# Teaching technical creativity through Robotics: A case study in Ghana

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# Abstract

Creating technology that is relevant and accessible to developing communities is an emerging area of scholarly and practical importance. Diversity in both the creators and consumers of advanced technology is required to develop sustained and useful applications of robotics, AI, and other technical fields in developing regions. Increased diversity will result in a wider array of technological innovations that are of benefit to both developed and developing regions. However, due to restricted access to technical resources, infrastructure, and expertise, technology education in developing communities is non-trivial. Thus, international partnerships and creative course designs are required. In response to this need, we developed a partnership between Carnegie Mellon University in Pittsburgh, USA and Ashesi University in Accra, Ghana to design and implement an undergraduate introductory Robotics course targeted towards the Ghanaian context. This hands-on course, which to our knowledge is the first of its kind in Ghana, introduced students to the fields of Robotics and Artificial Intelligence and guided them to develop technical creativity by designing, building, and programming small robotic systems. This paper presents an overview of the course, its outcomes, lessons learned through its implementation, plans for its sustainability, and projected future directions.

# Contents

# 1 Introduction

Addressing the unique challenges that pertain to creating technology relevant to developing regions is becoming a subject of increased attention among researchers across several disciplines ([10],[9],[13],[20]). The goal of such endeavors is to enable technology to serve the needs of a wider segment of human society and to assist in solving some of the most difficult challenges of global development, spanning domains including healthcare, agriculture, education and manufacturing. Artificial Intelligence, Robotics, and other advanced technology fields have much to contribute in these domains. The resulting technological innovations are of benefit to both developing and developed regions because they advance the state of the art and enable new applications.

In this paper, we argue that success in applying technology to the needs and challenges of development requires increased diversity in the creators and consumers of advanced technology. Specifically, participants from developing regions must be involved in this process. There are inherent benefits that result from applying a diversity of ideas and perspectives to any creative enterprise. Furthermore, participants from these regions have a unique understanding of the relevant problems as well as the cultural context, available resources, strengths and challenges that will influence the creation of innovative and useful solutions.

As such, one of the needs of many developing communities is for relevant educational opportunities aimed at creating local experts in advanced technology fields ([16, 1]). There are many challenges, including restricted access to technical resources, infrastructure, and expertise, that make technology education in developing communities a formidable task. Some of these challenges can be overcome by creative course designs that capitalize on international partnerships [13]. We present one such example: a partnership between Carnegie Mellon University in Pittsburgh, PA and Ashesi University in Accra, Ghana, to design and implement an undergraduate introductory Robotics course aimed at assisting Ashesi students to further develop their technical creativity. We present an overview of the course, its outcomes, lessons learned through its implementation, plans for its sustainability, and projected future directions. Through this case study we hope to inspire similar initiatives and encourage further dialogue about strategies for success in such endeavors.

# 2 Background

Ghana is a country on the West Coast of Africa, with a population of approximately 22 million, and a per capita GDP of $2500 [2]. The five public universities in Ghana each specialize in different fields of study. For example, the country's premier public technical university, the Kwame Nkrumah University of Science and Technology, offers undergraduate and graduate degrees in many traditional engineering disciplines such as electrical, civil and mechanical engineering. In recent years, several private universities have been established and some of these, in addition to the public universities, offer undergraduate programs in Information Technology and Computer Science. In addition, there are many private institutes that offer IT-related diploma and short courses, and demand for these courses is very high. While a few universities have masters programs in Information Technology and Telecommunications, no university in Ghana provides graduate programs in Computer Science: for this, students have to travel abroad, significantly influencing the availability of Computer Science expertise for academia and industry. The promotion of ICTs for development is a current priority of the government [19], as evidenced by the establishment in 2003 of the Ghana-India Kofi Annan Centre for Excellence in ICT [3]. This institution's mandate is to stimulate the growth of the ICT sector in the West African sub-region.

## 2.1 Ashesi University

Ashesi University [1] is a small private university in Accra, Ghana, with a stated mission ”to train a new generation of ethical and entrepreneurial leaders in Africa; to cultivate within our students the values of life-long learning, concern for others and the courage to think in a bold and enterprising way.” Central to Ashesi's educational philosophy is the idea of sustainable development. We aim to nurture technical and business leaders capable of critically analyzing problems and designing creative, suitable and sustainable solutions to them. Students at Ashesi can major in Computer Science, Business Administration, or Management Information Systems and they are all required to take a broad collection of courses in the liberal arts.

Firmly grounded in the African context, Ashesi continues to build its local faculty while maintaining strong ties to international institutions. For example, faculty from the University of Washington, Swarthmore College and the University of California, Berkeley play strong roles in curriculum design, and the university regularly welcomes visiting faculty from around the world. Despite its small size and relatively short existence (it started instruction in 2002), the university is already receiving significant attention within and outside Ghana for the quality of its programs and its innovative approach to education in Ghana ([22],[11],[14]).

## 2.2 Carnegie Mellon University

Carnegie Mellon is a private, co-educational university in Pittsburgh, PA, U.S.A. which began as Carnegie Technical School, founded in 1900 by industrialist and philanthropist Andrew Carnegie as a technical school for working-class Pittsburgh. In 1912, it became Carnegie Institute of Technology and merged with the Mellon Institute of Research in 1967 to become Carnegie Mellon University. Carnegie Mellon has many world-class research centers, including the Robotics Institute, a world leader in developing robotic technologies; a part of the School of Computer Science. Carnegie Mellon is currently working towards defining and implementing a vision for globalizing our education. The goal is to create a community ”that is dynamically engaged with other peoples and other cultures” with ”an understanding of history, culture, and worldviews,” an awareness of ”the interaction and transformation of the world through technology,” knowledge of ”the great intellectual debates in history and in the contemporary world,” and ”an ability to work with people of diverse cultures and in diverse countries.” [23]

### 2.2.1 TechBridgeWorld at Carnegie Mellon

In accordance with its theme of globalizing education, Carnegie Mellon University recently launched the TechBridgeWorld initiative ([12][7]) to explore research and educational opportunities in computing technology relevant to developing communities around the globe. The primary goal of TechBridgeWorld is to increase the diversity and impact of computing technology through the enrollment of developing communities as consumers and producers of this technology. To this end, TechBridgeWorld launched several programs with a focus on education and is currently exploring technology applications relevant to topics such as health, agriculture and disaster response. TechBridgeWorld's education initiative has two primary thrusts: (1) Providing educational opportunities for Carnegie Mellon University students to learn more about developing communities and the relevant challenges in technology, and (2) Creating technology aids for education relevant to and accessible by developing communities. All programs under this initiative are strongly linked to active partners in developing communities. Through these partnerships, bridges are formed between the community at Carnegie Mellon University and partnering developing communities to exchange knowledge, expertise, and creativity.

We have begun to explore the first thrust of the education initiative by creating on-campus opportunities to study topics relevant to the theme of technology for developing communities, and opportunities to engage in field studies and implementations of relevant technology in developing communities. The second thrust of the education initiative is further focused in two ways: (1) Creating technology aids to allow improved access to basic literacy in developing communities, and (2) Creating computing-technology related courseware relevant to and accessible by developing communities. The case study highlighted in this paper results from this education initiative.

# 3 Case Study: A Robotics Course in Ghana

A number of factors motivated the decision to design and implement an introductory robotics and artificial intelligence course at Ashesi University. The first was an observed tendency of students to think of Computer Science in a very narrow way: for example, in terms of software engineering applied to web and database applications and business productivity tools. Our goal was to encourage students to recognize the breadth of Computer Science and their ability to harness its power to solve challenging problems in the context of a developing country. Through this process we hoped to enhance the technical creativity and problem solving abilities of the students while expanding their perception of computer science and exposing them to a wider knowledge base and range of skills that could be applied to the problems they would encounter in their professional endeavors. A hands-on course in Robotics and Artificial Intelligence was chosen as a platform to achieve our goals because of the multi-disciplinary nature of these topics and their ability to excite students and inspire them to be creative ([15],[21]),[15].

The course, titled "Introduction to Robotics and Artificial Intelligence" [5] was piloted during the summer of 2006 as an optional summer experience open to third and

Figure 1: Course participants and instructors

fourth year computer science majors. There were seven participants: six men and one woman drawn evenly from the two classes. They were familiar primarily with the Java programming language and the Windows operating system. Their previous computer science coursework included standard courses such as programming, software engineering, databases and operating systems. The fourth year students had already taken an introductory course in Artificial Intelligence. All the students also had a broad liberal arts course base and had participated in the required Leadership Seminar series at Ashesi. Few of them had any prior knowledge of practical electronics, and several had limited math backgrounds. The students cited various reasons for taking the class, including enjoying solving problems, wanting to get a ”taste” of robotics, liking to understand how things work, and wanting to enhance their problem-solving abilities. Several students also talked about a fascination with Artificial Intelligence and a desire to learn how to apply AI to real, practical problems.

## 3.1 Course Design Philosophy

The following principles inspired the design and implementation of the course and are important to the larger goal of enabling the students to apply technology to development: 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.

**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 and involve local community:** A key goal of the course 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.

## 3.2 Equipment and Infrastructure

Ashesi University provided computer laboratories equipped with networked computers and one of these labs was converted into a robotics lab for the duration of the course. However, Ashesi was not equipped with electronic or mechanical laboratory facilities or tools, and so relevant electronic tools and components were purchased to create a small electronics lab for the project. Improvisations were made for tools that were not available.

The course used Lego [6] for the robot mechanisms and the Handy Board [4], programmed in Interactive C on Linux, for the computational platform. We also used the CMUCam [8] for vision capabilities. We chose this platform based on capabilities and budgetary constraints. Each robotics kit cost approximately $850, and the entire equipment budget including nine kits and basic electronics equipment (soldering irons, multi-meters, etc.) was roughly $8,500. Ashesi University purchased six robotics kits and the electronics equipment, and Carnegie Mellon provided an additional three kits for use in the course. Carnegie Mellon contributed the expertise for the course design, and the course was co-taught by all four authors. The course was designed to fit into a $10,000 budget. It is possible to adapt the same course to contexts with a lower budget by having students share robotics kits or reducing the number of different sensors purchased in each kit.

## 3.3 Curriculum

The class met three times a week for nine weeks. Each meeting day had a one and a half hour lecture in the morning and a three-hour lab in the afternoon. Some lab sessions had formal activities scheduled, especially in the first week of the course. The remaining lab sessions allowed the students extra time to work on their tasks and projects, and to get help from the course instructors as needed.

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 the field of robotics, with lectures on mobile robot kinematics, control, sensing, path planning, search, machine learning (parameter estimation and classification), machine vision, manipulation, and team coordination.

Students completed four tasks and three short quizzes in the first five weeks of the course, and a 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. The first task was to design and build a machine to deliver a small ball to a goal using locally available materials, and with a very small budget. Subsequent tasks required the students to build a Lego robot, program it to perform basic motion patterns, add onboard sensing to enable it to navigate a maze, and finally implement the wave front planning algorithm to enable the robot to navigate an environment with obstacles.

Figure 2: Building machines from local materials

The final projects were formulated according to individual interests and capabilities. This was done to enable students to explore their individual interests, and also to require each student to take ownership of his/her project, rather than relying excessively on team members. The projects included navigation in a changing environment using repeated A* searches, grid-based mapping of an unknown environment using sonar, vision-based estimation of traffic density at an intersection, and the development of a robot that played Tic-Tac-Toe with a human opponent. Students presented their work to friends and members of the Ashesi community at a poster and demo session held on the last day of class. This culminating presentation linked the course to the community and helped students further develop their dissemination skills.

Figure 3: Ashesi students working on tasks and projects

### 3.4 Outcomes

**Technical Skills:** The students found that the course challenged them greatly. They learned about the intricacies, frustrations and joys of working with hardware and software integration, the inevitability of noise and errors when dealing with real-world sensors and motors, and the importance of practical applications based on an appropriate theoretical foundation. They acquired important system development skills, with a focus on the iterative nature of design, development, and testing. In the words of one student, they learned to ”test, test, test!”

Figure 4: Ashesi students presenting final projects

**Confidence:** One way to measure the learning outcomes of the course is by the success of the projects and the concluding poster session. The poster session was a boost to the confidence of the students when they realized how much they had achieved and how interested the audience was to hear about their projects. One student, at the end of the course, admitted that he used to be afraid when faced with technical challenges, but that he had gained confidence through working on the projects in the course. Building confidence is an important step to enabling these students to participate actively in developing creative, suitable and sustainable technology relevant to their context.

**Awareness of research and professional organizations:** Some of the most important outcomes of the course from a development perspective were not planned but emerged from discussions and interactions with the students. For example, we had a very spirited and interesting discussion during one classroom session which revealed the feeling of isolation that a technical student and professional in a developing country may experience. The students asked questions at length about professional organizations such as AAAI and IEEE and how and why they could join them. They also asked about research and conferences and how they could participate in them. The students were interested to hear about the instructors' research, and were motivated by the fact that they could understand some of the techniques and approaches used in this research. After several questions following a lecture that discussed A* and similar algorithms, one student, whose name begins with 'H', announced that he would design an 'H*' algorithm and thus earn his PhD in computer science. The motivation and excitement that prompted this announcement was exactly what we hoped to engender in the course.

**Knowledge and Technical creativity:** At the end of the course, the students completed an exit survey probing their impressions of the course and their attitudes towards Robotics and Artificial Intelligence. 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 artificial intelligence, exploring the possibility of graduate education in robotics, incorporating some of the algorithms learned into future programming tasks, and focusing more effort on testing implementations. The students also made suggestions on how to improve the course in future years. 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 Artificial Intelligence.

**Impact on other academic endeavors:** A few weeks after the completion of the course, it is still much too early to evaluate the full impact of this pilot implementation. However, there are already indications of a broader impact. One far sighted student in the class chose a project that related to his final year thesis on modeling vehicle traffic. His robotics project was on automated techniques for estimating traffic density at an intersection by counting vehicles using a vision system.

**External interest:** It was initially planned to open the course up to students outside of Ashesi. Unfortunately, the invitation went out on rather short notice, and there was interest from only one individual who ended up deciding not to take the course. However, after the program started and since its conclusion, there have been numerous phone calls to the university both from students and from industry representatives requesting information regarding when the program will be run again. In addition, some students of other universities have requested permission to carry out robotics projects with supervision from Ashesi University faculty. A previously unknown robotics group, consisting of a mentor and secondary (high) school students in the south western part of the country, has expressed interest in collaborating with the university. They already have ties with a high school in Philadelphia (USA). As a result of this interest, Ashesi University will continue to run the robotics course incorporating it into the existing AI course.

## 4 Discussion

In analyzing the case study presented in this paper, several questions come to mind: In what ways is this course similar to and in what ways is it different from introductory robotics courses already offered by several universities in developed regions? What is the benefit of the international partnership between the two universities? Why is this experience relevant to the topic of AI in ICTs for development? What lessons did we learn from this experience that can be generalized to and enable the success other such endeavors?

## 4.1 Comparison with Other Courses

Overall, this course shares much in common with existing introductory robotics courses (e.g. [21][17]). Students were introduced to the key challenges of robotics and to some of the techniques that have proven successful. Classes contained theoretical information that was then tied to labs and projects to emphasize the practical relevance.

The key difference between this course and similar introductory robotics course lies in its intent to teach technical creativity through robotics, and in its customization to the Ghanaian context. Beginning with the first lab assignment and continuing throughout the course, we tried to emphasize what the students could create by combining state-of-the-art techniques with local resources and local knowledge to achieve local impact. Indeed, particular emphasis was placed on what the students could create in the next 5-10 years of their expected working life. The course was also customized to the local Ghanaian context by phrasing many of the in-class examples to scenarios that the students were most familiar with, or to situations that we all observed in Ghana where robot technology (not necessarily just mobile robot technology) could have a significant impact. As such, lectures often emphasized the applications of component technologies of robotics such as sensing, machine vision, and machine learning, and discussions repeatedly encouraged students to think of local applications of these technologies. Furthermore, each student was encouraged to carry out a final project based on his/her interests.

## 4.2 Benefits of the International Partnership

One of the aims of the Computer Science department at Ashesi University is to make available, for the first time in Ghana, advanced courses such as Robotics and Artificial Intelligence. The motivating philosophy for this is that such courses challenge students to combine critical thinking with the application of technical knowledge. The skills developed in these courses translate directly to the workplace, allowing graduates to help design systems that improve the businesses in which they work and the societies where they live. The challenge of gaining access to relevant expertise in these specialties has limited our ability to meet this goal. As such, from the Ashesi perspective, the partnership with Carnegie Mellon was an opportunity to build capacity to teach Robotics as part of the existing Computer Science program. From the Carnegie Mellon perspective, the international partnership with Ashesi University offered an opportunity to extend the university policy of globalizing education ([23], [18])[21]. In teaching this course, we gained valuable experience on how to effectively design technology courses for students in developing countries - a totally different context to what we are more traditionally familiar with. The knowledge we gained will help us more effectively teach similar courses in the future, and will also be useful for teaching other courses that have a technology basis. Individually, seeing students learn and create is by itself extremely rewarding. Moreover, there is a great sense of impact that one feels from teaching a class to encourage technical creativity in a developing community. As a researchers and educators, social impact is a key component of our shared goals.

## 4.3 Lessons Learned

In the hands-on tasks and projects, especially when students do not have much experience building systems, it is important to monitor the level of frustration. Although some amount of frustration is unavoidable when building and testing real robots and learning to handle this is an important skill to be taught, ideally this should be balanced by a sense of accomplishment when the task is completed successfully. Frustration can be managed by carefully reviewing and testing each task before assigning them to the students. Demonstrations can be scheduled such that students are steered towards incremental development and testing, which is another important skill to be taught. It is also important to understand what will work with a given class size. Having individual 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.

## 4.4 Future Directions

Ashesi University aims to continue to offer this course to its students in the future. While it may be farfetched to start a research program in robotics locally, it will be useful to have ongoing projects to address local problems using locally available materials. Students will then have avenues to continue their exploration after completing the course. It will also be useful to organize robotics competitions among students and any interested groups. This will stimulate growth and creativity. It will inspire students to study even more of the theory in order to construct robust, reliable machines for their competitions. Short programs, talks and demonstrations can be organized periodically for secondary school students to get them introduced to the exciting field of robotics. This will generate sufficient interest and help sustain the program, while continuing to encourage creativity and innovative problem solving. In teaching this course, one of the key limitations we have noticed was the lack of a suitable textbook. While there are a number of good robotics textbooks available, they generally fall into two categories: technical books that focus on a small sub-set of robot technology, or introductory books that are educational but fail to convey knowledge about state-of-the-art robotics techniques. Furthermore, none of these textbooks specifically address the context of a developing community, and many of them are priced out of the range of students and practitioners in developing regions. There is a gap, therefore, that needs to be filled. We hope to explore ways to fill this gap using on-line media in our future work. In addition to a lack of suitable text books, there is a significant lack of low-cost but capable robot platforms. That is, there is a need for something more proficient than Lego can provide but of sufficiently low-cost as to be useful to universities without large hardware budgets. To address this problem, we are in the preliminary development stages of a robotics kit modeled on the Open Source Software approach. We are also working on creating an online repository of technology-related courseware relevant to developing communities. Online access to computing-technology courseware is available via several online resources. However, many of these sites provide access to courseware designed for developed communities where technology applications are ubiquitous and where access to computers and relevant resources is made relatively easy. Starting with the Ashesi robotics course, we seek to create and disseminate courseware that is purposefully designed to be relevant to developing communities where access to technology and financial resources are scarce, and where the role of technology has not yet been defined in the community. This online educational resource will provide educators around the globe with the opportunity to extend and evaluate the courseware available through the repository, and also share best practices relevant to teaching computing-technology in developing communities. The goal is to empower younger generations in developing communities to become both consumers and creators of relevant computing-technology and to encourage new and creative technology solutions to relevant problems in developing communities rather than mimicking technology solutions that prevail in developed communities. We envision the result of this initiative will be an advancement of the diversity, richness, and impact of the field of computing as whole.

# 5 Conclusion

This paper made the argument for creative course designs to help develop expertise for technological innovation in developing regions. It presented, as a case study, an introductory course in robotics and artificial intelligence, implemented as a partnership between Carnegie Mellon University and Ashesi University. Through tasks and projects, the course assisted the students to further develop technical creativity while introducing them to the exciting world of robotics and artificial intelligence. Empowering technical students in developing regions through such educational initiatives can have an important and long-term impact on the innovative application of technology to the challenges of development. The international partnership forged between Carnegie Mellon University and Ashesi University for this project enabled us to overcome many of the challenges that hinder technology education in developing regions. We hope this case study serves to encourage further endeavors along these lines.

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