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An Action Research Report from a Multi–Year Approach to Teaching Artificial Intelligence at the K–6 Level

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Abstract

In Australia, the *Scientists–in–Schools* program partners professional scientists with teachers from K-12 schools to improve early engagement and educational outcomes in the sciences and mathematics. An overview of the developing syllabus of a K-6 course resulting from the pairing of a senior AI researcher with teachers from a K-6 (primary) school is presented. Now entering its third year, the course introduces the basic concepts, vocabulary and history of science generally and AI specifically in a manner that emphasises student engagement and provides a challenging but age appropriate syllabus. Reflecting on the course at this time provides an action research basis for ongoing maturation of the syllabus, and the paper is presented in that light.

Introduction

This paper provides an account of the first two years of an AI program within a K-6[1] school in Australia. The course is the result of the partnership of a practising research scientist with teachers from a K-6 school facilitated by the Scientists-in-Schools program. As the partnership enters its third year we provide details of and reflections on the course, its syllabus, the level of engagement and the effectiveness of teaching AI at the K-6 level. The program aims to utilise AI to provide an engaging theme about which to construct a broader interest in science and to introduce some of the basic concepts of science. Early indications are that a multi-year approach tailored for age appropriateness is showing promise but maintaining student engagement is critical and is supported by a multi-modal syllabus extending across several areas of the school curricula. The unstructured approach to the development of this course, punctuated now by a period of reflection, provides an action research basis for ongoing development (Pine 2008).

Scientists–in–Schools

The Scientists in Schools program is an initiative of the Australian Government funded through the Department of Education, Employment and Workplace Relations and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and it:

"... *promotes science education in primary and secondary schools, helps to engage and motivate students in their learning of science, and broadens awareness of the types and variety of exciting careers available in the sciences."— Dr. Jim Peacock, Australia's Chief Scientist 2006–2008*

Teacher–scientist partnerships are created through a matchmaking service provided by the program. Guidance, information and development activities are provided by Scientists-in-Schools but partnerships are unstructured in that the content and level of involvement are negotiated by the individual scientists and teachers. The partnership reported here is one of the more successful case studies and has benefited from an enthusiastic and supportive group of teachers and an experienced and committed scientist. For more information see http://www.scientistsinschools.edu.au/.

About the Authors

Dr Clint Heinze is an AI researcher with a background in intelligent agent research, software engineering and modelling and simulation in defence (Tidhar et al. 1999; Heinze et al. 2001; Heinze, Smith, and Cross 1998; Heinze et al. 2002). He has lectured in AI and software engineering at University level and is currently Head of Aerospace Operational Analysis in the Defence Science and Technology Organisation (DSTO). He has been involved in the Scientists–in–Schools program since 2008.

Janet Haase is the current principal of Manchester Primary School and a skilled senior teacher. The inclusion of the Scientists-in-Schools program at Manchester Primary School is part of a broader effort under her leadership to provide complementary extra-curricula activities within the school.

Helen Higgins has over 30 years experience as a K-6 teacher and is dedicated to the well-being and development of children through innovative curricula and placing high expectations on students and is a strong supporter of the involvement of science in her classrooms.

[1]Australian schools are normally designated P-6 or P-12 but despite the nomenclature there is no practical difference to the US convention of K-12.

Figure 1: Scientists-in-Schools is a program that partners professional scientists with teachers in an effort to increase educational outcomes in mathematics and the sciences. The type, content, and extent of these partnerships are at the discretion of the scientists and teachers involved and tailored to the needs of the students and the background of the scientist.

Manchester Primary School

Manchester Primary School[2] is a government P–6[3] school in the eastern suburbs of Melbourne, Victoria, Australia. It has a current enrolment of just over 300 students. It is a high-achieving school with a dedicated staff and excellent leadership. Student outcomes are high, particularly in light of its comparatively low Index of Community Socio-Educational Advantage (ICSEA)[4].

Pedagogy

The pedagogical basis for this course is provided by the central concepts underpinning teaching professionalism and policy in Australia, with a best practice approach from experienced teachers.

The Epistemology is not the Pedagogy

An important element of the success of this course has been the partnering of a career research scientist with skilled teachers. Few K-6 teachers would have the scientific knowledge necessary to develop a 7 year AI course and even fewer AI researchers have the knowledge of developmental psychology and pedagogical practice required to teach young children. A partnership of this kind is one of the few practical ways of delivering a high-quality course of this type, particularly one with a hands-on approach where students are encouraged to *do* AI as opposed to *learning about* AI (Papert 1972). The partnering of scientists with teachers provides a coupling of those with the content knowledge and methods and process knowledge of various disciplines (i.e. the epistemology) and those with the pedagogy. We would support the view that it is mistake to assume that the epistemology of a subject is the same as the pedagogy (Kirschner 2006).

A Continuous Multi-Year Approach

The life experiences, exposure to concepts and requisite background knowledge necessary to develop an understanding of AI are extensive and not present in young children. But by exposing students over their early education to the *building blocks* of AI it is possible to establish, albeit in a rudimentary way, the concepts that support deeper understanding in their later education. A focus here is on a staged approach over the students K-6 education where information is prioritised by its age-appropriateness rather than a structured syllabus that would be typical of University courses. Put another way, the concepts of AI are introduced, over the course of seven years in manner that is determined more by the age and capabilities of the students than by a logical structuring of the course content by topic. More generally this is true of the broader approach we have adopted to science with concepts such as hypothesis testing which can be introduced to five year olds in a play-based manner ("What do you think the robot will do if you push that button?") as a prelude to a more comprehensive account of the scientific experimental method in later years. There is no attempt to provide the students with an account of the structure of the AI course and classes are left deliberately unconnected. Llinks between subject matter across years of the course are left for the students to discover.

Age Appropriateness

A challenging curricula that sets high expectations of students is important in achieving excellent outcomes but recognising the limits of the capabilities of children to understand and integrate concepts is crucial. Surprisingly, some sophisticated concepts are grasped quickly while seemingly simpler concepts take much longer – anecdotal examples are given in later sections. As the course develops and lessons learned are fed back a better understanding of the capabilities and capacities of students is allowing refinement of the syllabus.

Curricula

With respect to the AI content we would agree with the general thrust of Sloman (Sloman 2010) though we would differ on many of the practicalities. A future paper will address this in greater detail.

Cross-Curricula and Multi-Modal Learning

Students are provided with a syllabus over the course of seven years that includes: an opportunity to play with robots; to program Artificial Intelligence; presentation of semi-formal lectures; the conduct of formal experiments; role-play as robots; and in the context of the cross-curricula approach to AI may produce related art work or stories. An

[2]Further information about the school is available from http://www.manchesterps.vic.edu.au/

[3]In Australia primary schools are generally, though not exclusively P–6, taking students from aged 5 until 12 or 13. These are broadly comparable to elementary schools in the USA.

[4]For more information on ICSEA and its use in measuring student performance see http://www.myschool.edu.au

action research approach to the development of this course took as an assumption that a multi-modal approach would be beneficial. There is little evidence that this is in fact the case, though increased levels of student engagement are reported. Similarly, it was assumed that a cross-curricula approach to the teaching of AI would provide benefits and incorporating science in general and AI in particular into other parts of the curricula also seems to aid student engagement. Robots built in art class, related stories written or read as part of a focus on literacy and elements of biology, history and philosophy can be carefully introduced. In many, perhaps most, western education there is a move toward cross-curriculum approaches in the teaching of science (National Centre for Initial Teacher Training in Primary School Science 2006).

Adding AI to the Science Curricula

A desired outcome of the Scientists–in–Schools program is to broaden the science vocabulary and literacy of students. Beyond the demonstration and introduction of the concepts and practices of science, it is important to integrate the ways of thinking about problems and the language of science into broader educational activities. Facilitating this requires the cooperation of teachers in extending and developing ideas talked about in the science program into other areas of the curricula. The AI syllabus of the course should be seen as part of a *whole of curricula* approach to studies that integrates, science, art, literacy, numeracy to improve outcomes across a broader base. There is evidence (National Centre for Initial Teacher Training in Primary School Science 2006) that a cross-curricula approach is effective at the K-6 level and though our experiences provide no real empirical evidence upon which to assess the efficacy, anecdotally the results are promising. Development of the curricula in coming years will examine this further. The study of AI is appropriate as it provide an entertaining, engaging, sustainable and developmental course that provides content that can support the needs of many students. AI provides examples that introduce the broader concepts of science and engineering and history, philosophy, biology and literacy are also introduced as a part of the AI curricula and in support of general cross-curricula studies. This integration of a broad based view of AI as part of a more holistic view of education would likely be supported by Sloman who argues for this approach at the undergraduate level (Sloman 2010).

There are some fundamentals of general science that are well covered by Australian K-6 schools - measurement, error, estimation, and elements of the natural sciences being good examples. Similarly many aspects of information and communication technology are well catered for, but there are critical aspects of science that benefit from greater reinforcement. To this end some of the topics introduced during the teaching of AI include the following.

Scientific method The scientific method is introduced in various ways at different ages. Very young students are asked to guess what might happen when they move near to a robot and older students are presented with more formal experiments to conduct on robots, computers and their classmates.

What is Science? A definition of science is introduced and discussed. The limits of the definition of science are explored in subtle ways and students are asked to consider where the boundaries of science are.

The History of Science For most classes care is taken to include a reference to a scientist or event that marks an important part of the history of science. Often this is done in passing and is not focussed upon to any extent and includes some small story about the scientist. The intent is to personalise the conduct of science and to show students that science is a field of human endeavour conducted by ordinary people. The intent is to create the impression (a true one) that science is accessible to them.

Invention and innovation Several classes have been devoted to invention and innovation. Students consider questions such as: "What are the most important inventions?", "Where does innovation come from?", and "Can a computer have an imagination?".

Philosophy Teaching AI provides many opportunities for introducing philosophy of mind and philosophy of science as additions to the primary focus. AI is an excellent subject for posing philosophical questions about the nature of cognition, the mind, the brain, and intelligence. To date the approach has been to leave most these questions unanswered by anyone but the students, although their ideas are occasionally gently drawn out and examined, the focus being on inquiry over knowledge.

Syllabus

The development of the syllabus has been largely unplanned, responsive and somewhat opportunistic. The description here tends to suggest a planned structuring that really was not present. An action research approach allows for incremental improvement and this post-hoc description of the first two years provides an indication of the direction the course is headed. It is important that any course of this nature fits within Governmental policy guidelines and Manchester Primary School is covered by the Victorian Essential Learning Standards (VELS) (Victorian Curriculum and Assessment Authority 2007), these define the content and style of education. The nature of the AI syllabus is described here in the context of the VELS levels(Victorian Curriculum and Assessment Authority 2007). Broadly the VELS are based on research into developmental psychology and pedagogy and we adopt a consistent approach (Bransford, Brown, and Cocking 1999). A very brief account of the emergent course Syllabus is presented ordered by VELS level and grade.

Level 1: Prep

For young students in their first year of schooling (aged 5-6) the focus is on imaginative play built around robots. Students are encouraged to explain the differences between robots: for example a programmed robot that behaves autonomously and a radio controlled car that is driven remotely. In pairs they play the part of a robot and a controller taking turns to command the other. These types of games build an appreciation of different levels of autonomy attributable to people, animals and various machines.

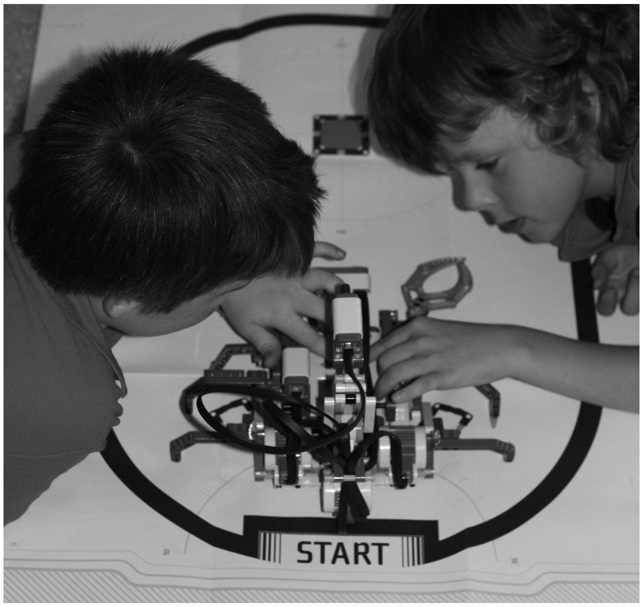

Figure 2: Grade 2 students with a standard Lego Mindstorms robot scorpion known as *Spike*. Discussions, demonstrations and play associated with different levels of autonomy in robots provides an engaging introduction to AI where the younger students require interactive play-based activities while still supporting scientific concept formation.

Level 2: Grades 1 and 2

A focus here is on the Lego Mindstorms Robots[5], different types of sensors and how they control a robot. Computer programming is introduced by talking about design, coding, compilation, testing, execution without actually doing any programming although different languages are presented and compared to English and other national languages. The idea of stimulus-response, in both robots and animals is presented and a class is devoted to senses and sensors, with students asked to consider how *we* perceive our world and the sorts of sensors that different robots might require. More generally we consider questions of the nature of science and philosophy and ask such things as "What is science?" and "What isn't science?".

Level 3: Grades 3 and 4

Using the Lego Mindstorms Robots students modify existing programs, observe the results and develop their own ideas for robot behaviour through design, code, compile and test. An experiment is conducted where students are given a robot and a worksheet that contains a partial description in pseudo-code of the program it will execute. The students conduct tests to determine the nature of the program and fill in the blanks in their worksheet. This gives them an appreciation for hypothesis testing, for reverse engineering and for some of the structures of computer languages represented in pseudo-code.

Java is introduced as a contrast to the Lego Mindstorms language and students shown the steps of design, code, compilation and test. The intent is not to produce students who are able to code in Java but simply to introduce the idea that different languages must be thought about in different ways. The graphical nature of the Lego Mindstorms language makes it an excellent choice for teaching students programming and a more traditional textual language like JAVA provides a suitable counterpoint.

Senses and sensors are considered again, building on their Grade 2 exposure and some more complex senses (proprioception for example) are discussed in the context of how machines might be given sensors with similar capabilities.

In many classes, art and literacy being examples, the idea of design before execution is encouraged at the school. This is reinforced in the context of robotics and AI through the use discussions, narrative, pseudo-code and pictures to describe the required behaviour prior to programming. Again the desired outcome is nothing more than students who understand the importance of design in the context of computer programming and are comfortable with the idea that behavioural descriptions for AI can exist in a variety of forms besides that of a computer language.

The role of AI in computer games is discussed, primarily because students are very familiar and very engaged with the subject matter. Semi-formal lectures in the history of AI in games are given. These lectures are a good introduction to the types of instruction that students will receive in higher education and are suitable for this type of content where holding their interest is never a problem.

Level 4: Grades 5 and 6

For the older students more structure is provided and the content is focussed on bigger issues of AI and cognitive science rather than the detail of programming and robotics. Topics covered to date include:

Cognition and the Mind Mind brain duality, do we really have a mind, what is it if we do, what is the difference between a robot and a human if we don't. Could we build a mind? Could we build a brain?

Video Game Opponents and the Turing Test Some multiplayer games support both human and virtual opponents. These games can be useful in providing students an environment where they attempt to differentiate real and virtual players. This simulation variant of the Turing Test is helpful in prompting consideration of issues in AI and provides an entertaining class as students try to guess which opponents in the game are their friends.

Change and attention blindness A class has been developed around a study of change blindness based on a set of great examples.[6] Students conduct an experiment to measure the time taken to become aware of a change in a

[5]For more information about Lego Mindstorms see http://www.legomindstorms.com, see also Klassner (Klassner and Anderson 2003) who describes the use of Lego Mindstorms for teaching AI in post K-12 contexts and Sklar et. al. (Sklar, Eguchi, and Johnson 2002).

[6]http://www.psych.ubc.ca/ rensink/flicker/download/

pair of flickering images and the results form the basis of a discussion about the reliability of our senses and cognitive function and whether or not a computer could be similarly tricked.

Errors A class is devoted to errors of two types. The first is a discussion that promotes the idea that science is one of the few professions where being wrong (in the context of an hypothesis) is valuable because knowledge is still generated. The second is a broader discussion about whether a computer can make a mistake and what it might mean if it does. What does it mean to "fool" a computer?

Insights and Future Work

Much of the development of this course has been ad-hoc, emergent and incremental and has the nature of action research (Pine 2008). Only a little initial planning was undertaken and for the most part the course has grown and changed in response to requirements. Some of the benefits we describe are post-hoc explanations of events, topics and synergies that were not initially planned. The students have surprised and inspired with their capability to understand and explain significant concepts and to see relationships between science and their everyday lives.

Insights

Insufficient evidence exists to be conclusive but insights and anecdotes from the first two years of the course include:

- Continuous engagement is important and students respond to a syllabus that builds over time and adds to their prior knowledge. The changes in learning styles and psychology of students as they develop from age 5 to age 12 are large and catering for this whilst maintaing some continuity in an AI syllabus is challenging but possible.
- It is important to not underestimate the students. Notwithstanding the need to provide age-appropriate materials it is often the case that providing content that is almost ridiculously challenging will sometimes result in astounding levels of understanding[7]. Grade 3 students can program robots using the Lego language and some Grade 6 students can design and write list sorting programs in Java.
- It is important to support different modes of learning. Some students grasp AI and computer programming by experimenting with robots, some by role-playing a robot-commander whilst a friend plays a robot, some by modifying existing source-code, and some by telling stories about what they would like a robot to do and seeing the translation into a computer language.
- Basic literacy, syntax and grammar are a barrier to computer programming when students are still developing their understanding of human languages. Experiments with easy to follow ”fill in the blanks” sheets where the basic structure of a robot controller was provided and the students were required to reverse engineer the details of the code by observing the behaviour of the robot where one helpful way around this issue. This proved to be a good way of blending hypothesis testing, the structure of computer languages and the fun of playing with different robots. The link between the structure of computer languages and English was drawn and the students where encouraged to write stories that included structures like ”if-then-else”.
- Object oriented concepts seemed to grasped (at least superficially) quite easily, possibly because of *Pokemon*, a metaphor that several students arrived at without prompting. Exposure to games where physical properties and capabilities (data and methods) are attributed to entities (objects) which also inherit characteristics of their "type" provide an excellent metaphor for OO. Pokemon, Magic the Gathering, and similar card based games provide a metaphor aiding the teaching of programming.
- The Turing test was grasped intuitively by students familiar with computer games as they were accustomed to the differences between human and computer entities in their multi-player games. Many could give a reasonable account of things that AI could not do. Unfortunately for the basis of the Turing Test, most students also thought computers substantially more intelligent than their friends indicating that, at least in their eyes, the Turing test was surpassed years ago. Discussions with students about the basis of a more traditional view of the Turing Test indicated that most students believe the Turing Test to be an inadequate test of intelligence, but the concept of the test was enthusiastically discussed. One of the authors has previously conducted similar simulation based variants of the Turing Test in a professional capacity and with secondary students where it was accompanied by a more formal scientific method (Goss, Pongracic, and Heinze 2000). Extending the Turing Test in line with these types of experiments is planned for the future with Grade 5-6 students.
- Most students seemed to grasp the idea that a computer language should be translated into a form that a robot could understand. Hence the need for a compiler or interpreter. Interestingly however, very young students wondered why a robot who could speak (through simple prerecorded snippets) couldn't understand English when spoken to it.
- The tendency to anthropomorphise robots was strong in K–3 students (much less strong by Grade 6) and students tend to conflate AI with natural intelligence. The large majority of a class when asked if a robot scorpion had feelings answered that it did, but when asked the same question about a doll the answer was almost unanimously no. By Grade 6 this anthropomorphism was gone. Older students understand that the robot does what it has been programmed to do in the context of environmental stimuli, younger students have a less clearly defined notion about exactly what sort of autonomy and intelligence a robot has. Educational issues aside this makes younger students much more fun to interact with.
- Many students like the link between playing with robots, making robots in art class and writing stories about robots.

[7] At least the scientist was astounded!

There is no evidence from our work that this has a direct educational benefit but it seems to aid engagement.

- It is not clear that content as technically and conceptually challenging as AI could be presented to young students without a partnership of scientists and teachers. Certainly the authors would heartily endorse it as a guiding principle for delivering positive educational outcomes of the type discussed in this paper.

Future Work

Future iterations of this course will continue to employ AI as the mechanism for introducing a more sophisticated view of general science into the curricula. AI is suitable because of the breadth of engaging and interesting subject matter. Almost any field of science can be made engaging but AI leverages the interest that almost all students have in computer games. A broader AI curricula that introduces basic concepts and exposes children to a range of interesting questions thrown up by AI is to be preferred. This much the same approach as has been taken previously in other fields (Carroll, Gaudagna, and Penningroth 2001).

There is a plan to increase parental involvement in the school science curricula. Scientists-in-Schools has tended to pair a single scientist with a teacher from a school (due to the relative scarcity of available scientists) but parents without a science background can play an important part in the understanding of science with relatively little instruction. Many parents (including the author) report children who spend (or desire to spend) too much time playing computer games. With imagination these games can be converted to science projects with educational content.

Integrating the general science and AI curricula with the Digital Excellence Program[8] and this is currently being pursued and the possibility of more formally structured Grade 5/6 Computer Programming Course is being investigated. There are significant impediments to the conduct of a programming course, not least of which is the time and opportunity cost considered against other educational priorities. Experiments conducted so far have include a computer game based version of the Turing Test and Change Blindness but more could be done to include the scientific method and formal experiments into the AI program. Finally, this paper is itself, an extension of the broader goals of the Scientists-in-Schools program as it provides the opportunity for teachers to collaborate with a scientist on the review and reporting of the course that together they conduct.

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[8]For more details of the Digital Excellence Program see http://www.digitaledgeltd.com/uk/index.html