareness of the problem. According to a 2003 Gallup Survey, the vast majority of Americans believe that improving pre-college math and science education is a national priority that must be addressed and in industry, a 2005 survey by Sencer Stuart Research found more S&P 500 CEOs obtained their undergraduate degrees in engineering than in any other field.

How can educators address these problems? Can we increase retention and recruitment? How do we prepare our students for a rapidly changing technology landscape and endow them with the skills to succeed? Potential answers to these fundamental questions are bound up in some of the new pedagogical thinking that has emerged from research in learning [4], [5], [6] along with the last decade's discourse on recruitment and retention in engineering. We believe that robotics offers engineering educators unparallelled opportunities to make this discourse practicable.

In this paper, we present a preliminary report on our use of a robotics research platform to develop a contextualized, social and self-paced education for lifelong learning. The term "lifelong learning" acknowledges the futility of agonizing over how to cram yet more material into an already overburdened curriculum [7], [8]. "Training" must give way to "facilitating" — guiding students to develop capabilities such as problem solving, critical thinking, leadership, communication skills, to acquire the rapidly evolving specific professional tools that they will need to create knowledge and wealth over a professional lifespan. The term "self-paced" encapsulates our belief that students need to develop the skills to learn not only at a pace dictated by a traditional course but also at their own pace and be uniformly challenged and engaged despite entering the class with vastly different skill levels.

The mass of educational research over the last decade yields compelling evidence that cultural and gender diversity cannot be supported by the traditional "authority" centered and externally paced lecture-hall/problem-set model of engineering pedagogy [9], [10]. Our new learners flourish in settings where context is continually apparent, where the why of an idea is stressed at least as much as the what, and where they are engaged in collaborative problem-based learning [11]. It is now widely recognized that such settings are most readily achieved by an inquiry-focused pedagogy stressing cooperative team-based projects [12], [13]. Group projects allow differing intellectual strengths to come to the fore and gain recognition at appropriate and often differing junctures [14]. They provide an authentic context for service-based learning wherein those further along lend a hand to those struggling with mutually familiar obstacles. Project based active learning also provides students with an opportunity to transfer the knowledge gained in lecture to a physical instantiation of the theory, improving retention and understanding [15], [16].

In this paper we offer a preliminary assessment to develop a new freshman introduction to electrical and systems engineering informed by these ideas. Comprised of the three segments outlined in Table 1, we focus in this paper on a discussion of the “social” lab component of the class wherein the philosophical approach finds its most significant influence. We will describe a lab experience split between service learning and collaborative investigations using a current robotic research platform. Both experiences are explicitly designed to promote team projects — experiences known to serve the interests of diversity and increase retention [17] The chief role of the lecture hall, then becomes to illuminate the “context” the relationships between today’s artifacts and tools; between today’s tools and theory; between today’s research and tomorrow’s needs. We defer to another venue a discussion of new lecture materials we have developed in support of the lab experience.

At the cardinal foundations of this course, students are asked to become independent learners and are given the opportunity to focus on problems of their own choosing at a pace that is self-selected. While such an approach could no doubt be supported in a great variety of technological settings, we believe that our adoption of a research-grade robot as the focus of laboratory inquiry significantly promotes that pedagogical approach. For the research agenda of robotics is intuitively immediately apparent: the gap between what people assume robots should be able to do and the tasks our most sophisticated present day machines can presently accomplish remains startling. Clearly, this surprisingly stubborn and startling gap presents a compelling invitation to engineering science and a wonderful pedagogical opportunity. Since so much remains unknown about even what is the fundamentally hard problem of robotics, such a laboratory environment creates numerous settings where simple empirical curiosity carries the potential to escalate into deep inquiry at the horizons of human knowledge. Thus, a robotics lab promotes nontrivial early empirical experiences that provoke undergraduates to immediately participate in research (which itself confers many educational benefits [18], [19]). In this spirit, few of the labs we have created entail any absolute “answer” or even a specific solution [6], allowing students to use and develop their creativity and intuition, skills demonstrated by the very best of engineers in trying to solve these open ended problems.

No doubt, the freshman setting relaxes much of the tension between our philosophical position and the real need of engineers to master a specific body of previously codified knowledge. While we are convinced it is readily possible to carry this same pedagogical stance beyond the freshman year into the very heart of the technical demands of engineering education, a discussion of the general problem lies well beyond the scope of the present paper. For present purposes, we simply note in passing that the simple fact of today’s broad technological explosion implies that students from their first freshman courses on, could be exposed to research platforms and systems that incorporate the very best of current technology across a wide range of fields and specialties.

The outline of the rest of this paper is as follows. In section II and III we describe our novel robotic platform and coding infrastructure used in the course. In section IV and V we detail our implementation of our new fresh-man level course, give examples of the course material, labs and service learning projects that the students worked. In section VI we present preliminary results from our analysis of the course. Finally in section VII we discuss future directions for our curriculum and the potential for creating a national model for engineering education.

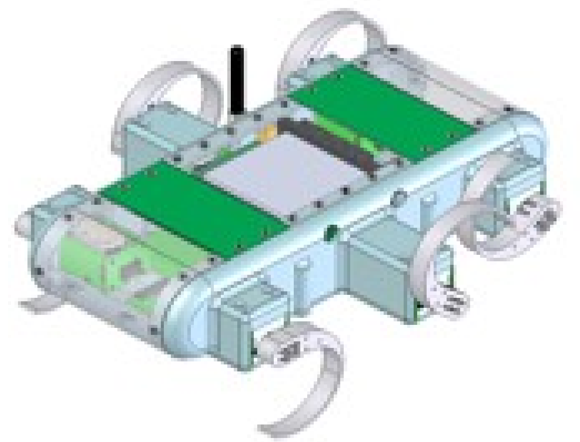

Fig. 1. Edubot: A modular hexapedal robot, Edubot provides students with the opportunity to explore ideas from a wide range of fields including, math, biology, systems and electrical engineering, mechanical engineering etc.

II. A OVERVIEW OF THE PLATFORM: EDUBOT

The high pace of change in technology presents new challenges to educational systems. As a preview of this technological explosion, we want our students from their first freshman courses on to be exposed to research platforms and systems that incorporate the very best of current technology from a wide range of fields. With this observation in mind, we have used our modular mechatronic design and implementation infrastructure to build a platform, which we call the *EduBot system*. Based on RHex [20], Edubot is a true research level platform. Its hierarchical and modular coding and electromechanical infrastructures allow students to encounter research level problems at a suitable layer of abstraction, and its relatively cheap price allows for distribution to the class environment. For example the modular mechanical infrastructure (as shown in figure 2) allows students to design and implement unique leg designs. While robotic systems can very effective in educational programs by combining many fields of engineering and science in one unified platform, we feel, many present educational robotic systems fail to provide a long lasting and strong impact on the educational experience for two different reasons. First they are static and cannot adapt to varied educational levels and settings. Second, they fail to expose students to complex, novel open-ended problems. Addressing both these failure modalities, legged locomotion systems offer an excellent educational environment compared to wheeled and tracked mobility systems. With legged systems the space of exploration is very large as sound theory has only reached a very initial state of development

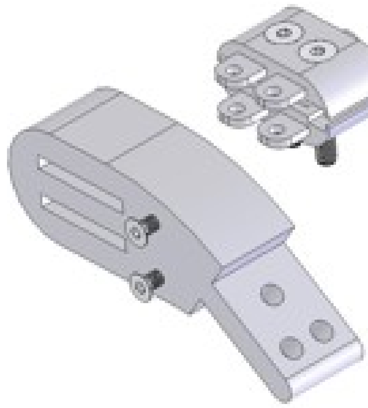

Fig. 2. Edubot: A modular hexapedal robot, Edubot provides students with the opportunity to explore ideas from a wide range of fields including, math, biology, systems and electrical engineering, mechanical engineering etc.

in the literature. This enhances the design of labs aiming to promote an embrace of open-research problems.

III. The project environment

Creating an environment where first year students can productively engage serious robotic projects, despite their lack of coding, math and engineering background that is normally necessary to work on research level platforms seems essential to the success of the course. At The University of Pennsylvania, the first semester of programming is taught in Java. With that in mind we developed a Java front end to the robot code for ESE112 (the first semester course). The front end allows students to interact with the system through a small set of function calls that mimic the functionality of the joystick which normally is used to control our robots. Through this Java front end we are able to gradually increase the richness of the interaction by the introduction of additional parametric freedoms and function calls. An example the interface used for the first project is given below:

static void calibrate()
static void postureMode()
static void manualMode()
static void turnRobotOnce()
static boolean keyPressed()

DESCRIPTIONS:
calibrate(): Calibrates the legs of the robot using the ground reference. We call "calibrate()" in order to coordinate the legs. Call this method before making the robot stand for the first time.
postureMode() : Call this method to make the robot stand up.
manualMode() : Method to switch to manual tripod mode. The robot must be standing in order to enter the manual tripod mode. Once in manual tripod mode, the robot is ready to walk or turn.
turnRobotOnce() : Method to turn the robot in place in one second discrete time increments.
keyPressed() : method that detects if [Enter] key has been pressed. It returns 'true' if the key is pressed.

This example suggests how a simple Java front end can be used to draw novices in to a larger robot laboratory environment.

During the second semester students are introduced to C coding in the programming recitation portion of the course. To match this experience, in the laboratory students are given a C interface to the robot. Having a semester of engineering under their belts, the students now work with actual robot side code using a rich C environment in which they can complete the assigned projects.

IV. A few examples from our Implementation

In accord with our stated objectives and over-arching philosophy, students are asked to research several topics not covered in the lectures and apply that knowledge to solving research level questions in a novel laboratory. Examples of these laboratories include: writing and executing code to optimize the running speed of the robot, autonomous navigation of a channel using accelerometers (see figure 3, and proposing and then partial writing of an academic robotics paper. In addition, projects such as designing new legs for the robot, endowing it with the ability to climb the steps of the Philadelphia Museum of Art, or first designing and then embedding a touchdown sensor into the legs, emulate the cycle of theory, specification, design, simulation, and implementation that all modern engineers encounter and must understand to successfully realize a system [21], [22].

Working with the robots, students get hands-on experience with some of the issues addressed by the more abstract theory presented in the lecture component of the class. For example, in the fifth project of the first semester students are required to choreograph a dance with Edubot. Students encounter principles such as static and dynamic stability, gait construction as well as hierarchical code to structure the over 2000 individual leg movements that comprise a dance routine.

Each lab also consists of a pre-lab that often contains one or more open-ended questions requiring students to access the literature. Examples include describing an algorithm for mapping a unknown room and hypothesizing why SLIP may be a model for efficient legged running.

The integration of the curriculum does not stop in the laboratory. Computer programming homework such as building circuit models, studying mass-spring-damper systems and the modeling of crank and lever systems combine the abstract lecture material with the teaching of programming. Table I gives an approximate outline of the first semester course ESE 112, sketching what is covered in all three segments of the course.

In keeping with our philosophy of treating students as researchers the final project in the course asks students to propose and then sketch out a research (conference) paper.

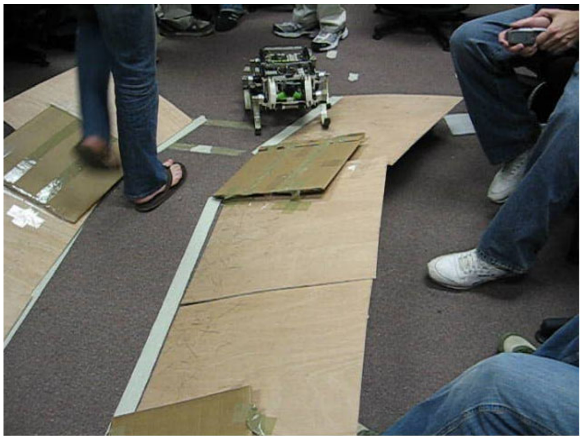
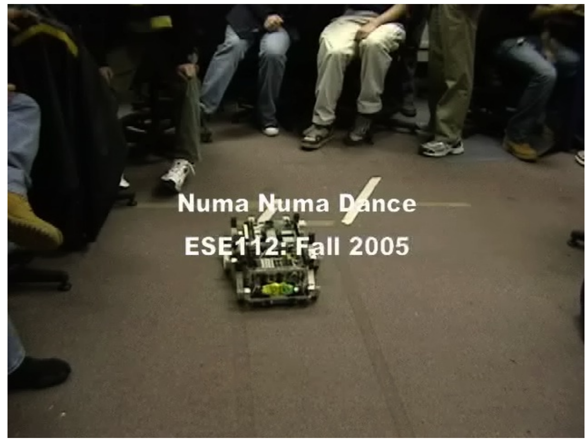

Fig. 3. Autonomous navigation and dance labs.

TABLE I
CONDENSED OUTLINE: ESE 112

Wk	CS Content	ESE Theory Material	Laboratory Material
1,2	• Classes • Objects • IDE intro	Memoryless Devices: • Review electrical MKS units - voltage, current, power, resistors, current & voltage dividers • Digital building blocks	• An introduction to various pieces of lab equipment (screwdrivers, nuts, bolts ,wires etc) • Mini Project 1: Wall hugging mouse • Building and test circuitry • Java Program to compute power assigned
3,4	• Conditionals • Loops • References	Devices that exchange power and store energy: • Power Sources • Discrete state recording devices Device Measurements • Waves and optical signals	• Introduction to Java Libraries for RHex • Mini-Project 2: Turn around every now and then • Student write code to use the robot and an attached laser pointer to compute index of refraction of unknown transparent plastic sheet
5,6	• Arrays • 2D arrays	Continuous device communications • Signals: Sinusoids; Modulation/Demodulation Digital device communication • Princliples of Telecommunications	• Service Learning Training: Tutorial on wall hugging project with high school students. • Mini Project 3: Getting a leg up • Students are given a set of hips and then design, build and test their own legs for the robots
7,8	• Nested Loops • Break • Continue • Java I/O	Analog computational devices: • Computers: Spring-Mass-Dampers; RLC Circuits; Neurons Fabrication: Materials, AVLS;	• Mini-Project 4: Exploring unknown environments • Students write code to have the robot autonomously navigate a path using only accelerometers
9,10	• Polymorphism • Abstract Classes • Inheritence	Linear and Non-linear devices Circuit Analysis • Dynamical systems theory • Virtual work: least action	• Mini-Project 5 dance behavior project • Five week service learning programs begins
11,12	• Math Concepts • Memory Management	Memoryless Devices: • Review electrical MKS units - voltage, current, power, resistors, current & voltage dividers • Digital building blocks	• Mini-Project 5 dance behavior project continues • Five week service learning programs continues • Final ”research paper” project assigned
13,14	• Exception Handling • Software design	Memoryless Devices: • What is a device? • Systems philosophy	• Final Research paper project continues • Service learning continues

Students in groups of three submit proposals for research. These proposals include abstracts of the potential paper and references to the current research literature. The course staff then chooses from the proposed ideas and each group works to submit an outline of a complete paper. The papers involve research on the robotic platform, Edubot, but are otherwise open. Exposing students to the research paradigm results in creative solutions, improves writing skills and promotes the development of self-motivated learners. As remarked in the introduction, this process, set against the present, immature state of robotic science, has proven to offer a very powerful stimulus for creativity and discovery. There are a number of proposed ideas and questions that have emerged from this ”novices” setting that have been taken up as research projects under graduate student supervision.

V. Service Learning

Beyond the benefit to the local community, the impact of learning by teaching has long been established. Research suggests that student participants in service learning retain knowledge, gain a deeper understanding of the material, and are more likely to emerge as community leaders [23], [24]. Leveraging the University of Pennsylvania's top ranking in its geographical region [25], we integrated service learning throughout both courses.

As shown in figure 4 undergraduates work with high school students from the West Philadelphia school system over ten two-hour sessions. Working in teams of approximately four (two high-schoolers and two undergraduates), each group completes three robotics based projects. In the first of these projects students build a simple wall following mouse (from a commercially available kit). In the second project, students are exposed to programming constructs through LEGO robotics and are asked to build a robot that solves a problem in an are of interest. During this second project the high-school students are introduced to basic programming concepts. Some examples include; basketball shooting, fire-fighting and trash collection. Finally the last five sessions are devoted to choreographing a dance with Edubot. After a brief introduction to Java, the high school students are given access to the dance moves that the undergraduates created for their own similar project. Then, they choreograph a short dance to music of their choosing by combining code written on their own with the undergraduates' project code.

VI. Outcomes

In the first, pilot year of implementation, the new curriculum was introduced to a group of 17 volunteer students. This group shared a fall-semester lecture course with other students (n = 27) enrolled in the pre-existing curriculum, but also participated in an additional lab component as well as the service learning component. Thus for one semester, the new and old versions of the curriculum were being run in parallel with an overlapping lecture component. Students in both the pilot curriculum group and the traditional curriculum group completed a common set of six graded problem sets and one midterm exam. (Students in the pilot group had alternative assignments for another midterm and final exam.) For the assignments that both groups completed in common, we were able to carry out a direct comparison of their performance. As shown in table II, students in the two groups performed similarly on the midterm exam ($t = 0.62$, $df = 42$, $p = 0.54$). However, there was a significant difference ($t = 2.28$, $df = 42$, $p = 0.028$) between the two groups on their performance on the problem sets, with the pilot curriculum group scoring higher than the traditional curriculum group. Mean scores out of 300 possible points were 241 (sd = 28.2) for the pilot group and 214 (sd = 43.5) for the traditional curriculum group. Because students self-selected into the pilot group, we cannot assume that this difference is due solely to the different curricula experienced by the two groups. Nevertheless, these findings give us some reason to believe that the changes introduced in the pilot curriculum in terms of pedagogy, content focus, and increased time demands do not seem to place students at a disadvantage in learning standard course material. The advantage seen for the pilot group on the problem sets further suggests that students in the pilot group may be gaining stronger skills in applying course concepts in creating mathematical models of complex situations and understanding the abstract lecture material.

Fig. 4. Penn undergraduate students working with high-school students on one of three robotics projects completed over ten-two hour sessions.

TABLE II
Comparison of Traditional and Pilot Curriculum Groups on Shared Midterms and Problem Sets

	Traditional N=27	Pilot N=17
Midterm Score ($t = 0.62$, $df =42$, $p = 0.54$)	83%	86%
Problem Set Score ($t = 2.28$, $df=42$, $p= 0.028$)	71.3%	80.3%

Throughout the semester students were also are asked to fill out surveys and were interviewed about their experiences in the course. Though preliminary, the results thus far have been encouraging. Survey and data collection from the pilot year of the course (N=19) show a 98% attendance rate in the laboratory. 95% of students chose to take the optional second semester follow-on course. More than 90% of students rated the course as "very good" or "excellent" and reported that they would recommend the course to incoming students. The service learning component also showed promise with 90% of undergraduates responding that they would like to continue doing some form of service learning throughout their undergraduate education and 70% of high-school students responding that they were more likely to pursue an education in engineering.

Anecdotally, it appeared that enabling students to learn and discover on their own elicited passionate work. Below is a sample of typical comments from students:

"Great, At first was a bit annoyed at what seemed unhelpful — now I welcome having to think"

"Challenging and thought provoking — allows us to develop our own theory and thoughts to our problems."

"Liked independence and discovery aspect"

VII. Future Directions

In the short term we hope to take the ideas from this course and extend them throughout the ESE curriculum at The University of Pennsylvania. Specifically, we are hoping to create a research based junior level class that combines ideas from biology, systems science and robotics. Our long-term goal is that this course will serve as a national model for engineering education. To that end, we plan to conduct much more extensive assessment to understand where we are and are not meeting our pedagogical goals and then to develop exportable course materials. We are also working to prune the very ambitious course outline given in table I to respect the time constraints of the freshman year.

VIII. acknowledgements

We are grateful for the help and discussions with numerous people in the development of this course. Those include, Siddharth Deliwala, John Keenan, Sam Russem, Matt Piccoli, Aaron Jacobson, Jean Griffin, Sansern Somboonsong, Jon Clark, Gabriel Lopes and Hadas Kress-Gazit. We thank Robert J. Full for many crucial discussions as well as his general inspiration and particular exposition of the central thesis in this paper: that an inquiry-based research paradigm is becoming the appropriate model for college level instruction in science and technology. This work was supported by NSF, in part under DLR award #0530563, and in part under FIBR award #0425878.

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