Robotics Education in Emerging Technology Regions

G. Ayorkor Mills-Tettey, M. Bernardine Dias, Brett Browning, and **Nathan Amanquah**

Robotics Institute, Carnegie Mellon University
5000 Forbes Avenue, Pittsburgh PA 15213, USA
ayorkor@cmu.edu, {mbdias, brettb}@ri.cmu.edu

Ashesi University
PMB CT3 Cantonments, Accra, Ghana
namanquah@ashesi.edu.gh

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, 2000). 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 the necessary expertise as well as the 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 a 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 topics ranged from soccer-playing robots and robots responding to traffic signals, to entertainment and assistive robotic projects. Some projects focused on algorithms for path planning, while others emphasized sensing and learning.

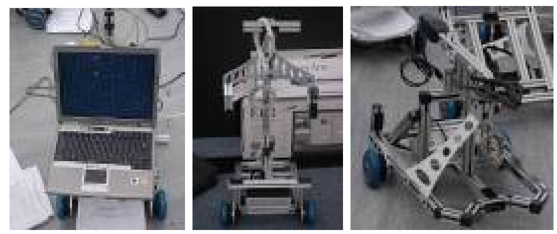

Figure 2: Student-assembled robots

Case Study in Ghana

Ashesi University[4] is a small private university established in 2002 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. Through a partnership with TechBridgeWorld[5] at Carnegie Mellon University, an introductory Robotics course 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 aimed to enhance the students' technical creativity and problem solving abilities by engaging them in hands-on robotics projects. Another goal was 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

One of the networked computer laboratories at Ashesi University was converted into a robotics lab for the course. Students had access to this lab for limited (but long) hours on week days and some weekends. Ashesi was not equipped with electronic or mechanic laboratory facilities or tools, therefore, relevant electronic tools and components were purchased to create a small electronics

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

5 http://ww.techbridgeworld.org

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

lab for this course, 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 from the 3rd year and 4th year class levels. Their previous relevant coursework included Java programming, software engineering, databases, and operating systems. The robotics course used Lego for the robotic mechanism; a MIT Handy Board, programmed in Interactive C on Linux, for the computational platform; and a CMUCam for vision. Costing about US$750 per kit, this platform was chosen due to capabilities and budgetary constraints.

Figure 3: Ashesi students working on a project

Introduction to Robotics and AI

The class met three days a week for nine weeks with lectures each morning and labs each afternoon. The course began with an introduction to robotics, an introduction to Linux, programming in C, and basic electronics. It then continued with lectures on mobile robot kinematics, control, sensing, path planning, machine learning, machine vision, manipulation, and team coordination.

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. The bulk of each task was a hands-on activity designed for teams of 2-3 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 it 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.

Figure 4: Building machines from local materials

The final projects, formulated according to individual interests and capabilities, 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.

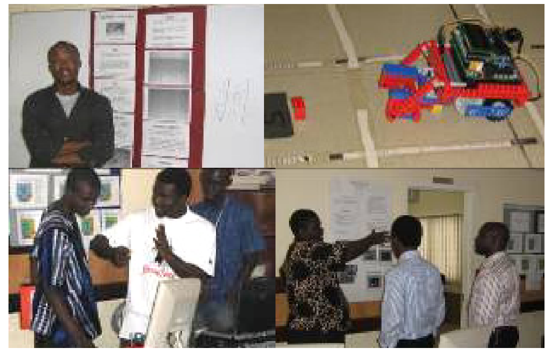

Figure 5: Ashesi students present at the poster session

Discussion

The students in both case studies found that the courses challenged them greatly. Beyond technical knowledge, they learned about system development and the intricacies, frustrations, and joys of working with hardware and software integration. They also learned iterative design, the importance of practical applications based on an appropriate theoretical foundation, the inevitability of sensor noise and motor errors, 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 as it resulted in increasing the confidence of the students when they realized their level of accomplishment and received good feedback from the audience. In both courses, concerns of some students dominating assignments were alleviated by requiring both team and individual assignments, and by assigning a large percentage of the course grade to the individual 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 and poster presentations, of their final project. Student performance in lab and homework assignments, quizzes, 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 vital to promoting successful technology leaders. Thus, courseware includes lectures and assignments to promote effective reading, writing, listening, and presentation skills.

Impact involving local community: A key goal of these 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.

Despite their many similarities in structure, learning outcomes, and impact, the two courses were not identical. 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. Concerning the number of students and the gender distribution of the class, the Qatar course had many more students, 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.

Course Evaluation

At the end of each course, a variety of written and oral surveys were employed to evaluate their impact. In the Ashesi course, about half of the student exit surveys indicated that students initially thought of Robotics solely in terms of humanoid robots but that the class dispelled this notion by exposing them to the breadth of the field. All the students felt they had gained technical creativity, citing ideas for novel applications and improvisation skills as examples. Some students indicated that the class inspired them to take additional related courses, explore the possibility of graduate education in robotics, incorporate some of the newly learned algorithms into future tasks, and focus more effort on testing in development. Suggested improvements to the course included 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.

At CMU-Q, 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

Through the collective experiences of these two case studies many important lessons are learned that can greatly benefit educators who undertake technology education in similar contexts. While the technical content of the two courses was similar to what would be taught in many introductory robotics courses, some key differences in teaching these courses in emerging technology regions are:

Student recruitment: Because of the novelty of the subject, more effort needs to go into advertising that highlights the relevance of the courses to attract students.

Fostering innovation and emphasizing breadth: Since computer science (CS) activity is a new endeavor, there are few local CS alumni and as such, little connection to the history of CS development. This makes it challenging for students and the community to appreciate and understand how new computing-related technology gets developed. Extra effort needs to go into bridging this gap. Furthermore, because local CS infrastructure (that is, the products and applications of CS research) is in the early stages of development, it is useful to spend more class time discussing the potential and breadth of the field.

Making connections to career choices: It is useful to have in-class discussions that engage the students in exercises to explore suitable CS careers and the potential application of CS and Robotics in the local community. Relevant topics include discussions about local industries and the potential impact of technology on these industries, and also introducing students to professional CS organizations, conferences, and publications.

Confidence-building: Due to the limited number of local CS role models, there is a need to build confidence that state-of-the-art CS technology can be accessible in and made relevant to the local context.

Relationship-building and negotiation: Building ties with the local community is important to bolster support for the study of Robotics. In some cases, establishing longer hours of access to labs and negotiating workloads with family and social responsibilities is new territory.

Entrepreneurism: A significant entrepreneurial attitude is required to both teach and study Robotics in these settings. Instructors and students have to be willing to take risks and to find creative solutions to problems.

Providing research/project opportunities: With few ongoing CS research and development activities, such courses are, in many cases, a student's only opportunity to work on robotics projects. This is in contrast to regions where students have opportunities to get involved in faculty research projects outside of class and thus build on the knowledge gained in class. As such, a good course design should provide more opportunities for the creative use of the knowledge gained in class. For example, having student-designed projects, rather than a fixed final project for the entire class, requires more work from the instructor, but motivates good students to get a taste of research and become creative in using technical tools to solve problems. This helps students overcome the mental block that makes them think that they cannot develop new technology.

Ensuring sustainability: To ensure sustainability, it is useful to have an easily accessible set of course resources geared at CS faculty who are not necessarily roboticists. These resources should include integrated, hands-on activities, as well as recommendations for locally available materials relevant to the implementation of the curriculum. Furthermore, a plan to support curriculum and resource development is also necessary to sustain any robotics education program. This could include seminars, journal subscriptions, and opportunities to attend conferences.

Some additional lessons learned from teaching these two courses are generally applicable to undergraduate robotics education in a variety of settings:

Utilizing experience-based learning: Hands-on tasks and projects develop the students' problem-solving and decision-making abilities by reinforcing abstract concepts with concrete experiences.

Providing presentation opportunities: An 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 is valuable to provide the students with an opportunity to share and reflect upon what they accomplished with friends, family, faculty and others.

Minimizing Frustration: Although some amount of frustration is unavoidable when building and testing real robots and learning to handle this is an important lesson to be taught, frustration should ideally be balanced by a sense of accomplishment when the task is completed successfully. Frustration can be minimized by carefully reviewing and testing tasks before they are assigned.

Controlling class size: Having individual final projects is very motivating for the students, as it enabled them to explore individual areas of interests and further develop their strengths. In the two courses, this was successful because the small student-to-instructor ratio enabled significant input and guidance from the instructors both in formulating and in executing the projects.

Conclusions and Future Directions

This paper reports on our experiences in designing and teaching introductory robotics courses in Qatar and Ghana, two contexts in which computing technology is in its early stages of impact. The premise of our teaching approach is that Robotics is a great tool for inspiring and motivating students to be technically creative. We discuss the motivation, challenges, approach, impact, similarities and differences in teaching robotics in these two settings and highlight lessons learned from these experiences. Both courses were successful and popular with students, faculty, administrators, and parents, and will continue to be taught and enhanced in future years.

The case studies illustrate two possible models for establishing such courses in technologically emerging regions. In the case of Qatar, Carnegie Mellon's local campus, as part of the larger Education City initiative, is an invaluable resource. In the case of Ghana, implementing a Robotics course involved creating an international partnership which enabled Ashesi University to develop the capability to teach such courses in the future. This latter model is exciting in that it is accessible to many universities and can result in a myriad of creative course designs while addressing the challenge of the scarcity of the necessary experience to develop and teach such courses in technologically emerging regions.

The authors are currently working on enhancing the courses. Robotics hardware and software used in the Qatar course has been significantly enhanced by making the robot components more robust, and by creating more software infrastructure to enable students to complete more complex assignments. Several fun elements have been added to allow the robots to "sing," "dance," recognize objects of interest, and track faces. The Ghana course is being expanded to a regular semester-long course and is being promoted among a variety of potential students. We are also creating an on-line, open-source virtual community to enable sharing of resources and experiences for teaching computing technology in similar regions.

References

Maxwell, B. A., and Meeden, L.A. 2000. "Integrating Robotics Research with Undergraduate Education." *IEEE Intelligent Systems Magazine*.

Rosenblatt, M., and Choset, H. 2000. "Designing and implementing hands-on robotics labs," *IEEE Intelligent Systems*, Volume 15(6).

Sachs, J. 2002. "Science, Technology & Poverty: Five Ways to Mobilize Development in Low-income Countries," *IAEA Bulletin*, Making a Difference, Volume 44, Number 1, 2002