Robotics Education in Primary Schools: a Tasmanian Case

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BACKGROUND

The whole world is facing a shortage of professional engineers. Even though STEM education has been developed world-wide for P-12 kids to address the issue among many others, the engineering component in STEM is limited, especially at Primary School levels. We argue that engineering concepts should be introduced to primary school children through robotics as it covers all aspects of STEM and can be made fun and engaging. However, the challenges are the limited resources of schools, the shortage of skills among teachers and the cognitive limitations of students in their inability to cope with traditional lock-step, text-based programs or the university style talking head videos. The success factor at the primary robotics program is the method of delivery and the form of the topic being delivered.

PURPOSE OR GOAL

This paper presents a Tasmanian case of robotics program in primary schools. We try to address 3 fundamental issues in relation to running a successful robotics program. The first is the financial constraint of public schools which restrict them from accessing the robotics hardware and software. The second is the engineering skills of classroom teachers which contribute to the lack of confidence in running a robotics program in their teaching plan. The third is the cognitive ability of targeted students which require a more considered approach towards the delivery of the engineering concepts via robotics. Consequently, the research question we addressed was how to strategically roll out a robotics program so that it can engage more schools, teachers, parents and students with the ever evident problem of limited resources in our public schools.

APPROACH

We have taken a strategic approach towards rolling out a robotics program. We have developed the www.DrGraeme.net and www.DrGraeme.org websites to host free robotics tutorials that emphasize inductively-based learning. We have sought industry funding to purchase robotics hardware and software to be borrowed by schools that cannot afford the equipment. We run robotics training workshops for teachers in different regional areas of Tasmania. We participate in classroom teaching via normal school sessions or after school programs that provide immediate help to teachers and students. We also run weekend programs to engage both parents and children so that parents may provide some scaffolding for children with special needs.

ACTUAL OR ANTICIPATED OUTCOMES

Tasmania has experienced a lot of success with robotics over the past few years. We have produced several world champions in RoboCup Junior international competitions and multiple Australian national winners. www.drGraeme.net has been a huge success attracting both national and international viewers

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

Robotics is a power replacement or extension to current STEM program. It can be introduced to primary schools with careful planning of resources and teaching materials. However an extended roll out requires support at all levels of the society with government playing a pivotal role.

KEYWORDS

Robotics, primary school, engineering education.

Introduction

The fast development of science and technology requires more people who possess strategic thinking and complex problem solving skills. The biggest challenge of current education is to develop these skills through our teaching curriculum. Many countries have consequently thrown immense resources into science, technology, engineering and mathematics (STEM) education with this ultimate aim. However, one of the critical success factors of STEM programs at lower Middle and Primary School levels is to make them fun and engaging. Many afterschool STEM programs do not see their program as being solely aimed at improving test score results, but instead they strive to increase involvement and exploration with STEM, to decrease anxiety around STEM and energize motivation. According to Hidi & Renninger (2006), curiosity and enjoyment are not only critical steps, but they feed into each other and become integral to increased and continued engagement with STEM activities.

This continuous engagement with STEM can be achieved with robotics programs. Robotics provides a “Play” environment to learners but has been envisioned as a good educational program that integrates the content and skills of STEM. It provides a constant opportunity to solve problems. “Robotics is increasingly being considered as the fourth “R” of learning, “Reading, wRiting and aRithmetic” that modern-day students must understand to succeed in a highly competitive, technology-driven world” (Stemcenterusa). It can integrate all STEM subjects including mechanical, electrical, electronics, control engineering, computer science, technology, math and science. Besides it adopts a more effective approach towards problem solving which is gradual and self-motivating so students really enjoy the process and can expect to achieve continuous progression towards higher levels of sophistication. Often students can work for hours on a single robotics challenge, a behavior that cannot be easily observed with a paper based approach to teaching.

The combination of engineering and software problems and solutions creates a dynamic environment that helps students develop problem-solving skills that involve math, engineering, physics, and logic as they work toward tangible goals. Robotics engages students in complex, strategic problem solving and higher order thinking through the engineering process of solving a challenge using the combination of software and a robot.

In addition, robotics exposes students to the future direction of modern technology which is ubiquitous, highly interactive, multi-modal, adaptive and autonomous. A well designed robotics teaching program could address the current issue of ICT education which is largely limited to surface-level familiarity with prevalent applications, consequently creating consumers of technology. Robotics can help students build deeper understanding IT systems and develop productive learning and problem solving strategies so that they can become creators and designers with IT rather than consumers.

Why robotics in primary schools

Introducing engineering concepts at primary levels matches children’s innate interest in building and their capacity for creative thinking. Successful experiments in introducing engineering in primary schools have been documented and reported with positive results from integrating engineering concepts in other subject areas taught in schools (Barger, Bilber, Poth & Little, 2006) and by creating learning contexts in which children need to apply the engineering design process of asking, imagining, planning, creating and making improvement (Hester and Cunningham, 2007; Hotaling, mcGrath, McKay, Shields, Lowes, Cunningham & Lachapelle, 2007). Robotics provides enormous opportunities with research experiments using robotics program to integrate with other STEM subjects. Tai’s study (2006) revealed the positive correlation between students’ early exposure to science and engineering and their future career choice in these disciples. This is confirmed by another study by Hester and Cunningham (2007) that discovered that early exposure to engineering concepts increase children's awareness of and access to scientific and technical careers. Numerous new technologies have been developed to teach engineering concepts such as LEGO education, VEX IQ etc.

Unfortunately, robotics has not been widely adopted at primary levels. One reason could be related to the stereotype that robotics concepts can only be consumed by high school students and above which has an impact on the production of robotics teaching resources. Most of them have adopted a paper based approach which largely denies the younger students entry into these programs due to their cognitive inability to handle abstract deductive logic, ie, unable to translate written description into an abstract mental 3-D model, and then bring that mental model into a physical form by assembling various components into a whole (Inhelder & Piaget, 1958; Faulkner, 1992). Considerably less attention has been paid to elementary and middle school students.

The world is experiencing a shortage of professional engineers. This is unlikely to change with a recent UK research that found only 15% of the primary students surveyed aspired to be scientists. Most students stereotyped scientists to be white, middle-class, male and highly intelligent people and are beyond their scope of capabilities (ASPIRES Project, 2014).

The challenge for education providers is the design of an adequate program that can engage children. We believe the desired program should possess several basic features. Firstly, it should engage learners in personally-meaningful design experience (Papert, 1993). Secondly, it should give allowance for fiddling and tinkering with, for instance, on-screen building pieces to create computer games, interactive stories, animations, music and art and the ability to share their creative work with others to achieve collaborative learning and mutual improvement (Resnick & Silverman, 2005). The critical role of students' creative thinking and their experiences with innovative design challenges had been documented earlier by Kafai (1995). Thirdly the program should make specific features as user friendly as possible so that children can quickly understand the basics before moving onto more imaginative and creative activities (Resnick, 2007).

Problems with robotics in primary schools

For a robotics program to run smoothly, schools need hardware resources in terms of the robotics kits and computers to be used for a program. Currently the official educational version of a typical robotics set such as LEGO EV3 MindStorms with software costs roughly AU$715 (including GST) per set, or AU$450 for the Home/Retail set. With a class of around 25 students, a normal class for Tasmanian primary schools, there is a minimum requirement of 13 sets to allow pair work for students and one extra set for the class teacher. This would cost roughly AU$7,500 including a software site license and courier cost, if bulk purchasing price reductions were used. With the limited educational budget for public schools at the present age, the biggest stumbling block is the financial constraint of a school to source the robotics hardware. The second issue is related to the computing setup of a primary school. Some schools may have installed a handful of computers in their classrooms but may find it difficult to fit a whole class into a room with sufficient space for 13 or more computers and enough floor space for robots to run around.

There are two aspects to the second challenge. US schools feel restricted by the limited space available in the current curriculum for engineering (Barger et al, 2006; Hester & Cunningham, 2007). Australia seems to be worse. The newly released Australian Curriculum (2013) does not have specific coverage on engineering, let alone, robotics. Principles and school teachers need to be convinced that a robotics program can cover some areas of STEM and most areas in the IT component so that the overall teaching program can meet curriculum requirement. The second aspect is the limited skills of teachers who often feel rather uncomfortable about teaching engineering as they generally have no previous introduction to engineering in their teacher training. Consequently a robotics program targeting at primary schools should be designed to match the national curriculum in the science and IT areas and should also be designed to reduce the learning curve for teachers.

The third challenge is related to the target student age group. There is hardly any robotics teaching resource with the primary level students as a target group so adopting any existing resources is a recipe for failure. A new program with a different teaching approach is required that can should consider a) students with lower cognitive abilities, b) self-paced learning, 3) engaging a larger group of students, both boys and girls, with varied learning capabilities.

Strategic approach

A strategic approach has been adopted in Tasmania to address the three problems covered in the previous section. The strategy includes alternative means of sourcing hardware resources for schools, the training of teachers and parents via different types of scaffolding and developing an effective teaching program.

Sourcing robotics hardware

The experience of the researchers in this research is that the Principal of a school who makes budget allocation should experience the benefits of robotics before they feel committed to this type of program. In the past few years, we have made various attempts to source external funding from industry such as Google Australia and local funds from Tasmania Community Fund to purchase robotics hardware. These resources are made available for schools showing interest in our program. This completely lifts the financial burden of participating schools doing robotics. Due to the enthusiasm of the teachers and students in robotics and also the pressure from parents to proceed with the program, a lot of schools have started budgeting for robotics hardware on an annual basis, slowly building up their entire sets for the whole class. For those schools that still do not have sets, we lend them our robots on a rotating basis, with each school making a booking for a particular school term.

The argument for using robotics hardware is the perceived value of robot building which can not only improve young learners' motion control and three dimensional skills but also allows learners to experience first-hand problem solving approach in engineering, in most cases an iterative process of problem analysis, building, testing, refining a product. With the plan to extend the program to more schools, there is always the potential problem of limited hardware resources. We have a plan to adopt a new approach using a combination of Virtual World and physical robots so that the broader concepts of robotics could be tried and tested online and that prototypes could also be built to be tested in the real world.

Training teachers and parents

The training of teachers was done in several ways. It started with in-class intervention of one of the researchers. When a school class has access to the LEGO hardware sets, the researcher goes to the robotics teaching sessions to provide onsite support for the teacher as well as the students. The teacher uses the same online resources as their students and is usually a few steps ahead of students when they run the program the first time. The onsite support gives the class teachers more confidence. In some cases they quickly develop sufficient basic skills to be independent in later runs. Since 2007, six primary schools in the Hobart area of Tasmania in Australia have adopted the program with onsite support. Several primary schools have kept the robotics program as their core curriculum for a few years now having built up their own robotics sets over the time.

As it is insufficient to limit the program to only a regional area, the researchers also resort to industry for funding to run training courses for school teachers from all parts of Tasmania. One of the sources came from Google's Computer Science for High School (CS4HS) program. This program provides funding to University academics to conduct workshops for high school teachers in the computer science discipline. The researchers presented a strong case to Google Australia and obtained permission to run a robotics training course for both primary school and high school teachers. In the 2013 round of funding, we used the majority of the funds to increase our stock of hardware sets and ran three workshops in the South, North and Northwest of Tasmania to reach more teachers. Some schools had already started doing robotics using our online robotics tutorials for their teaching. Others had it in their forth--coming teaching plans. All expressed pleasure about the opportunity to meet face to face with the web-based robotics content providers and to be part of the network of teachers sharing an interest in robotics teaching. The researchers also scheduled post workshop sessions for Skype discussions to answer questions if they arose.

The other important human resource we used is the parents through the weekend robotics program. This practice is reflecting the notion of learning ecosystem which originates from Bronfenbrenner's (1979) ecological theory of development. According to this theory, besides the critical role of schools in influencing young people's lives, it is also important to acknowledge the influence of families and peers, after school programs and community resources like parental and grandparental helps in schools, science centers, museums, libraries and media. It is believed that tapping these additional resources could assist in lifting some of the educational burden from schools and distributing it among various public and private institutions.

A weekend robotics program can be an additional environment for teachers, parents and students to communicate the essential characteristics of engineering work, the creativity, teamwork work of engineers. It can be designed to permeate engineering concepts to students and the wider community through a careful design of the various challenges that require all participants to discuss prevailing issues and design possible solutions for them. Hopefully it can stimulate the younger generation enough for them to consider engineering as a future career.

Designing an effective robotics teaching program

Children at different age levels demonstrate different cognitive capabilities. As a result technology tool sets have always been designed for a target age group and embed in the tools varied complexities and related concepts (Resnick, 1998). For example, LEGO Mindstorms and VEX robotics sets target children over 10 years old and are anecdotally bijou toys for those gifted, talented or predominantly boy students. We believe that with due diligence to the design of a LEGO or VEX based robotics program and the right choice of a teaching method, it is possible to attractively introduce a robotics program to students of both sexes at a low age group and in a normal classroom setting. However some design principles must be applied.

Firstly, the program must use an inductive learning approach. "Inductive teaching and learning is an umbrella term that encompasses a range of instructional methods, ...they are all learner centred, meaning that they impose more responsibility on students for their own learning …building on the widely accepted principle that students construct their own versions of reality rather than simply absorbing versions presented by their teachers" (Prince and Felder, 2006, p123). The research project presented in this paper supports inductive learning by providing students' structured guidance via www.DrGrae.me , a series of logically sequenced videos and challenges for viewing at users' own pace, allowing them the time to experiment with their tools and incrementally constructing their own understanding. We expect children to have multiple attempts, to make mistakes and to improve overtime because that is how children at this age group learn! Another reason for using videos is to bypass the limited reading skills of the target children. The traditional “lock-step” approach inherent in some text-based approaches in robotics instructions has been a big stumbling block for younger children.

Secondly, this inductive approach should encourage creative and independent thinking, but in a way that does not punish students for making mistakes. Our current educational system with its exams for assessments does not allow mistakes which has a long term negative impact on children who stop being explorative and adventurous in their creative thinking. Our robotics program should give students the opportunity to demonstrate their creativity, eliminate the fear of making errors, and encourage students’ sharing and mutual learning.

Thirdly, it should introduce repetition of fundamental skills without risking boredom among children. Repetition is the key to retention but it is important to design a learning program that is problem-based so that children are more focused on reaching a problem solution without realizing they are repeating, but really consolidating, those already acquired skills. To achieve this goal, a careful planning is required for incremental skills building to maintain children’s confidence and to design challenges that mimic real life scenarios. Examples include RoboCup Junior events such as the Rescue Challenge with the scenario of rescuing humans in times of disaster. World events with similar objectives include the FIRST competitions, the World Robot Olympiad, and the VEX Robotics Competitions. The objective of each is to provide challenges that help sustain students’ interest and motivation to continuous learning.

A program based on these principles, using LEGO MindStorms, is hosted on www.DrGraeme.net with partial content as shown in Table 1. The program emphasizes both physical robot building and programmable robot functions. It enforces the engineering approach towards problem solving by designing various challenges that require children to carry out a design process using brain storming, developing a prototype, programming required functions, testing, analyzing, refining, retesting etc. until a final product is reached, which could still be a compromised product of various software and hardware constraints.

Program outcomes

The strategic roll out of the robotics program has been very effective. The resource issue can never be resolved with the current government funding for primary schools. However, with borrowed LEGO kits from University of Tasmania, more schools have run a robotics program as part of their teaching curriculum. Some schools have received so much positive feedback from both parents and children, especially after confidence busting experiences in National and International robotics competitions, that they have decided on a long-term program. The practical preparation is building up robotics sets to run the program every year. An increasing number of primary school teachers have developed the confidence in running a robotics program after the researchers’ classroom onsite assistance. CS4HS teacher training workshops have helped build a robotics teaching community in Tasmania and the post-workshop Skype sessions help resolve some robotics technical and programming issues. The weekend parent student robotics sessions have been very successful seeing increased enthusiasm in robotics in students as well as parents!

The website that provides learning resources as shown in Table 1 provides modular content with predefined objectives on robot building and programming. Each module builds on the skills of previous modules so that the process becomes an iterative but progressive learning progress. The initial tutorials that set out the basics are entirely video-based hand-holding tutorials. When the basics have been assimilated, challenges are given to students, with no obvious solutions being provided to them. This is the space for students to demonstrate their

Table 1. Robotics Program Design

Robot building	Robot programming with (Challenges)
2 wheeled Robot with building instruction	Move in a straight line, smile, speak (Racing)
3 wheeled robot with building instruction	Make a curve, (Far Side of the Moon)
Robot free build	Move straight, in curve and make a turn (Floor Cleaning)
3 wheeled robot with one light sensor	Push all randomly-positioned “bulls” out of the ring without the robot leaving the ring (Minesweeper) Straight line following (RoboCup Junior Rescue)
3 wheeled robot with two light sensors	Straight & curved line following (RoboCup Junior Rescue)
Free build with more sensors	Move within boundary, sense objects & action (SUMO, Tug of War)
Free build with choice of sensors	• (Circuit race using light sensor) • (Circuit race using touch sensor) • (Circuit race using ultrasonic sensor) • (Transport in War Zone)
Free build with choice of wheels and gears	• (Move without wheels). • (Tug-of-war) • (Robot Catapult) • (Robot food foraging) • (Sound-controlled Robot) • (Solving a maze) • (Climbing the steepest mountain) • (Robot Soccer)

skills and creativity. For example in the challenge “Far side of the Moon” in which the robot starts from a model “Earth” to complete a return trip around a model Moon, a usual solution is a combination of straight lines and curves. However, since there is no set restriction on how a robot completes the route, students have demonstrated all types of solutions, from completing the whole task with one large circle around the Moon to a more explorative robot circling around the moon multiple times before returning to Earth (Ying & Faulkner, 2013). Students also created different robots, from simple two wheeled robots, to more capable robots with more wheels for stability, more gears for mobility and more sensors for capability. These multiple building process increased student’s 3-D visualization and 3-D manipulation skills and gave students much more confidence when it came to tackling later challenges that require "free build" robots challenges such as SUMO, Minesweeper and Tug of War that occur later in the program. See Table 1. This building background also seemed to give the students more confidence in robot building when they were challenged by robotics competitions such as RoboCup Junior and First Lego League. These “free build” challenges also require students to consider optimization in the practice of engineering.

When the online resources are used in a classroom setting, time is allocated for all robots to demonstrate performance. There is also time allocated for sharing among students, and reflecting on various solutions for future improvement. Some of these robot runs are also video-taped and uploaded onto the website to be shared with the online community. From the educational perspective, they are evidence and measurement of students’ robotics building and programming skills and their levels of creativity.

The authors have done weekly observations of five primary schools in Tasmania, Australia that integrated the use of the DrGraeme.net robotics materials for teaching. Our studies date back six years. All students in these classes were paired and worked collaboratively on modulated challenges. Even though the students could vary in their speed of building robots and their time spent on programming the robots to complete a challenge, the enthusiasm and excitement from the students were unanimous. The classrooms were always noisy. Students had no concept of failure. There were always multiple attempts to complete a task but students showed no sign of boredom. Students made changes to their constructions or programs and tested them with giggles and laughs.

Our observations suggest that the program particularly benefits both below and above average students, as well as shy students because it gives the children the control of their learning pace so that male and female students with different learning abilities can simultaneously participate in the program and learn at their own pace with fun.

Another rewarding outcome for students has been the increasing number of students' involvement in robotics and their successes over the years in robotics competitions, both nationally and internationally. Users of our program have produced several world champions in RoboCup Junior international competitions and multiple Australian National winners.

Conclusion

The strategic approach towards rolling out a robotics program in Tasmania has been very successful. The developing online program hosted on www.DrGraeme.net has been used by national and international users from over 150 countries with Google Translate reporting translation of pages from the web site into over 40 different languages. It also has a marked impact on Tasmanian schools, teachers and students, especially those running a robotics program. When students representing Tasmania make media coverage with national and international level successes, it is clear message to the community that robotics is making a difference to the children in our community and they can be role models for others. However, more schools are yet to be convinced to start a robotics program and future lobbying is necessary to extend the Australian curriculum to include robotics in the current STEM programs.

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