Teaching Technology Using Educational Robotics

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Introduction

The interest in mathematics, science and technology based courses at both pre-university and tertiary levels have been steadily declining over the past number of years. This is particularly felt in regional areas such as Rockhampton, Queensland (Chiou 2004). To overcome this problem, different strategies have been employed to regain popularity in these areas of studies. Many schemes have been undertaken to implement these strategies. One of more successful and promising strategies attempted by Central Queensland University (CQU) is the utilisation of robotics as an educational tool. However, its implementation cannot be haphazard lest the interest in robotics will quickly diminish as its novelty wears off. Hence, long term planning is required in order to maximise the potential of educational robotics. At the same time, educational robotics should be implemented with great caution as not to cause a reverse effect where it may inadvertently detract students from traditionally based mathematics and science subjects. This paper describes such a project carried out at CQU.

Project Mindstorms

While the practice of using robots as an educational tool to introduce, teach and promote technologically based subjects is a recent development (Druin and Hendler 2000), the concept itself dates back to the early 1980s. From the year 2002 to 2004, the Educational Robotics and Research Group at Central Queensland University have been involved in Project Mindstorms. Named after Papert's (1999) seminal work and also Lego's (2004) line of robot construction kits, the project's main objective is to promote mathematics, science, engineering and technology to pre-university and tertiary level students in regional Central Queensland. Originally, there were two basic goals. The primary goal is to ultimately establish enough interest in students to allow them to enrol in these technologically based courses at tertiary level upon graduating high school. The secondary goal is to design a comprehensive educational robotics curriculum for pre-university level that would provide continuity into mainstream technology courses at tertiary levels. Through succeeding investigation however, it is revealed the project has enough collective expertise and resources to actually develop an advanced curriculum for first-year and second-year university studies.

The schedule of the project was initially carried out in two phases. Phase I was fundamentally to introduce educational robotics in the region. Phase II was the development of a more formal and more comprehensive educational curriculum at pre-university level. In this phase, the project also organised and ran an annual robotics competition. Phase III was integrated into Project Mindstorms at a later date to develop an advance robotic curriculum.

Phase I

The project's earlier activities in 2002 include that of promoting educational robotics to the public, schools, running workshops and summer schools. That is, to make the project's presence and purpose known to audiences spanning from primary school to pre-university level students. These involve school visitations and running demonstration during national and state sponsored science fairs, such as the National Science Week and Central Queensland Multicultural Fair. Longer workshops that ran from three days to weeklong sessions were carried out at summer schools. Most notably are the Siemens Science School Experience and the Women in Mathematics, Science and Technology summer school robotics workshop held annually at Central Queensland University. Every opportunity is taken to send a team of instructors to schools to provide professional development to teachers who were keen in starting robotics classes of their own.

Phase II

Subsequent follow up (in 2003 and 2004) from Phase I was the development and implementation of a curriculum that would provide guidance in the delivery and teaching of a year-long comprehensive robotics course at pre-university level. The objective of this phase is to gradually incorporate mainstream mathematics, science and technology topics into the robotics curriculum. This is carried out in order to maintain the interest of the students without losing sight of the primary objective. The major challenge in the development of this curriculum is to provide a syllabus that would not require skills or knowledge beyond that of what a science school teacher currently knows.

In addition, an extracurricular activity, the annual Central Queensland Junior Robotics Competition (Bell 2004), was organised during Phase II of the project and facilitated by CQU. The competition is to provide a platform to showcase the collective involvement of the community, schools, teachers, students and the university in the area of educational robotics. The competition features the Robocup Junior Australia event that is organised and run at the international, national and state levels (O'Connor 2004). To cater to all students from different age groups and grades, the competition provides three major categories to students to participate. These categories are: robo soccer, dance robots and rescue robot challenges.

Phase III

In mid-2004, a review of the project's resources and expertise revealed that it has the infrastructure in further developing an advanced curriculum in educational robotics. This curriculum is based on the pre-university syllabus, but with advance concepts. The purpose of this curriculum is once again, to allow a subtle introduction of mainstream science and maths subjects without losing the interest of the students. The syllabus is also developed to be challenging enough to motivate students to want to enrol in other currently available university courses to further their understanding and skills required for more complex studies of robotics other related areas.

The Curriculum

The curriculum can be divided into two major syllabuses, Phase II and Phase III. The former is developed for pre-university level while the later syllabus caters to tertiary first and second year level.

Phase II Educational Robotics Syllabus – Pre-University Level

Phase II's syllabus consist of four modules, where each module is to be delivered in a standard 10 to 12-week school term. Hence, the complete Phase II syllabus can be covered in a four-term year. The modules are an introduction to robotics design followed by three technology-based modules. These three modules are data logging, engineering and applied computing (Table 1). However, as mathematics is inherent in all four modules, it was decided that a whole module allocated to it would be unnecessary at this level to teach robotics. In delivering the sequence of the modules, it is of utmost importance that the first module, introduction to robotics, be delivered first. Teaching and introducing the topic of robotics early on in the curriculum ensures that strong motivation is established to provide sustainable interest for the rest of the modules (Beer, Chilel and Drushel 1999; Chiou 2002a). However, the remaining technology-based modules can be taught in any order at the instructor's discretion.

Table 1. A summary of the syllabus used for educational robotics at pre-university level

Module 1: Introduction to Robotics Design	**Topics:** 1. What are robots? 2. The hardware, 3. The software, 4. Types of robots, 4. Autonomous robots, 5. Mobile robots, 6. Static robots, 7. Articulated joints, 8. Introduction to RoboLab, 9. Programming methodology, and 10. Putting all this together. **Challenge:** Design, construct and program a simple robot to pick and remove as many objects as possible from a predefined area. The robot must be able to detect these objects and avoid obstacles.
Module 2: Scientific Datalogging	**Topics:** 1. What is datalogging? 2. How to interpret data? 3. Simple statistical analysis, 4. Types of sensors, 5. Light sensors, 6. Temperature sensors, 7. Data logging, 8. Putting all this together. **Challenge:** Design, construct and program a simple electro-mechanical device that can read barcodes. Upon reading the correct barcode, the device should activate a door to release a piece of 'treasure' (i.e., Lego block, etc.).
Module 3: Engineering	**Topics:** 1. What is engineering? 2. Electronics, 3. Mechanical engineering, 4. Structures and reinforcement, 5. Gears, trains, racks, 6. Motors, 7. Articulated joints, and 8. Putting all this together. **Challenge:** Design, construct and program a simple robot arm with two articulated joints to simulate a pick-and-relocate movement.
Module 4: Applied Computing	**Topics:** 1. What is computing and programming? 2. Program structure, 3. Variables, 4. Procedures/Functions, 5. Conditional statements, 6. Loop control, 7. Concurrent and multi-tasking, and 8. Putting all this together. **Challenge:** Design, construct and program a simple wheeled autonomous robot that is capable of finding [simulated] food and feeding itself.

Table 2. A summary of the PBL-based syllabus used for teaching robotics at a tertiary level.

Module 1: Robotics Design	**Challenge:** Design, construct and program an autonomous wheeled motor vehicle capable of performing self-directed parking. Its function should also include the ability to navigate itself to the allocated parking slot prior to attempting the parking exercise.
Module 2: Scientific Datalogging	**Challenge:** Design, construct and program an autonomous explorer-type vehicle that can navigate over an undefined terrain (e.g., simulated Mars surface), collect rock samples and perform multiple datalogging functions. It should be able to identify and avoid coming in contact with [simulated] dangerous spots.
Module 3: Mechatronics/ Engineering	**Challenge:** Design, construct and program a factory assembly line to simulate the sorting and packaging of different sized parcels. Students must use vision/image processing and some pneumatic systems.
Module 4: Applied Computing	**Challenge:** Design, construct and program a device that can perform a repetitive task that is normally considered mundane by human operators. Students are encouraged to propose their own challenge and use any combination of skills acquired from the other modules. For example, a cash register, poker-slot machine, a dot-matrix printer, an Enigma cipher device and text-to-Morsecode-to-text transceiver.
Module 5: Intelligent Systems	**Challenge:** Design, construct and program a team of two robots that can play against another team in any reasonably challenging sports. Most popular category is soccer playing robots. The emphasis is for students to implement intelligent function in each robot. The topics expected to be investigated by the students are fuzzy logic, neural networks, genetic algorithm, evolutionary algorithm and swarm intelligence.

Fundamentally, the technology based modules correspond approximately to the areas of science, mechatronics and computing science respectively—core areas that can be commonly found in subjects relating to mathematics and science. Even though the development of these modules focuses on respective areas of science or mathematics, the emphasis of individual topics and experiments is deliberately set in the context of robotics (Jones, Flynn and Seiger 1999). Assessment at the end of each module is based on a set of robo-challenges. Robo-challenges are modelled after problem-based learning (PBL) teaching methodologies. Working in groups of three or four, students are given two weeks at the end of each term to solve a problem. Students then design and build a working prototype of the proposed solution.

Phase III Educational Robotics Syllabus – Tertiary Level

The more advance curriculum in Phase III provides continuity for students to seamlessly progress from high school into tertiary studies in the field of robotics. There are five modules at this level. The first four modules are advanced versions of the curriculum found in Phase II. The fifth module, introduces intelligent system concepts (Table 2). Each of the five modules can be delivered in a standard 12 to 13 week university term. However, unlike Phase II, the tertiary curriculum would require formal assessment to test the students' knowledge and level of understanding at the end of each module. The assessment material would be in the form of projects to be carried out by the students and assessed throughout the end of each module (Chiou 2002b). The method of delivery of each module is fully based on the PBL model. After an introduction at the beginning of the respective modules, the students are given a challenge. The students are to perform their own research and learning throughout the duration of the course (with guidance from the instructor) to produce the most optimal solution in tackling the given challenge. The challenge is designed in such a way that most of the required topics relating to the specific module will be inadvertently investigated by the student.

The Tools

The hardware and software equipment used in each phase of the project's activities are robot building kits and flowchart—based programming software to control the robot.

The Hardware: Mindstorms Robotics Invention System

The Mindstorms Robotics Invention System (RIS) manufactured by Lego in Denmark was developed and released in the late 1990s. The contents of the kit are an assortment of approximately 700 pieces of building blocks, gears, wheels, tyres, pins, racks, brackets, electric motors, sensors, microswitches, electrical cables and other parts necessary to build a fully functional educational robot. At the heart of the RIS set is the RCX, a programmable 'smart brick' package in a similar look-a-like design to Lego's familiar building blocks. The RCX has an embedded Hitachi H8 microcontroller (Polpeta and Frohlich 2003) capable of accepting a combination of three different types of sensors such as light, temperature, rotational, and sonar sensors. The microcontroller has three further output ports capable of controlling a combination of electrical motors, actuators, lighting, solenoids and pneumatic systems. The functionality of the RCX can be further extended with add-on peripheral hardware. This can include a realtime video camera system and adaptors that allow specialised sensors to be attached to the RCX, thus extending its usefulness beyond that of an educational tool to that of a fully functional prototyping tool.

The development of the RCX is partly based on the *Handyboard*, a palm sized microcontroller developed by Martin (2001) at the Massachusetts Institute of Technology, USA. The concept behind the Handyboard can itself be further traced to Papert's (1994) seminal work on using cutting edge electronic devices to teach children technology (Martin 1994). Therefore, from the onset of RIS's original proof-of-concept, the motivation behind its development has a foundation in proven educational technology and theory. In addition to selecting an established educational product, other reasons for selecting the Lego's RIS includes: re-useability, affordability, product recognition, availability and user support (Chiou 2004; LUGNET 2004).

The Software: RoboLab

The programs for the robots are written on a *Windows* or *MacOS* based computer that are later uploaded wirelessly to specific robots via an infrared transceiver linked to the computer. This transceiver is part of the RIS kit. The programming software used is RoboLab, developed by Tufts

University, USA (2003). RoboLab has in-built functionality: programming language and datalogging capabilities. The programming language is based on a flowchart programming approach. It can be customised to cater to different student level, hence its intended users can range from primary school pupils to professional roboticists. The programming functions include if-then statements, loop management, linear variables, abstract variables, concurrency, multitasking and real-time communication protocol with the RCX. In addition, it is capable of realtime vision and image processing.

Figure 1. Lego Mindstorms Robotics Invention System.

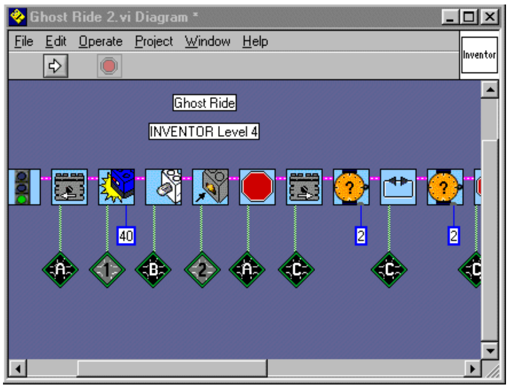

Figure 2. RoboLab programming screen.

Based on LabVIEW (Cyr 2002; National Instruments 2004), RoboLab in conjunction with the RCX can be used as a sophisticated datalogging device. Many of the experiments in the curriculum include using the RCX with appropriate sensors to measure temperature, light, pH levels, humidity, lux level, barometric air pressure, voltage and linear acceleration. Data gathered in these experiments can be downloaded to RoboLab for further assessment using its full range of built-in statistical and analysis tools.

Preliminary Evaluation and Results

As Project Mindstorms was initially carried out as a promotional and not a research activity, no formal method of evaluation was ever conducted at Phase I. However, records were kept of details of participants. These records indicate that as a result of the first 18-month period of the project, approximately 1,500 students and 120 school teachers from 36 schools in the region participated in one or more of the workshops ran by the project team. Surveys and anecdotal feedback gathered at these workshops indicated a very high level of interest in educational robotics.

In 2004, Phase II was carried out at a selected school located in Rockhampton. This involved an instructor from the project team conducting a 3-hour lesson every week. 16 students (12 males and 4 females) from year 10, 11 and 12 attended the class. In addition, two schoolteachers from the school attended these lessons as observers and also part of their professional development. Even though a larger number of teachers and students showed interest in attending these classes, they were however limited to the hardware resources available at the school. The selection of students and participation of the schoolteachers were left at the discretion of the school's management. The students worked in teams of 4, totalling four teams. The school is now up to Module 3 of the pre-university syllabus and is expected to complete Module 4 in the final school term of 2004. At the beginning of the year, only one year 12 male student showed an interest in continuing on in any technology-based courses at tertiary level. At the end of Module 2, an initial survey and feedback showed that 5 males (not including the original year 12 male) and 3 females showed great interest in continuing in a technology based course; 3 male students will seriously consider a technology based course; and the remaining 3 male and 1 female student still retain their preferences for non-technology based courses, but their interest in technology-based courses have significantly increased in comparison to the beginning of the term. These results however, are tentative and only a final enrolment at Phase III would give a more accurate indication of the level of success for this project. Nevertheless, the preliminary survey does offer a glimpse that educational robotics can help build interest in technology based courses. In addition, continued feedback gathered from the current group of students continues to show progressive interest in educational robotics and the likelihood the students will continue their involvement in robotics by enrolling in one of the existing technology based courses at tertiary level.

Summary

To make certain that robots can be used successfully as part of a strategy to halt declining numbers in students enrolling in mathematics and science based courses, a formal approach has to be undertaken. This is to ensure that interest does not quickly diminish as the novelty in robotics wears off. To accomplish this objective, Project Mindstorms at Central Queensland University have set out to introduce robots as an educational technology in three separate phases, where each phase builds on the foundation of the previous one. In this way, any project that is modelled after this basic framework can expect to have reasonable results, as preliminary feedback indicates, in regaining the popularity of mathematics and science based courses.

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