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Web Based Robotics Program for Teaching Creativity

Ying Chen
University of Tasmania, ying.chen@utas.edu.au

Graeme Faulkner
University of Tasmania, graeme@ieee.org

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Ying Chen
Graeme Faulkner
School of Computing and Information Systems
University of Tasmania
Australia
Email: ying.chen@utas.edu.au

Abstract

Creative thinking is one of the critical professional skills in this contemporary world that requires innovative approaches to problem solutions in response to constant changes. However our current educational system that is geared towards limiting mistakes is reducing students' chances towards experiments with creative ideas. Educational research has rekindled the value of the kindergarten approach to learning which encourages diversity and creativity through students' tinkering with learning objects. This paper presents a web-based robotics teaching program that develops learners' programming and spatial skills and stimulates their creative thinking. It introduces a video-enhanced inductive teaching method in order to reach students of various cognitive capabilities at the primary school level. This program has been running successfully for over 6 years in Tasmania, Australia. The online free resources provided in DrGraeme.net have also attracted a large international audience.

Keywords

Web based teaching program, creative thinking, inductive teaching and learning, robotics

INTRODUCTION

We are living in a world that is characterized by a high degree of uncertainty and rapid changes. How to better prepare the younger generation with adequate skills has become the challenge for our educational system. Research in education and psychology has attempted to identity those skills that can provide long term benefits to people in both professional and personal life. Creative thinking skills have been regarded by many as critical skills to be developed early in a person's life (Resnick 2007; Florida 2002; Melchior et al 2004; Papert 1993; Sawyer 2006). Creativity is as important in education as literacy and numeracy and should be treated with the same status. However the current educational system limits creativity by stigmatizing mistakes. Sir Ken Robinson (2013) in his TED talk comments that our educational system simply "kills creativity". Mistakes are the worst things students can make. The unfortunate consequence is we are educating students out of their original capacities. If teachers are not prepared to give students the chance to make mistakes, the latter can hardly be original. If students are not given the opportunity to fix their own mistakes, they will never build the confidence to deal with mistakes or failures in future. Seery et al (2013) have reported that some controlled adversity or setbacks in one's life can have a positive impact on one's optimal well-being.

Creative thinking usually refers to the generation of new ideas within or across domains of knowledge. It can draw upon or sometimes intentionally break with established symbolic rules and procedures. It usually involves the behaviours of preparation, incubation, insight, evaluation, elaboration and communication. (NC State University 2013). Creative thinking needs to be taught and cultivated but this information cannot be directly deposited into students' heads by educators. While the theories of these skills can be taught, it is the first-hand experience that can really internalize students' confidence to try new ideas that contain a risk of failure and taste the fruit of creativity.

Researchers have been experimenting with modern technology to enhance the teaching of creativity. This is a natural choice for optimal educational outcome since today's generation is growing up surrounded by a whole variety of technology based devices. Mitchel Resnick (2007) has been a pioneer in integrating technology and learning. He advocates the principle of the "kindergarten approach to learning" which is characterized by a spiralling cycle of Imagine, Create, Play, Share, Reflect, and back to Imagine. The cycle coincides with the behavioural pattern of creative thinking mentioned above. The argument is that the iteration of this cycle can help internalize creative thinking (I Create to Educate, 2013). In the traditional kindergarten environment, students are given various objects with which to play, wooden blocks, beads, drawing items, sandpits and buckets etc. In the modern environment with new technology there is the addition of new resources for learning creativity, from drawing artistic work on a computer screen, to playing literacy or numeracy focused games stimulating thinking. The more advanced development includes computer software that teaches programming skills with graphic interfaces such as Scratch (Scratch, 2013) that allows learners as young as 8 to create their own games and share their work. LEGO Mindstorms (Modern Teaching Aids, 2013) targets at a more advanced group and gives learners the opportunity to build interactive robots. Recently ScratchJr, a spin-off of Scratch, has been developed to target kids as young as 4 to program computers before they can even read (Reilly, 2013).

This latest advancement using technology for education also reflects Piaget's famous assertion that "Play is the work of children" (Teachosaur Thoughts, 2013). This constructionist approach to education demands that any educational software that aims at teaching creativity should integrate play, design and learning. It should also engage learners in personally-meaningful design experience (Papert, 1993). Research has documented positive correlations between students' creative thinking and their experiences with innovative design challenges (Kafai, 1995).

Another practical factor for any educational program design results from the recognition of students' relatively shorter concentration span, especially among primary school students. Resnick & Silverman (2005) emphasize that it is critical to make the specific features of a program as user friendly as possible so that students can quickly understand the basics before moving onto more imaginative and creative activities. Resnick (2005) and his research group in MIT embedded this principle in their development of Cricket and Scratch. These software packages enable students to fiddle and tinkle with onscreen building pieces to create computer games, interactive stories, animations, music and art. They can also share their creative work with others and build new ideas onto other students' work.

LEGO Mindstorms is a similar package for programming, as it also provides a visual graphics based interface lowering the entry level into computer programming. However, LEGO also requires the actual building of robots which develops students' engineering, spatial and motion control skills. The learning process adopts the same kindergarten approach. The LEGO package enables students to build dynamic and interactive robots with LEGO blocks and wheels and extend robots' capabilities with gears and various sensors. These robots are programmed by the students to perform interactive tasks. Students learn to build a construction to realize certain design perspectives. They also learn concepts related to sensing, feedback and control. In the process of playing with robots, through refining the building and fine-tuning the computer programs, students experiment, explore and test the programs and boundaries. Students learn about common patterns and generate their own rules of doing things. Creative thinking permeates the entire process.

The challenge with using LEGO for teaching creativity is the stereotype that the tool set targets at boys and even smart boys. An appropriate method must be used to engage a wider variety of students, especially girls. There are a few text based instructions on LEGO, these being only appropriate for students with a mental age of 14 to 15+ years that are equivalent to gifted Grade 6 to average Grade 8+ students. The argument is these students have either passed or are in the upper end of Piaget's Propositional or Formal Operations Stage (Inhelder & Piaget, 1958). They are able to handle abstract deductive logic as they generally have the reading maturity to be able to take a written description, translate that into an abstract mental 3-D model, and then bring that mental model into physical form by assembling various components into a whole.

However we wanted to extend the creative potential of a younger age group that had a mental age of about 10+ years, approximately equivalent to Grade 5+. These students are approximately at the upper end of Piaget's Stage of Concrete Thought (Inhelder & Piaget, 1958). We knew from considerations of Gardner's theory of Multiple Intelligences that if we could present the material in the context of what Piaget called concrete instances we may be able to present to this younger group material of similar complexity to that used with the 14 to 15 year-old students. The LEGO MindStorms robotics set with its NXT-G visual programming language provides the basics for a concrete representation in the programming interface. However additional visual support is still required to engage this younger group in both the building and programing of robots. A video based instruction delivery method is chosen as a result of these considerations. Remembering the concentration span of students in this group, we decided the individual videos were to be short, preferably less than 2 minutes. All tutorials were planned to be mainly inductively based, as few of the students had developed an ability to handle abstract deductive logic. We are aware of controversy regarding the respective merits of teaching deductive, inductive and abductive logic (Faulkner, 1992), but would justify our use of inductive logic in this case on two bases, one that it is useful, and the second that we believe that training in the use of inductive logic is important as many adults rarely have sufficient information to make purely scientifically-deductively-based decisions. In real life most people end up having to make inductively-based satisficing decisions. Starting out in 2007 with borrowed video and robotics facilities and no funding, we built up a series of tutorials based on these ideas, and used these to work with mainly Grade 5 and 6 teachers in robotics programs.

RESEARCH METHOD

The research aims at exploring the effectiveness of a video-based instruction in teaching robotics concepts and skills to young students. It follows the process of a website design and content development, to the testing of teaching materials via classroom usage and website hits as evidence of user acceptance and site popularity. Video recordings capture the data on students' participation and enthusiasm about the robotic activities developed for the program and analysis of the recordings give researchers some insights on students' skills in programming and creative thinking.

The project follows three design principles. 1) It provides a video based inductive approach so that it can cater for learners with limited reading skills. The use of individual videos allows the students to work at their own pace, freeing them from the "lock-step" approach inherent in some text-based approaches in delivering instructions. This particularly benefits both below and above average students, shy students, and takes account of the difference in ability of male and female students at this stage of their intellectual development. 2) It should encourage creative and independent thinking but in an unintimidating way. It should give students the opportunity to make multiple attempts, try various ideas without the fear of making mistakes. 3) It should introduce repetition of fundamental skills yet still maintain a fun learning experience. As is shown in DrGraeme's website content (Appendix 1) the skills in both the building and programming of robots are carefully structured to require repetitions but students are not aware of the repetitions. They are more focused on tasks. For example, building three different robots require the repetition of some basic building skills but each later robot needs the addition of some new items for more capable robots, such as more wheels for stability, choosing different wheels for different robotic challenges or floor surfaces, adding various sensors to detect external objects and using gears of various sizes or shapes to give action to more parts of a robot etc. In accordance with these building and engineering advances, the programming skills are incrementally introduced and enhanced. Repetition is the key to retention but care must be taken to reduce boredom in students. Taking a fun approach can help sustain students' interest and motivation to continue learning. The ultimate goal is to enable students to build dynamic and interactive robots that can solve real-life-like problems. In the International RoboCup (2013), one of the competition categories for junior students is Rescue in which robots mimic the real life scenario of rescuing humans in times of disaster.

The online website provides learning resources in modular format as shown in Apendix 1. Each module has a predefined objective with specific skills in robot building and programming. Each module builds on the skills of previous modules so that it becomes an iterative but progressive learning process. 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.

To give a purpose to the learning of specific skills, the program carefully designs a challenge for each module. For instance, the program that allows running in a curve builds on a previous module for running in a straight line. It is followed by the challenge "Far side of the Moon" in which the robot will start from the earth to complete a return trip to the moon (Appendix 1). A usual solution can involve a combination of straight lines and curves but the instructor sets no restriction on how a robot completes the trip so students can be creative in designing a path a robot takes. In our experiments with primary schools, students' solutions demonstrate extraordinary creativity. See Figures 1(a) to 1(h).

These modules initially use three different robots, each of which is relatively simple and quick to build. We found in our observations that the many re-builds gave students much more confidence when it came to tackling later challenges that require "free build" robots such as Robot SUMO, Minesweeper and Tug of War that are created in the program (Appendix 1). It also seemed to give the students more confidence and building skills when they were challenged by robotics competitions such as RoboCup 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 run their courses. This is the time for sharing among students and reflecting on various solutions for future improvement. These robot runs are also video-taped and uploaded onto the website to be shared with the online community. Recordings of participants' solutions to various challenges provide data on participants' engagement in the program, the creativity of participants in their solutions, and the programming skills they have learnt and applied in their robotic commands.

RESULTS AND ANALYSIS

The program has been adopted by multiple primary schools teachers in Tasmania and incorporated in their weekly teaching plans for over 6 years. It has also experienced world-wide success. The website (www.DrGraeme.net) that hosts the robotics program attracted 2 million hits from 158 countries in 2012 and Google Translate has reported translating pages of the website into 40 languages in response to user requests.

Video-enhanced inductive teaching approach

Resnick (1998) comments that there are different tool sets for different age groups due to the cognitive levels of students and the complexities of projects and their related concepts. Consequently developers of educational tools always have a target group. We have discovered in this research that adopting a video-enhanced inductive teaching method can help expand the range of target students, especially towards a seemingly lower cognitive capacity. Our experience with LEGO Mindstorms is a typical example. The tool set with its focus on robotics has always been perceived as a bijou toy for gifted, talented or predominantly boy students. However we have successfully used it in normal classroom teaching sessions engaging students of various capabilities. The authors have done weekly observations of five primary schools in Tasmania, Australia that integrate the use of the DrGraeme.net robotics materials for teaching. 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 tasks, 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.

Prince and Felder (2006) asserted that "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" (p123). To cater for various age groups our research uses video recordings as resources for students' observations on the types of robots that can be built and the tasks that can be achieved by some robots. Students can make up their own mind whether to repeat the processes in the videos or to follow their own creative paths, eg to design a different robot, to do a different set of tasks, or to complete a predefined task but in an innovative and unique way different from others. Equipped with these aims they search for required resources which can be LEGO pieces or desired programming codes suitable for the tasks in hand. They may engage in discussions and share tips with others. In the classroom with a collaborative learning environment students are subconsciously taking responsibility of their own learning. More capable students have the opportunity to engage in further explorations and thinking which result in more creative solutions to challenges.

Robotics for developing creativity and independent thinking

Recent psychology research has reported the significance of spatial ability in the development of creativity. According to the study reported by Kell et al (2013) tracking the career paths of 563 intellectually talented individuals over a 30 year span, the role of spatial ability is found to exceed those played by the traditional measurement in verbal and maths abilities. Spatial skills may be a greater predictor of the future creativity or innovation than math or verbal subtests of SAT tests, particularly if these people continue to work in math, science and related fields. Building robots with LEGO pieces is a valuable chance of developing 3D spatial skills. At the same time creative and independent thinking permeates through the entire process of creating an interactive robot. This creativity is demonstrated at every level of robot building. The challenge "Far side of the Moon" has the story line of the human exploration of the moon. The expedition is for a robot to start from the earth for the moon but circle around it before returning to the earth. This initial robotic challenge introduces the basic programming skills: moving in straight lines or curves, making turns and how to combine them to complete the expedition to the moon. Figure 1 reveals a range of diversity in students' solutions with each arrow line, straight or curved, one programming command. Students' solutions vary from using only one command to complete the task, Fig.1(g), to fiddling with numerous commands with additions of turning directions, Fig.1(h). Dirversity is the source of creativity.

When students advance to higher levels, creativity becomes an integral part of the game. Often, students need to design the final construction using different types of gears, different sized and types of wheels and a wide selection of sensors including light, ultrasonic, colour, pressure sensors etc. This exercise requires a high level of creativity as students can be restricted by available resources, the constraint on the size of the robots and the stability of robots. This complexity is further increased by the desirable capabilities a robot is programmed to demonstrate. A lot of times this process can be a trade-off between the engineering building solution and the programmed interactive ability of the robot. The "Tug of War" challenge can be a classical example. Working within the constraint of size and resources, students need to build a robot that is solid, that has the appropriate mass, to choose the type of wheels that give the best grip on the competition floor, to design the gears for minimum turning speed, to maximize the motor torque etc. Students can generalize a lot of rules from the process of refining their robots. Some rules are generic and can be applied to everyday science. Students may understand better why motor vehicles need regular checks on tyres for safety and how gears can be connected to enable multiple parts of a motor vehicle to work together.

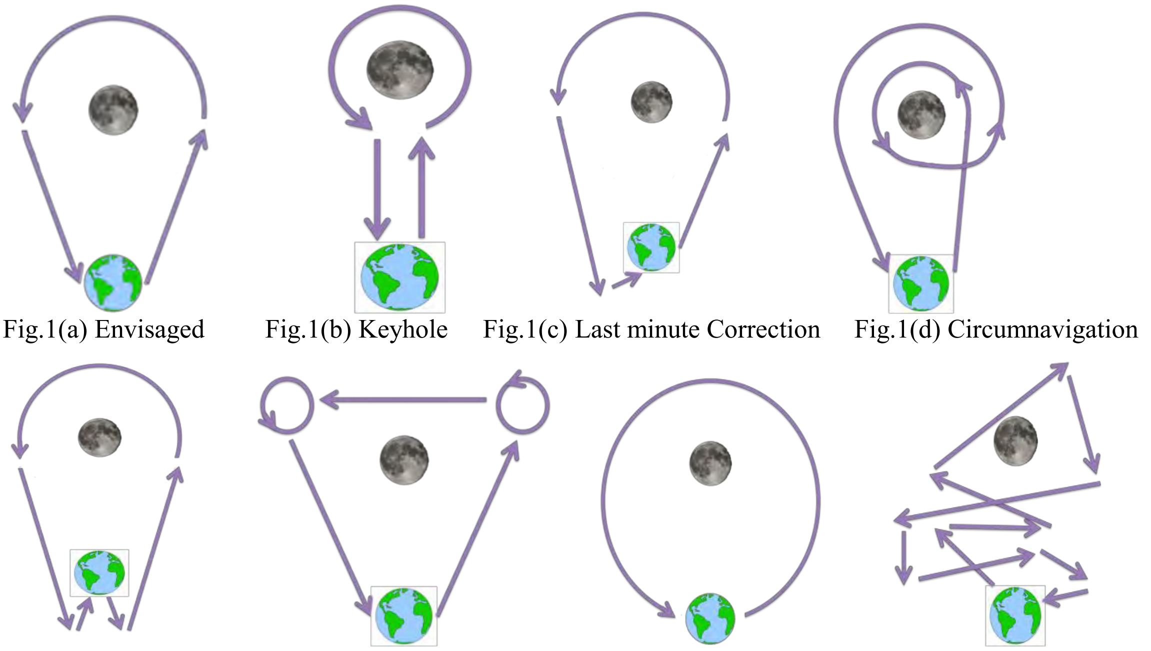

Fig.1(a) Envisaged Fig.1(b) Keyhole Fig.1(c) Last minute Correction Fig.1(d) Circumnavigation

Fig.1(e) Reverse Start Fig.1(f) Whirling Dervish Fig.1(g) One Command Fig.1(h) Apollo13

Figure 1: Selected student solutions to the challenge "Far Side of the Moon"

Tasmanian school students who have used the program have taken the skills to a whole range of robotics based competitions and events and have won multiple national and international titles. These competitions require the students to be more creative and independent in their thinking and problem solving approaches.

Repetition with fun

In a traditional classroom, teachers face two challenges. One is the varied concentration span of students and the other is the difference in the cognitive abilities of students. Some fast learners or those students with a shorter concentration span can easily get bored. Even though LEGO MindStorm is a child's toy for playing with robots, it is not a guarantee for success in a classroom setting. Robotics teaching programs that take the traditional text-and-deductively-based approach has been unsuccessful at the primary school level because they have required more advanced reading skills. In most cases they may require a longer preparation process before the learner can engage in creative tasks. Students can easily lose interest before even starting to have fun. However, with our video based inductive approach students do not need to understand text based materials or diagrams. Initial setups are made as simple as possible so that students can quickly move onto the fun part of robotics. Repetitions of skills are carefully scheduled and tied with near authentic purposes in the form of challenges to stimulate interest and to make learning more relevant. The program also facilitates individual learning paces so that it solves teachers' problem in trying to cater for different learners. Fig 1(f) is a good example of a fast learning student having the extra time to provide an additional interesting solution using a Whirling Dervish circuit (2013). With robotics program, students are not forced into a learning environment. They are playing with a toy and having fun. They feel in charge when ordering robots to do things for them. They have fun checking whether their robots behave and they will "fix" them if otherwise. Observation in a classroom setting shows that students are so involved in the program that they often lose count of time. There is so much enthusiasm from students that teachers have often found it difficult to stop some students for breaks.

CONCLUSION

This paper presents a web-based robotics teaching program that has successfully implemented a video enhanced inductive teaching approach that develops primary school students' robotic building and programming skills and stimulates their creative and individual thinking. The web environment with video clips as assistive self-paced learning method provides a safe and flexible working space for students from Grade 5 and above with varied cognitive capabilities. It is also effective for facilitating individualized learning in a normal classroom setting. We have demonstrated that combining skills consolidation with fun challenges can sustain students' learning interest, resulting in more opportunities for creation and originality. We have also noted that the level of enthusiasm towards robotics is similar between girls and boys at primary and early secondary levels, something that we would have expected at this stage of their development. We postulate that it is essential that these types of programs be introduced before physical maturation, when students' interests turn more towards "relationships". The successful results of this program suggest that it is worthy of further study, with a view to possibly wider adoption.

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Whirling Dervish circuit, 2013. Retrieved 10 October 2013 from http://www.youtube.com/watch?v=GJIofU-0jC0.

APPENDIX 1

www.DrGraeme.net content structure

Website Modules	Robotics Challenge List
Choose from MiniBot, TuftsBot or Bot-ticelli	Build first simple 2 wheeled robot
Introduce and download a program to the Robot.	Teach first robot to move
Introducing more robot abilities.	Teach first robot to smile, speak, and travel a pre-determined straight-line distance
FrostBot Robot.	Build second more advanced robot (3 wheeled)
Introduce Robot traveling in a curved path.	Robot travels "from the Earth, around the Moon, and back to land on Earth"
Robot path planning - students design their own robot path to "clean" the floor.	"Clean" a chequerboard floor by traversing all squares at least once.
Choose from ClareBot, DomaBot or new FrostBot	Build third robot, (3 wheeled robot with a light sensor)
Students invent their own program to use a light sensor to stay inside an enclosed arena.	Push all randomly-positioned "bulls" out of the ring without the robot leaving the ring.
Robot follows straight and curved edges and lines using light sensors.	Follow an edge using one light sensor Follow a line using two light sensors
Student Robot Design (or TasBot)	Build fourth robot which has mounting points for many sensors.
Robot versus Robot SUMO – students build their own robot designs.	1. SUMO using light sensor, 2. SUMO adding an ultrasonic sensor
Robot versus Robot Circuit Race – students build their own robot designs.	1. Circuit race using light sensor, 2. Circuit race using touch sensor, 3. Circuit race using ultrasonic sensor
Avoiding "mines" during a robot journey – students build their own robot designs.	Deliver goods from Home to a distant port, avoiding randomly placed "mines" along the way.
Extra Challenges requiring more advanced programming and building skills, including the use of gears – students build and program their own robot designs.	1. Build a robot that moves without using wheels. 2. Robot tug-of-war 3. Robot Catapult 4. Robot food foraging 5. Sound-controlled robot 6. Robot solves a maze. 7. Robot climbs steepest mountain. 8. Robot Soccer.