A Roadmap for Technology Literacy and a Vehicle for Getting There: Educational Robotics and the TeRK Project

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***Abstract*—Current technology literacy trends in the United States show declining interest and engagement in technological fields of study. We propose a roadmap by which robotics applications can enliven technology education and capture the interest of new students. We also describe our current efforts to design appropriate technologies and apply them at the middle school, high school, and college levels.**

I. Troubling Technology Literacy Trends

SOMETHING is dangerously wrong with science and engineering education in the United States. At a time when total college enrollment is booming, most science and engineering departments are seeing decreasing student interest in high technology fields. The forecast is especially dismal for Computer Science (CS) with interest in the CS major among incoming freshmen dropping by 60% from 2000 to 2004 [1]. These trends are a uniquely American phenomenon, as science and engineering enrollment is climbing in nearly every other part of the world. Technology industry leaders are becoming increasingly concerned that a workforce shortage is imminent in high technology fields, and this will cause the United States to lose its technological edge [2].

We believe that there are two underlying reasons for the drastic decline in Computer Science enrollment. First, science and engineering fields have failed to engage a broad range of intelligent and creative thinkers, especially women and minorities. By appealing to only a narrow cross-section of college undergraduates, science and engineering programs shrink the pool of potential applicants by at least half, as women make up the majority of undergraduate college students. Second, high school and introductory college courses in science and engineering often bore and discourage students, when they should be inspiring and exciting them to continue their studies. As a field, we are missing critical opportunities to bridge the gender gap and engage students at different points along the educational pipeline.

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Engaging and creative educational experiences with technology at the middle school and high school levels can help to stimulate life-long interest in technological endeavors for both girls and boys. While adolescents are given some opportunities to engage with technology, many of the experiences that hook boys on technology are not capturing the interest of girls in the same way. Video and computer games are frequently violent, repetitive, and perpetuate negative female stereotypes [3]. Most existing robotics opportunities are either competitive by nature (Botball [4], RoboCup Junior [5], RoboFesta-Europe [6], US First [7]), or are classes which incorporate competitive games into the curriculum. While these competitions can be a strong motivator for some, they also act to turn off those who would rather work in a collaborative environment than a competitive one. The development of technology experiences that appeal to a broad range of students is key to engaging a larger segment of the adolescent population in technology-rich activities.

Middle school age (11 – 13 years old) is one of several critical ages in terms of student identification and engagement with technology. Gender gaps in interest, confidence and performance, particularly in the physical sciences, have historically emerged when students are in middle school [8], [9], [10], [11]. At this age, students are actively developing identities that reflect combinations of peer culture and academic self. These factors make the early adolescent years a key time to incorporate technological literacy in girls' self identities, as well as to engage a diverse population of boys and girls.

High school students are another important target population because these students are making active decisions that will have a bearing on their future lives: which high school classes to take in preparation for college or career, which college programs to apply to, and which career paths to pursue. While some progress has been made towards reducing the gaps in math and science achievement and enrollment in advanced math and science coursework, boys are still much more likely than girls to choose to study advanced physical sciences, engineering, and computer science [12].

Another critical point along the educational pipeline is the undergraduate Introduction to Computer Science course (CS1). The inadequacy of fielded CS1 programs is well-researched. Schoenberg and Margolis demonstrate that CS1 fails to attract and retain women because it does not contain key qualities that women find appealing: usefulness, relevance to other activities and interests, and intellectual depth [3], [13]. Moreover, the problem extends well beyond women alone. CS1 has poor engagement and retention with significant numbers of men as well. In currently ongoing studies, Blum and Frieze demonstrate that the above qualities are valued as much by men as by women [14], [15]. These new studies suggest that incorporating *usefulness* and *application-oriented programming* can play critical roles in turning around the current CS1 slump. Reforming the CS1 curriculum has the potential to affect a sea change in Computer Science enrollment. Additionally, as Advanced Placement CS classes[1] are required to be similar in nature to CS1, major reforms in the undergraduate CS1 curriculum may have a positive impact at the high school level as well.

Robotics has recently evolved into an effective tool for education and presents a sound opportunity to help solve the problem of motivating and exciting students to study science and engineering [16], [17]. We submit that new technologies, particularly robotic technologies that enable multi-modal sensing, computation, and actuation, have the potential to enliven learning experiences at the middle school, high school, and college levels and bring about a positive change in students' experiences.

Rich embedded devices, such as kinetic sculptures, dramatic performances by robotic casts, humanoid robots, and light show and music-playing robots, all have the potential to excite and inspire students who see courses such as computer science as irrelevant to their interests. Our hypothesis is that enabling state of the art technology to be a superior creative outlet for those with diverse interests beyond technology is an effective way to significantly increase and diversify the technology-literate community.

Our lab has been developing educational robotics applications since 1998. Through the Toy Robots Initiative [18] and the Personal Rover Project [19] we have brought educational robots to informal learning spaces [20], [21], [22] as well as formal learning environments [23]. With our colleagues at the University of Pittsburgh's Center for Learning in Out of School Environments (UPCLOSE) we have conducted formal educational evaluations on several of these efforts and found measurable, positive learning outcomes resulting from the robotics experiences [21], [22], [23]. In this paper we outline the components that we believe are necessary for a successful, engaging educational robotics application. We then describe our current efforts under our latest project called Telepresence Robot Kit (TeRK) which aims at broadly disseminating rich technology learning experiences that appeal to a diverse cross-section of learners.

[1] Advanced Placement classes allow high school students to study material at the college level. Based on their scores on special Advanced Placement tests, students may be able to skip introductory courses once they reach college, and go directly to a more advanced class.

II. ROADMAP

The qualities of usefulness, relevance to activities and interests, and intellectual depth are critical engagement and retention issues for technology literacy. We propose that, given the current technological state of the art in robotics, it is now feasible to develop a robotics roadmap that addresses infusion of these qualities into scientific and technical activities throughout the developmental pipeline, from middle school through college. Three critical criteria comprise such a roadmap, reinforcing the fact that compelling technology is only one enabler, whereas social and interaction design serve as both catalyst and guide.

A. High-functioning multi-modal robotics at an accessible and competitive price point

A recent confluence of inherently multi-modal technologies (e.g. mobile phone electronics; USB-based cameras; low-cost wireless transceivers) suggests that richly functional robotics is now feasible at significantly lower price points than seen before. Furthermore robotics itself, often thought of in terms of sensing and simple actuation, has become expansive enough to include interactive aural, visual, tactile, and motive qualities students can relate to: music, sound, light, and motion. A multi-modal robot should be a tangible device that can express and interact with multiple human senses in a compelling manner.

From a functional perspective, connectivity, sight, and sound are critical for a multi-modal robotic system. Specifically, we propose wireless connectivity, USB-based camera vision, high-quality sound, and servo action as core requirements. Yet the price point for such a solution should not exceed the cost of the LEGO Mindstorms kit, approximately $250. In terms of price sensitivity in educational applications, Mindstorms is at the upper threshold of school budgets, and even a high-functioning system, if priced higher, will achieve dramatically lower rates of use. The ARM processors prevalent in mobile phones, coupled with low-cost, high-end technologies such as USB 2.0 drivers and USB-based wireless transceivers, make this financial proposition realistic.

B. Software and hardware interfaces for life-relevant creative expression

We hypothesize that the quality of engagement can be significantly improved when a robot system can be used for creative purposes in concert with non-technological activities in the lives of the students: dance, writing, theater, music, sports, *et cetera*. Thus the system must operate outside its own technology bubble, putting forth software and hardware interfaces that allow for creative participation of the robotic system in non-technical daily activities in a variety of settings –school, work, home, and public spaces. To effect this unbounded level of interactivity, hardware must be truly robust, and software must provide multi-modal interconnectivity, including internet communication. We believe that a student inventor will desire to connect their robot to their email, their blog, other robots, and their immediate surroundings through the internet as readily as through local visual processing.

C. Internet infrastructure for vibrant networked communities

At each educational level, age level, and community of common interests, we believe that community-wide sharing has an important role in enhancing retention by providing a network of like-minded peers and friends. Such active community-building is a difficult task, and we believe the infrastructure enabling such sociality will prove to be as important as the technology of embedded systems in making educational robotics a successful enterprise. A well-designed infrastructure must support communities of practice and/or interest, e.g. high school computer science teachers, and in so doing must provide the functionality that distinguishes active, healthy internet communities from those that fail due to lack of interest and participation. Kim [24] identifies nine principles essential for vibrant internet communities, including:

1) Define and articulate your **purpose**
2) Build flexible, extensible gathering **places**
3) Create meaningful and evolving member **profiles**
4) Design for a range of **roles**
5) Develop a strong **leadership** program
6) Encourage appropriate **etiquette**
7) Promote cyclic **events**
8) Integrate the **rituals** of community life
9) Facilitate member-run **subgroups**

We believe that any project which successfully addresses the above three criteria can have a significant positive impact on technology literacy, and furthermore that any meaningful application of robotics to education demands that *all three criteria* be addressed. This naturally requires an interdisciplinary team of researchers and educators from design, embedded computing, robotics, computer science, education, and psychology to collaborate under a unified roadmap. In our own efforts, we are pursuing just such a course along one specific instantiation, that of a "Telepresence Robot Kit" for project-based, out-of-school and formal learning activities in middle school, high school, and college.

III. Our effort: TeRK

The Telepresence Robot Kit, or TeRK, project combines four thrusts of research and development in order to meet the requirements previously specified: 1) design of a microprocessor dubbed 'Qwerk', 2) development of a rich software API, 3) design of "robot recipes" for physical robot construction, and 4) development of a community web site infrastructure. The ways in which each of these technologies support the roadmap points are described in brief along with our specific plans for using this technology to launch communities at the middle school, high school, and college levels.

A. Technology

1) High-level Functionality at a Low Cost

The need for a low-cost and yet high-functioning multi-modal robot platform is addressed through two different aspects of the TeRK effort, namely the Qwerk microprocessor and the development of accompanying robot recipes. The Qwerk microprocessor was designed in cooperation with Charmed Labs LLC. With a bill of materials under $150, this processor is inexpensive, yet can form the core of the high-functioning, multi-modal robot necessary to impact technology literacy trends. The Qwerk is designed to control myriad robots; it can control up to four motors and eight servos, while interfacing to sensors with eight analog ports, sixteen digital I/O, and an i2c bus. It also has two USB sockets so that robots may include a USB webcam and a wireless 802.11b network adapter. Visual and aural robot interactions are made possible through support for full-color LEDs and high-fidelity audio playback.

The development of so-called 'robot recipes' also facilitates our goal of keeping robot designs low-cost yet high-functioning. Freely available on the internet, the recipes are composed of instructions on how to construct robots using commercially available, off-the-shelf parts. All robot designs can be built using only hand-tools.

2) Relevant Creative Expression

An important goal of the TeRK project is to allow anyone, regardless of technical experience, to use robotics to create and express their ideas. With software that allows out-of-the-box internet connectivity and support for wireless networking, someone unfamiliar with the complexities of computer networking is able to connect their robot to the internet. Several robot recipes, such as a robotic flower which incorporates multicolored lights, sounds, and various sensors, support creative and non-traditional expression using technology. Freely available software applications are designed for unique activities incorporating writing, theater, music, and light shows. A library of software will be available through the internet so that people can utilize advanced algorithms, for example face recognition software, without the need for an advanced programming background.

An important technical requirement for this system to succeed is an internet-based infrastructure for communication between communities of humans and communities of robots. Users will naturally want to be able to both control their robots regardless of locale, and to be able to share their robot hardware and software with friends and colleagues. We have been implementing a specialized "relay server" designed to enable registration of robots and people, with sharing of software and robot control from throughout the internet. This functionality will allow an individual to program, configure, and teleoperate a robot from anywhere, using just a web browser, even if the robot and the individual are at different firewall-protected locations (e.g. at university and at home on a DSL wireless hookup). Such functionality is essential to relieve the non-technology expert from being burdened with learning details of networking technology before being able to express themselves creatively with robotic technologies. As with all of our software, this entire relay server architecture is in the public domain.

3) *Web Community*

The TeRK web site [25] has been designed with the help of the web design firm LotterShelly LLC. The purpose of our site is multifold: support the development of a participatory community centered around robotics; enable free dissemination of robot recipes, software, and educational curricula; empower community members by encouraging the sharing of feedback, new recipes, new software, and new curricula. The intent is to expand the site as appropriate based on the uses and needs of the developing community. Keeping with Kim's recommendations [24], the site includes profiles that aim to highlight members' robotic interests and recognize their contributions to the web community. In order to encourage appropriate etiquette, all contributions to the site (posted feedback, new robot recipes, *et cetera*) are linked to the contributor's profile.

B. *Plans for Action*

We plan to create communities at the middle school, high school, and college levels through various applications of the TeRK technology. In cooperation with our partners at UPCLOSE, we are planning a formal rollout and educational evaluation process which we will use to measure the efficacy of the TeRK package in various educational settings. Early pilot experiments, combined with *in vivo* evaluation as the community builds, will enable follow-on refinements of the TeRK package.

1) *Middle School*

We believe that the technology experiences currently available to middle school students (e.g., Botball, LEGO Mindstorms, and computer gaming) are designed to engage individuals, primarily but not exclusively boys, who already have an interest in technology and competitive games. In order to encourage creative engagement with technology among a more diverse group of students, we have developed the Robot Diary Project. The Robot Diary is a customizable robot designed to serve as a unique means of exploring, expressing, and sharing emotions, ideas, and thoughts. We believe that by providing a tool that can be responsive to a user's interests, activities, and emotions, we can encourage creative technology use among students who are typically under-represented in more traditional technology communities. Our primary goal for the Robot Diary is to broaden girls' engagement with technology.

The Robot Diary is physically an expressive kinetic robot. Using the TeRK Qwerk board this robot has the ability to make sound, play music, create light shows, interpret diverse sensors and actuate motors for vibration and gesticulation. The Robot Diary kit will be a modular substructure, or skeleton, on which a variety of textures and patterns can be applied to create a personal expressive device with a standardized input/output architecture underneath.

For example users can choreograph their Robot Diaries to be responsive to a diary entry or other piece of text. Importantly, the user is responsible for defining the boundaries of the choreography – users will decide how the robot will respond to their diary entries, thus engaging in an ongoing intellectual experiment about how technology can interface with human emotions. Additionally, because TeRK robots are web enabled, Robot Diary users will be able to share the emotional content of diary entries through embodied robotic expressions with friends in a web-based diary community. This means that a user will be able to see how their friend is feeling by playing the friend's entry on their own robot. The actual written content of the diary entry would remain private, but the emotional expression will be shared publicly with the friend group. By incorporating technology into the existing community practice of sharing emotions and experiences, we hope to facilitate entry into the technology community among a more diverse group of users, particularly girls. Specifically, we strive to increase girls' motivation and interest in technology, and give them the confidence they need to continue their technology explorations.

Once Robot Diary communities have been established, we will conduct a series of studies to assess their impact. One set of studies will compare the experiences of girls participating in a Robot Diary community with girls participating in a more typical robotics community (e.g., Botball). Our evaluation will center around two key areas: identity and knowledge change. By identity, we mean the extent to which the girls come to view themselves as a part of a community that is interested in, competent at, and motivated to engage in technology with a mission. By knowledge, we mean the amount of declarative and conceptual robotics content (e.g., robot assembly, programming, debugging) that girls learn during their engagement with Robot Diaries. If we are correct in our belief that Robot Diaries will provide a unique and powerful educational opportunity for girls, we would expect to find knowledge gains and a positive identity shift for Robot Diary participants.

Although our initial work will focus on girls in informal learning settings, we believe that the Robot Diary concept can be expanded to a classroom setting and that it can be beneficial for both girls and boys. Once the platform has been fully developed, a second research project will investigate the use of Robot Diaries to support and enhance formal educational objectives in different areas, including literacy, science, and technology education.

2) *High School*

We believe that combining the arts and engineering fosters creativity and encourages students to engage technology as a means for both conducting science and producing innovative forms of personal expression. Neighborhood Nets is a project for high school students that promotes citizen science by combining robotic technology with public art and design to explore and address local environmental concerns. High-school students participating in Neighborhood Nets will use the Qwerk board as a platform for community oriented environmental sensing and collaborative creative expression. By outfitting the Qwerk board with simple sensors, student groups can monitor pollution and other environmental phenomena. Multiple Qwerk boards will be networked together to create a "net" that collects data from locations across a neighborhood or multiple neighborhoods. The sensed data can then be represented to the public through robotic sculptures or other forms of display that involve motion, light, and sound that participants design and build.

At its core, The Neighborhood Nets project employs an integrated arts and engineering curriculum to educate and empower students to use emerging technology (distributed sensor nets) and public art to produce representations and expressions of their neighborhoods. One of the key research questions is of what benefit is an integrated arts and engineering curriculum, i.e., a curriculum that privileges neither perspective but seeks to use the arts to inform engineering and engineering to inform the arts. A corollary question is how to best construct such a curriculum. In addition we are interested in better understanding if and how a participatory design process can foster technological literacy and improve the public understanding of both the given technology and of pressing environmental concerns in urban neighborhoods.

The Neighborhood Nets project will be composed of four phases: Discovery, Invention, Expression, and Communication. Each phase includes specific participant activities and research questions.

Discovery. In the discovery phase, students and researchers will work together to discover and articulate the implicit knowledge that residents have about their community. Through a series of activities such as walking tours, photo/video documentation, information mapping, and story telling, the students will use creative methods to represent the social and material ecology of their community. These activities build on a tradition of artistic engagement with the urban environment as a means to explore and represent those aspects of a community that are often not recorded in more “official” surveys, but nonetheless are important and distinctive to residents of the neighborhood.

Invention. In the invention phase, students and researchers will work together to invent, design, and construct robotic devices for sensing those aspects of their neighborhood that they discovered to be most salient in the discovery phase. This phase will begin with a series of informal workshops in which the students will learn about and explore the capabilities of contemporary sensing technologies. These workshops make use of and build on established methods of creative problem solving using performance, art, and design techniques to explore the limitations and possibilities of a given technology. Once the student groups have conceived of their devices and how they will function, using the Qwerk board as a ready-made platform and off-the-shelf sensors, the groups will work with engineers and designers to implement and deploy their devices in their neighborhood.

Expression. In the expression phase students and researchers will work together to design and produce public displays of the data being collected by their devices. These activities build on the artistic and activist practices of visualizing otherwise obscure, hidden, or ignored data, making public what is relevant to the community. Students will be encouraged to use the capabilities of the Qwerk board to explore kinetic modes of expression by producing robotic sculptures that move and make sound, learning basic engineering principles in the process. Students will also be challenged to consider how the displays they create interface with their neighborhood residents and present an image of their neighborhood to the broader community of the city. Of particular importance will be the question of how to represent the data they have collected from their devices in manners that are both appropriate and compelling.

Communication. In this phase, the students produce documentation of the project and share it with their neighborhood, local scientists and artists, the media, and city government. The purpose of this phase is to promote the idea that the work the students do as citizen scientists and public artists must be brought into the public discourse/record and not dismissed as “just the work of kids.” We believe that students’ communication of their process and findings beyond the class room is an integral part of the experience.

3) College

A prime target for the TeRK effort is to use robotics to motivate novice programmers, by exposing them to both practical and exciting applications of the art of programming. We believe that demonstrating these applications will help decrease the historically high drop-out rate seen in computer science programs during and following CS1.

Traditional introductory computer science courses are heavily focused on teaching programming, so much so that the general public considers computer science and programming synonymous. While this pedagogical strategy is effective at laying a strong foundation for programming skills, it creates curricula which do little to motivate students. Programming exercises rarely incorporate real-world data. By enabling assignments and curricula which allow students to tackle practical, real world problems by creating relevant and exciting software programs, multi-modal robotic systems such as TeRK can be used as a tool for major change in CS1.

Although the TeRK technology is a necessary condition for creating CS1 curricular technology, it is by no means sufficient. In addition to technological design, we plan to conduct extensive evaluations of existing CS1 classes to identify critical points in the current curriculum at which students lose interest, as well as creating and evaluating our own robotics centered curricula. As such, our major research questions in this project are focused on how to design and refine technology and curricula based on evaluations of current CS1 courses as well as courses piloting TeRK:

- What microgenetic learning mechanisms guide knowledge acquisition in CS1 today?
- Throughout the curricular arc of CS1, where and how are engagement and retention factors adversely affected?
- What critical touch points in CS1, if invigorated by concrete active learning projects, have the potential to have a significant impact on engagement and retention?
- What active learning modules can be designed agnostically for applicability across the most commonly used pedagogical approaches to CS1?
- What interaction richness (e.g. multi-modal sound, light, motion, sensing, internet connectivity, speech, visualization, *et cetera*) represents a spanning set of features required to satisfy the needs of active learning modules for CS1?
- What is the cost-minimizing software and hardware reference device that implements the above functionality and demonstrates significant improvements for CS1 curricula?

These questions represent the research agenda of this project. The ordering is significant because technology development can proceed only when the desired interaction richness has been clearly identified. Our project blends formal educational evaluation of existing CS1 together with the innovation that leads to validation experiments for new modules in CS1. We are convinced that an assessment-led research program is the only way to arrive at a solution that can truly have a great impact: tens, then hundreds, of CS1 teachers affordably introduce a new form of tool and problem set into their courses around the country, with ensuing statistically significant engagement and retention results.

We will address the issues of student motivation, conceptual understanding of Computer Science, and confidence by developing a program of robotics-based curricular modules to cover four of the main topics taught in introductory Computer Science classes across a diversity of textbooks, languages, and teaching styles. The modular approach represents an elegant solution to the wide diversity of contexts, lesson plans, and textbooks that we face in attempting to provide useful and effective curricula to the largest possible audience of college instructors. Furthermore, creating modules allows instructors to choose which concepts they would like to use TeRK robots to teach.

The evaluation of the curricular modules and the effect of these modules on the student must be developed in harmony with the curricula themselves. Our plan for designing the curricular modules is to:

1) Identify, through a study of textbooks and survey of instructors, a set of main topics that are covered in a large majority of CS1 courses.
2) Evaluate current CS1 classes to identify which concepts and topics are poorly communicated and uninteresting.
3) Develop curricular modules along with relevant software applications and robot hardware.
4) Pilot the modules and technology, and conduct intensive evaluations of these pilots.
5) Analyze the evaluation results in formal educational terms, and refine the curricular modules and technology as appropriate.

This plan, and especially steps three through five, represents an iterative design process that we believe will lead to new and demonstrably effective curricular options for CS1 instructors interested in increasing their students' motivation, confidence, and conceptual understanding.

IV. Conclusion

Robotics has the potential to enliven technical education for students at all stages of the technology literacy pipeline. We believe that three necessary components of a successful educational robotics application are 1) high-functioning multi-modal robotics at an accessible price point, 2) interfaces for life-relevant creative expression, and 3) internet infrastructure for vibrant communities of practice. Through the TeRK project we are striving to meet these demands and evaluate the outcome of educational interventions at three points in the educational pipeline. We hope that the results of these program evaluations will demonstrate the positive impact that robotics can have and serve to lay a foundation for future innovations.

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