TeRK: A Flexible Tool for Science and Technology Education

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Abstract

We present TeRK, a new contribution to the field of educational robotics. TeRK combines a highly functional, low cost controller, the Qwerk, with an extensive software infrastructure and lively web community to lower the barrier to entry for students, hobbyists, artists and researchers interested in using robotic technologies. We further describe our experiences in applying TeRK to engage and excite two audiences; middle school girls and students taking the introductory computer science course.

Background

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 (Vegso 2005). 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 (Bishop 2005).

We believe that there are two underlying reasons for the drastic decline in Computer Science enrollment. First, science and engineering fields generally have failed to engage a broad range of intelligent and creative thinkers, especially women and minorities. By appealing only to a narrow cross-section of college undergraduates, these programs shrink the pool of potential applicants drastically. 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.

A critical point along the educational pipeline for Computer Science is the Introduction to Computer Science course (CS1). The inadequacy of fielded CS1 programs is well-researched. (Schoenberg 2001) and (Margolis and Fischer 2002) 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. 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 2005) demonstrate that the above qualities are valued as much by men as by women. 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 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 for solving the problem of motivating and exciting students to study science and engineering (Druin and Hendler 2000). 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 group has been developing educational robotics applications since 1998. Through the Toy Robots Initiative (www.cs.cmu.edu/~illah/EDUTOY) and the Personal Rover Project **Error! Reference source not found.**) we have brought educational robots to informal learning spaces (All and Nourbakhsh, 2001), (Nourbakhsh et al. 2005), (Nourbakhsh et al. 2006) as well as formal learning environments (Nourbakhsh et al. January 2005). 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. In this paper we describe our current efforts in Computer Science education and beyond under our latest project called the Telepresence Robot Kit (TeRK) which aims at broadly disseminating rich technology learning experiences that appeal to a diverse cross-section of learners.

The TeRK Project

The TeRK project combines four thrusts of research and development: 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.

Qwerk: A Highly Functional, Low Cost Controller

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 motor and servo actuation 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 significantly 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-based wireless transceivers and webcams, make this financial proposition realistic.

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, pictured in figure 1, 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.

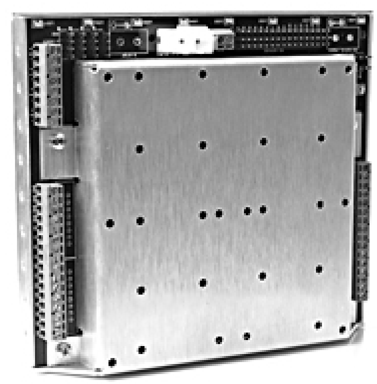
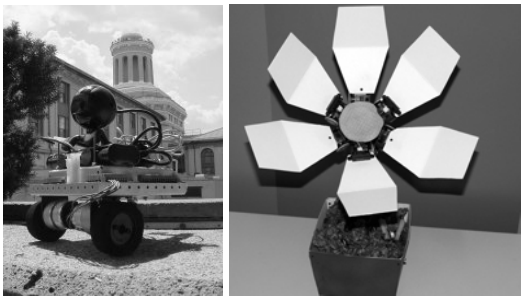


Figure 1: The Qwerk

The development of so-called 'robot recipes', two of which are picture in figure 2, 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.



(a) (b)

Figure 2: Two examples of a TeRK robot recipe - the Qwerkbot (a) and a robotic flower (b).

Extensive Software Infrastructure

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 implemented 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 allows 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, the entire relay server architecture is in the public domain.

Web Community

The TeRK web site (www.terk.ri.cmu.edu) 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. 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.

TeRK Programs

We have created a hardware, software, and collaboration space for interested students and hobbyists to begin developing interactive robots based on the QweRK's unique capabilities. In addition to the creation of this infrastructure, we are applying TeRK technology to two programs aimed at plugging holes in the leaking educational pipeline: The Robot Diaries program is aimed at engaging middle school girls with technology; The Robots in CS1 program is aimed at developing a CS1 class in which TeRK robots are used as tools for teaching Computer Science concepts. In cooperation with our partners at UPCLOSE, we are planning a formal rollout and educational evaluation process in both of these programs which we will use to measure the efficacy of the TeRK package in various educational settings.

Robot Diaries

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 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 – middle school girls 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 girl will be able to see how her friend is feeling by playing the emotional expression of her friend's entry on her 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 girls' entry into the technology community. Specifically, we strive to increase girls' motivation and interest in technology, and give them the confidence they need to continue their technology explorations.

We have taken the first steps towards creating the Robot Diary kit and interface software. In summer 2006 we created a participatory design workshop in which several middle school-age girls spent two hours once per week for six weeks with us. The workshop had multiple goals; for the girls, we aimed to make the experience enjoyable, increase their confidence with regards to technology, and teach them basic robotics skills and knowledge; for us, we wished to use this experience to identify key engineering and design requirements for the future Robot Diaries kit, and develop a participatory design toolkit for us to use to introduce other girls to Robot Diaries in future workshops. As a major goal of the workshop was to discover what kind of physical robot design was attractive to the girls, we did not use the Qwerk during this workshop; instead girls created robots out of prototyping materials such as cardboard boxes, fake fur, DC motors, servos, LEDs, battery packs, alligator clips, and bells.

Figure 3: A Summer Robot Diaries Creation

During each session, girls were introduced to a new modality: Ways of generating large and small motions, sound, and light. Sessions generally followed a schedule in which girls would first play a game to illustrate ways in which emotions could be expressed with a given modality; for example, they could be asked to express one of ten emotions using only non-verbal sounds. After the game, we would introduce the materials available for today's workshop, and how to design with them to reach a desired effect. The second half of the session was devoted to allowing the girls to become familiar with the new materials, and to build a prototype robot based on using current and previous materials together. Figure 3 presents an example robot built by one girl in the prototyping hour of session three – a servo actuated an offset cam that would close and open the dog's mouth.

We are following up on our work this summer by offering a fall workshop in which we will again engage in a participatory design process with a group of middle school girls. During the first three sessions in this ten session program, we plan to cover many of the same concepts as in the summer workshop. The major change will come in session four, when we allow girls to build a robot that is controllable by the Qwerk. Girls will take this robot home after session five. We will design an initial interface before this session to allow girls to send each other programs that they write to express certain emotions. For example, a girl may write a program with a unique set of action sequences to express 'happy', and send this program to other girls' robots to declare that she has had a good day. The initial interface provided the girls in session five will be improved and iterated upon based on the girls' suggestions; most sessions in the second half of the workshop will be devoted to a participatory design process in which the girls and researchers brainstorm together to improve the software.

Upon completion of this fall's workshop, we will have developed a hardware kit that is attractive to girls, field-tested interface software that allows middle school girls to access the hardware in a user-friendly way, and created a curriculum to familiarize girls with the technology as well as build their confidence in using it. Once Robot Diary communities based on this year's design work 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.

Robots in CS1

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 building basic programming skills, 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, and in which the larger concepts of Computer Science are often lost. By enabling assignments and curricula which allow students to work with real world data and applications and 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.

We have begun the process of creating a robotics centered CS1 curriculum. Collaborating with two Pennsylvania community college instructors, we are producing several curricular modules that, when taken together, can form the basis for a CS1 class using TeRK. Our aim in this effort is not to rewrite the goals of the CS1 course, but instead to make available a new tool for instruction. As such, each curricular module we select covers a major concept typically taught in current CS1 classes. We conducted a survey of ten popular CS textbooks and found that all textbooks covered the following major concepts, albeit not always in the same order: Variables, Simple I/O, Flow and Conditionals, Arrays, Errors and Exceptions, and Advanced I/O. We are currently creating assignments for several of these modules, using the TeRK robot to highlight the concepts in ways that we hope can engage and motivate students more so than traditional assignments.

We are also working with CS4HS (www.cs.cmu.edu/cs4hs), an organization at Carnegie Mellon which runs a yearly summer workshop to give high school CS teachers ideas for curricular modules in the month of class after the CS AP exam. At last July's inaugural workshop, we presented a TeRK based robot to 50 teachers and gave teams of six or seven teachers one hour to complete one of our first fully developed assignments; figure 4 shows one such team. Teachers were told to average the pixel values from the robot's camera, and cause the robot to react to flash-cards of different colors – we didn't specify how the robot should react, although we gave the example that a green card could cause the robot to move forward, while red could mean stop or back up. In the hour provided, most teams were able to successfully complete this assignment, which naturally highlights concepts from the arrays, flow, and simple I/O modules. In a striking example of the motivational power of robotics, those teams which did not finish the assignment refused to stop working, even though another session was scheduled immediately after ours. As we were not prepared to provide full curricular materials, this year's session was intended as a short demonstration of the advantages of using robots in CS. We have been invited back for an extended session next year and will provide teachers with sufficient curricular materials to allow them to run a robotics module in their classes.

Figure 4: CS4HS teachers programming TeRK Robots

In addition to technological and curricular design, we plan to work closely with our partners at UPCLOSE to conduct extensive evaluations of existing CS1 classes to identify critical points in the current curriculum at which students lose interest, as well as evaluating our own robotics centered curricula. The major research questions that this evaluation aims to answer are:

- 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?

Discussion

We believe that the interaction richness inherent in the design of the Qwerk controller coupled with extensive user-friendly software and a web community designed for collaboration represent a unique entrée to the world of educational robotics. We aim to use our newly developed technologies and communities to lower the barrier to entry for students, hobbyists, artists, and researchers interested in using robotics technologies. The flexibility of our approach is evident in the programs were are running for middle school girls and high school and college CS students – these audiences are very different, but both are well-served by TeRK. We are still in the beginning stages of this project, and are looking forward to evaluating our current programs while continuing to apply TeRK in new educational domains.

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