Robotics Education in Emerging Technology Regions

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Abstract

Robotics is a unique educational tool for many reasons including its ability to inspire students and motivate them to be creative. This paper presents our experiences in designing and teaching introductory robotics courses in Qatar and Ghana, two contexts in which robotics is not established and computing technology is in its early stages of impact. We discuss the motivation, challenges, approach, impact, similarities and differences in teaching robotics in these two settings. We highlight lessons learned from these experiences that are generally applicable to robotics education in emerging technology regions.

Introduction

Robotics in undergraduate education has the ability to excite students and inspire them to be creative (Rosenblatt and Choset, 2000, Maxwell and Meeden, 200). In technologically emerging regions, such as developing countries and other communities where computing technology is in the early stages of impact, there is a great need to inspire technical creativity and to train future generations to create technology that is locally relevant and accessible (Sachs, 2002). Thus the demand for relevant education in technology fields, including Robotics, is growing steadily. However, there are several challenges to teaching Robotics in these settings, including limited access to equipment, infrastructure and tools required for robotics projects. Relevant courses must also address cultural perceptions and potential fears of technology. Intellectually, the biggest challenge is in mapping classroom experiences to projects and concepts of local relevance and impact. This paper presents our experience in designing and implementing introductory robotics courses in two different technologically emerging regions: Qatar and Ghana. We describe the contexts for which the courses were designed, the content and structure of the courses, and the course outcomes. We also compare the two case studies and highlight lessons learned that are generally applicable to robotics education in emerging technology regions.

Case Study in Qatar

Education City, sponsored by the Qatar Foundation[1], is located on the outskirts of Doha, Qatar. It is a unique endeavor that includes departments from some of the world's leading universities, in addition to a primary school a high school, and numerous other bridging educational and research institutions. For this case study, we will focus on the Computer Science (CS) Department of Carnegie Mellon University in Qatar (CMU-Q)[2], which opened in August 2004. In the fall of 2005, the authors taught an introductory robotics course to 19 second year CS students, with 12 women and 7 men. 17 of these students completed this course titled "Autonomous Robots."[3]

Infrastructure and Preparation

Prior to the course, the CMU-Q students had completed two introductory programming courses in Java, an introductory robotics course, and an introductory mathematics course. Concurrent to the Autonomous Robotics course, the students were completing an advanced course in algorithms and data structures and additional mathematics courses. Each student in the course was provided with a US$1500 Dell laptop, which they could take with them to use as a dedicated machine for the semester, and with a US$300 Evolution Robotics ER1 robot; a robot kit built with X-beam aluminum construction and with a low-cost web camera for sensing. The laptops were installed with Linux and were fully networked. In addition, the students were given C++/Java software written by the authors that provided perception, tracking, and low-level motion control support, and a Java control program with a few example Behaviors. The students had 24-hour access to laboratory space seven days a week.

Autonomous Robots

Primarily, this course aimed to introduce students to robotics and to teach them theoretical and practical skills in programming robots. A secondary goal of the course was

[1] http://www.qf.edu.qa/
[2] http://www.qatar.cmu.edu/
[3] http://qatar.cmu.edu/cs/16200/

to apply concepts the students learned in the CS courses in a laboratory setting. Last but not least, the course was designed to expose students to the world of research and to encourage them to become more creative technical thinkers. To achieve these objectives, the course was taught as two lectures and one lab session per week. Assessment was continuous and varied in order to encourage the students to learn the theoretical and practical components of the course material, as well as to think creatively. The assessment incorporated 4 laboratory assignments, 5 homework assignments, a mid-semester research project, and a final project. The laboratory assignments involved teams of 2-3 students, where new teams had to be formed for each new assignment, while the remainder of the work was individual. The mid-term project required the students to meet with the librarian and technical writing staff, and to present an oral presentation and a written paper describing an existing robotics research project of their choice. The final project required the students to develop and demonstrate a robotics technology solution to problem of their choice, and to give an oral presentation and write a paper reporting their work. Finally, to conclude the semester, the students prepared and presented posters about their final projects to peers, CMU-Q faculty and staff, and to invited family members, friends, and media representatives.

Figure 1: CMU-Q students working on a project

Lecture topics for this course included kinematics, control, sensing and perception, path planning, machine learning, machine vision, manipulation, and team coordination. Some lectures were also dedicated to discussing on-going research in Robotics, and potential Robotics careers and applications in Qatar. The homework assignments followed the lecture material closely and were used to assess the students' understanding of theoretical concepts. The lab assignments required students to install Linux on their laptops and construct their robots from the kits, with a design of their choice and use the constructed robots to implement several capabilities. These capabilities included a simple potential field reactive navigation system, a state-machine based Behavioral controller to solve a simple game of knocking down blue fiducials, while spinning to 'identify' red ones, and a coordination mechanism to allow two robots to autonomously rotate and move a box a distance of 1m. The assignments were completed by mid-semester, and the remaining time was dedicated to the student's final projects. The final projects were formulated based on student interests and included a range of topics from soccer-playing robots and robots responding to traffic signals, to entertainment and assistive robotic projects. Some of the projects focused on algorithms for path planning, while others emphasized sensing and learning.

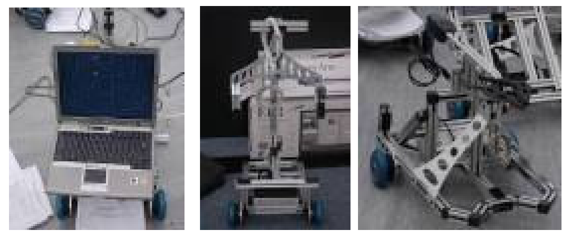

Figure 2: Student-assembled robots

Case Study in Ghana

Ashesi University[4] is a small private university in Accra that is emerging as a leader in Computer Science education in Ghana. Robotics, however, is a new topic for Ashesi where no engineering program is currently offered. Thus, through a partnership with TechBridgeWorld[5] at Carnegie Mellon University, an introductory course in Robotics and Artificial Intelligence (AI) was piloted during the summer of 2006. The course design was based on the authors' experience of teaching the "Autonomous Robots" course in Qatar. To our knowledge, this was the first Undergraduate Robotics course in Ghana. Titled "Introduction to Robotics and Artificial Intelligence,"[6] the course was designed to enhance the students' technical creativity and problem solving abilities by engaging them in hands-on projects while introducing them to the exciting field of robotics. The course also aimed to expand the students' perception of the breadth of Computer Science and to expose them to a wider range of knowledge and skills that could be applied to the problems they would encounter in their future careers.

Infrastructure and Preparation

Ashesi University provided computer laboratories equipped with networked computers and one of these labs was converted into the robotics lab for the duration of the course. Students had access to this lab for limited (but

[4] http://ww.ashesi.edu.gh

[5] http://ww.techbridgeworld.org

[6] http://www.ashesi.org/ACADEMICS/compsci/robotics.html

long) hours on week days and some weekends. However, Ashesi was not equipped with electronic or mechanic laboratory facilities or tools, and students had very little prior knowledge of practical electronics. Therefore, relevant electronic tools and components were purchased to create a small electronics lab for this project and improvisations were made for tools that were not available. The initial offering of the course had seven participants: six men and one woman drawn equally from the 3rd year and 4th year class levels. Their previous relevant coursework included basic programming, software engineering, databases and operating systems. The robotics course used a Lego robot mechanism with a MIT Handy Board, programmed in Interactive C on Linux, for the computational platform. A CMUCam was used for vision. This platform was chosen based on capabilities and budgetary constraints.

Figure 1: Ashesi students working on a project

Introduction to Robotics and AI

The class met three days a week for nine weeks with one and a half hour lectures each morning and three hour labs each afternoon. The first week of lectures covered an introduction to robotics and fundamentals such as the Linux Operating System, programming in C, basic electronics, and an introduction to the Handy Board. The course then continued with a survey of robotics, with lectures on mobile robot kinematics, control, sensing, path planning, machine learning, machine vision, manipulation, and team coordination.

Figure 2: Building machines from local materials

Students completed four tasks and three short quizzes during the first five weeks of the course, and a self-designed final project in the last four weeks of the course. The bulk of each task was a hands-on activity designed for teams of two or three students. Their first task was to build a machine to deliver a small ball to a goal using materials locally available within a very small budget. The next three tasks required students to construct a Lego robot, program the robot to execute basic motion patterns, add sensors to allow navigation through a maze, and implement a wave-front planning algorithm to navigate an environment with obstacles.

The final projects were formulated according to individual interests and capabilities. Final projects included navigation in a changing environment using repeated A* searches, mapping of an unknown environment using sonar, vision-based estimation of traffic density at an intersection, and a robot that played Tic-Tac-Toe with a human opponent. Students presented their work to colleagues and friends at a poster and demo session at the end of the course.

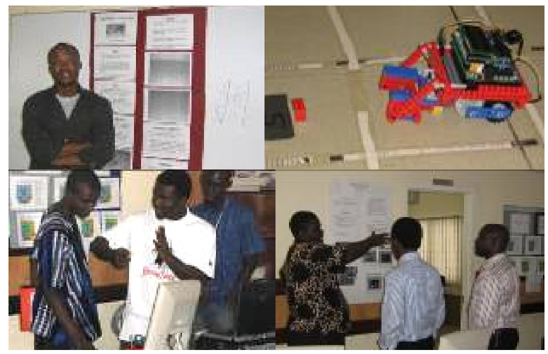

Figure 3: Ashesi students present at the poster session

Discussion

The students in both case studies found that the courses challenged them greatly. They learned about the intricacies, frustrations, and joys of working with hardware and software integration, the inevitability of sensor noise and motor errors, and the importance of practical applications based on an appropriate theoretical foundation. Beyond the specific topics covered in each course, students also learned system development, iterative design, and the value of testing.

Similarities and Differences

Common strategies in the two courses include changing team composition for each task, the requirement for individual final projects, and the concluding poster session. The poster session was a great success in both courses, and resulted in increasing the confidence of the students when they realized their level of accomplishment and that their projects impressed the audience. The primary mode of assessment for both courses was the final project. Since these projects were implemented individually, the students' knowledge and skills were best assessed through their performance in the implementation, demonstration, written report, oral presentation, and poster presentation of their final project. Student performance in homework assignments, quizzes, lab assignments, and class participation also contributed to their final assessment.

In addition to these practical aspects, the two courses also shared the following educational goals:

Encourage creativity: Assignments encourage students to be creative problem-solvers as well as technology experts.

Use local resources: Courseware is designed to maximize the use of local resources, thus making the courseware more accessible and affordable to local communities.

Inspire with examples of state-of-the-art: Lectures and assignments inspire students with examples of the state-of-the-art in theory and application of computing-technology.

Encourage a broad understanding: Courseware encourages students to appreciate the breadth of computing technology and its potential impact.

Teach technical skills: Lectures and assignments emphasize understanding, developing, and applying technology in the Robotics context.

Teach dissemination skills: Dissemination skills are paramount to promoting successful leaders in computing-technology. Thus, courseware includes lectures and assignments to promote effective reading, writing, listening, and presentation skills.

Impact involving local community: A key goal of the offered courses is to encourage creative thinking and problem-solving that is relevant to the local community. Thus, assignments are inspired by locally-relevant problems and indigenous resources, and students are provided with opportunities to present their work to the local community.

Thus, several key elements, learning outcomes, and impact resulting from the two courses were very similar.

Despite their many similarities, the two courses were not however identical; they had several differences. The course in Qatar had a longer time frame and access to more monetary resources in comparison to the Ashesi course. Thus, the robot platforms and the ratio of students to robots were significantly different in the two courses. Student preparation was also different since the Qatar students were in their second year, and thus had taken fewer computer science and mathematics courses in comparison to the students in Ghana. Another important difference is the number of students and the gender distribution of the class. The Qatar course was much larger in terms of numbers, and the women outnumbered the men in the class, in contrast to the Ghana course, which had only one woman student. An additional challenge in the Qatar course was to allow sufficient flexibility for students to respect cultural practices in terms of mixed-gender teams, while still requiring different team compositions for different team assignments. The courses were designed to alleviate concerns of some students dominating assignments by requiring both team and individual assignments, and by assigning a large percentage of the course grade to the individual final project.

Course Evaluation

At the end of each course, several means were employed to evaluate their impact. In the Ashesi course, the students completed an exit survey probing their attitudes towards Robotics and AI and their impressions of the course. About half of the students admitted that before the course, they thought of Robotics solely in terms of humanoid robots but that the class completely dispelled this notion by exposing them to the breadth of the field. All the students felt they had become more technically creative, citing ideas for novel applications, Lego-building skills, improvisation skills, technical report writing and a greater degree of logical reasoning as examples. Some of the things the students felt they would do differently in the future as a result of the class included taking additional courses in electronics and AI, exploring the possibility of graduate education in robotics, incorporating some of the newly learned algorithms into future programming tasks, and focusing more effort on testing implementations. The students also made suggestions on how to improve the course in the future. These suggestions include repeating the task to build a machine out of locally available materials at the end of the course, placing a greater emphasis on the mathematics and physics requirements of the course, and focusing more on AI and its applications in a broader context in the course lectures and assignments.

The course in Qatar was evaluated in similar ways. Some students completed course evaluations and others provided verbal feedback. All students rated their knowledge gain through the course very highly. The students felt a sense of accomplishment and independence after completing different assignments (especially their final projects), and several students were motivated to further explore topics introduced in the class. An informal survey of the class revealed that a high percentage of the students had never built anything before they were tasked with assembling a robot in the class. Thus, the first lab assignment was an especially empowering experience to many of the students. Additionally, students were excited about their ability to "write a program from scratch" and to discover their ability to research new topics, understand them, and implement them. The poster session was another tremendous success where parents, faculty, colleagues, and students all agreed that the students had acquired not only technical skills, but also dissemination and critical thinking skills. Suggestions for improving the course include improving the robotic platform which had many failures, including more exercises to build programming skills at the beginning of the course, and adding teaching assistants to the course.

Overall, students, faculty, and colleagues deemed both courses highly successful, and the two universities will continue to teach the courses in future years.

Lessons Learned

Many important lessons can be learned through the collective experiences of these two case studies. These lessons can greatly benefit educators who undertake technology education in similar contexts, and are therefore highlighted in this section.

From the students' perspective, hands-on tasks and projects develop their problem-solving and decision-making abilities through the use of material resources, processes, and technological systems. Thus, students are prepared for life-long learning in an emerging technological society because they have been exposed to activity-oriented laboratory experiences that reinforce abstract concepts with concrete experiences. This combined "know-how" and the "ability to do" in carrying out the assigned tasks helps students transform technological comprehension, communication skills, mathematical concepts, and scientific knowledge into implemented reality. Another important component of both courses was the poster session which ended in great success and provided a tremendous boost in confidence to the students as they completed the course. In general, it provided the students with an opportunity to share and reflect upon what they accomplished with friends, family, faculty and others from a variety of backgrounds.

However, not all lessons learned were due to positive outcomes. In the Ashesi course, one task which required the students to interface sensors with a robot and have it navigate a maze was particularly frustrating. In retrospect, the level of frustration could have been mitigated by reducing the amount of work they had to do which was not directly relevant to the task. For example, rather than requiring the students to build a robot from scratch, we could have provided them with a common basic mobility platform to enhance. We could have also structured the demonstrations to force students to develop and test incrementally, one capability at a time, and thus improve their probability of success. However, learning to handle frustrations and learning to build capability incrementally are also important lessons to be taught. Thus, in the hand-on tasks and projects, it is important to monitor the level of frustration. Although some amount of frustration is unavoidable when building and testing real robots, ideally this should be balanced by a sense of accomplishment when the task is completed successfully. Frustration can be minimized by carefully reviewing and testing each task before assigning them to the students.

Furthermore, it is important to understand what will work with a given class-size. Having individual final projects was very motivating for the students, as it enabled them to explore individual areas of interests and further develop their strengths. However, for this to be successful, there needs to be significant input and guidance from the instructor both in formulating and in executing the projects, which means that the instructor to student ratio must be carefully controlled as was the case in these two courses.

Another important lesson in relevant course design was that while it may be desired that facilities and equipment are state-of-the-art, recommendations for facilities and equipment to implement a curriculum should include locally available materials, to minimize cost and to make the instruction accessible and relevant.

Finally, in terms of sustainability, it is useful for teachers to have an easily accessible set of resources related to technology education with integrated, hands-on activities that are standards-based. A faculty development plan to support the curriculum and resources will also be necessary to sustain any robotics education program in the long term.

Conclusions and Future Directions

This paper reports our experiences in designing and teaching introductory robotics courses in Qatar and Ghana, two contexts in which robotics is not established and computing technology is in its early stages of impact. The premise of the teaching approach in both courses is that Robotics is a unique educational tool for inspiring students and motivating them to be technically creative. We discuss the motivation, challenges, approach, impact, similarities and differences in teaching robotics in these two settings and highlight generally applicable lessons learned from these experiences. Both courses were highly successful and popular with students, faculty, administrators, and parents, and will continue to be taught and enhanced in future years.

The authors are currently working on enhancing the courses in several dimensions. Robotics hardware and software used in the Qatar course was significantly enhanced over the summer by making the robot components more robust to failures, and by creating more software infrastructure to enable students to complete more complex assignments. Several fun software modules have also been added to allow the robots to "sign," "dance," recognize objects of interest, and track faces. The Ghana course is being expanded to a regular semester-long course and the course is being promoted among a variety of potential students. The authors are also creating an on-line, open-source course repository to build a community of educators committed to teaching computing technology in technologically emerging regions. This repository will include access to course materials, venues for providing feedback and engaging in discussions surrounding the course materials and their implementation, and version control for making available different versions of relevant course materials catered to a variety of contexts.

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