The impact of humanoid robots on students' computational thinking

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Abstract: The aim of the study was to understand the impact of humanoid robots on student learning, the integration of the robots into the curriculum and the pedagogical approaches that enhance and extend student learning. This research is part of a larger three-year study and draws on questionnaires, interviews and journals from teachers. Collected data were triangulated to determine how the humanoid robots were utilised in the classroom and recurring themes were documented. The research findings are presented in a thematic style and provide an insight into the educational benefits of using humanoid robots. This paper will introduce the 4plus4 Model that describes deep student learning when an innovative technology such as humanoid robots is integrated into a revised pedagogy. The preliminary findings focus on the 4plus4 Model that represent a richer understanding of the deep student learning and this deep learning is evident across a range of contexts from early childhood through to secondary.

Introduction

Robots in their various forms are increasingly accepted as technological tools used in classrooms to teach students about Science, Technology and Mathematics. The popularity and interest in robotics amongst teachers and students are steadily growing and robotics is being integrated into the school curriculum. However, the introduction of programming humanoid robots is relatively new to schools in Australia and pedagogical approaches and teaching strategies are still being devised. With technologies such as the NAO humanoid robots, students not only have to learn computer programming to control the robot but also to control the social behaviour and interactions with the humanoid robot.

This project aims to evaluate how humanoid robots are used in the early learning childhood, primary and secondary school curricula. Through the deployment of humanoid robots in schools and early childhood settings, the researchers want to understand how these devices are used by teachers to promote engagement and deep learning. The project also addresses the need to find the appropriate learning areas in the curriculum to integrate humanoid robots.

LEGO® robotics platform has been well established in education for over 20 years; however, humanoid robots are relatively new and the two platforms are distinctly different. The LEGO platform of robotics allows students to construct a robot with the use of LEGO blocks, sensors and motors. The LEGO platform is commercially available and programmable through drag and drop software or RobotC code. In contrast, the NAO platform is expensive and non-configurable. The robot is pre-assembled and takes the shape of a human form with two arms, two legs, a body and a head. Standing at 58cms tall, it has 25 degrees of freedom to allow movement of all of these parts. The robot senses and movements emulate human interactions, such as sight, sound, touch and social behaviours which can be programmed through drag and drop software or through Python code.

Over the past twenty-five years, many methodologies, courses, initiatives and competitions have been developed in the context of educational robotics. There is a consensus that robotics in education is valuable (Bredenfeld, Hofmann, & Steinbauer, 2010); however, the lack of empirical evidence to prove whether there is an impact in early learning centres (ELC)-Year 12 education still remains (Williams, Ma, Prejean, Ford, & Lai, 2007). One of the early supporters of robotics in education was Papert (1993) who believed in robotics and its potential to improve student learning. As teachers began experimenting with the technology, they found that the interdisciplinary nature of robotics made them valuable in Science, Technology, Engineering and Mathematics

(STEM) subjects.

There is an alignment between robotics and constructivism. Constructivism describes learning as being actively constructed by the learner, with the learner engaged in the learning, rather than passively receiving information (Piaget, 1973; Sjøberg, 2007; Vygotsky, 1962). Working with humanoid robots encourages a constructivist learning environment and builds on the mastery of the 4Cs that have been identified as important skills for students to develop. These 4Cs also known as 21st century skills have been identified as communication, critical thinking, collaboration and creativity (AT21CS, 2012; MCEETYA, 2008). Keane, Keane, and Blicblau (2014) state that appropriate situations need to be created to allow students to develop a mastery of the 4Cs and the use of humanoid robotics affords an environment where students can solve real life problems or conduct experiments, based on their interests and their skill level. This type of environment according to Alimisis (2012, p. 2) can engage "students' curiosity and initiate motivation."

Curiosity can be a powerful motivator of behaviour, initiating actions directed at exploring one's environment to resolve uncertainty and make the novel known (Arnone, Small, Chauncey, & McKenna, 2011). However, curiosity on its own does not foster deep learning. For deep learning to occur students are required to form judgements and think conceptually over longer and complex tasks. This in itself is challenging and stretches the thought process of students. According to Fullan and Langworthy (2013, p. 17) "technology can play an indispensable deepening and accelerating role across all education processes."

Method

In this project, two humanoid robots were deployed into various schools for a period of eight weeks each. Each school was considered as a separate case study from the perspective of the "qualitative or naturalistic research paradigm" (Merriam, 1988, p. 3). As the investigation is focused on description and investigation rather than on cause and effect, the research focus was on the impact humanoid robots have on learning and engagement in the classroom. The case study approach was chosen for a number of reasons; it was important to understand what was being done by teachers and students, the depth of the learning and the classroom context.

Multiple case study design (Simons, 2009; Stake 1995) was selected to investigate the use of the humanoid robot in different school settings and contexts. This allowed for exploration of the robots in school settings as well as enabling a comparison. While Stake (2006) argued that between four and ten cases is the preferred number when conducting multiple case studies, others make no such distinction (Yin, 2003). This research used five case studies both for richness and to be inclusive of all of the schools that participated in the study in the first year, however in this paper, we will be discussing the commonalities that have been identified.

Sample and Context

This study is based on the findings from the first year of a three-year collaboration with the Association of Independent Schools of South Australia (AISSA). The AISSA purchased two NAO humanoid robots (P!nk & Thomas) to use in independent schools in South Australia. The AISSA allocated the robots to selected schools for a period of eight weeks and sent out a call for interest in using the robots. The schools were invited to submit a proposal outlining how the school intended to incorporate the robot into student learning. The principals approached teachers and together the interested team wrote up an expression of interest to participate in the study. The university researchers were not part of the selection process, and their involvement commenced once the robot had completed its time in a school.

Before the humanoid robot was deployed in each school, the AISSA offered two days of professional learning to the participating teacher/s from the school. The professional learning outlined the project aims, emerging themes from the research and it was also designed to support teachers to program and code the robot. During the workshops teachers were encouraged to consider their pedagogical approach and data collection that would provide them with insights into student learning. At the end of each school term, participating teachers provided research data through:

- an online questionnaire;
- reflective journal; and
- a semi-structured interview

and this was collected by the researchers.

An AISSA researcher regularly made contact with participating teachers via email, phone calls and school visits.

The researcher took on the role of a critical friend to provide ongoing support to the teachers, collect data and disseminate ongoing findings from the project across the schools involved in the research.

Sources of Data

Twelve teachers were involved across the five schools. The participants represented a diverse range of teacher experiences, teacher career stages and attitudes, skills and confidence regarding digital technology. The teachers came from a variety of learning contexts from Early Learning Childhood (ELC) to Year 10 and represented a range of learning areas and subjects. In addition, the teachers were situated across a variety of demographic and socio-economic contexts including rural, semi-rural, inner metropolitan, small schools through to large schools, and low fee through to high fee paying schools. Each school was considered as a separate case study.

Table 1: The breakdown of participants in this study

Case Study	Stages of Learning	Teachers Involved	Classes Involved
1	Secondary	1	1
2	Primary	1	8
3	ELC/Primary (Lower)	6	4
4	Secondary (Lower)	3	4
5	Primary	1	2

In each school, multiple forms of data were collected to develop an in-depth understanding (Creswell, 2008). Data collection methods included questionnaire, semi-structured interviews, classroom videos, student work samples and reflective journals. To protect confidentiality each participant was assigned a pseudonym.

A mixed method was chosen as the method of evaluation because it was sufficiently open-ended to enable the researchers to reflect the complexity of all the cases. All sources of evidence were reviewed and analysed together, so that the study's findings were based on the convergence of information from different sources, not quantitative or qualitative data alone.

Questionnaire

A questionnaire was used to elicit qualitative responses. The questionnaire consisted of 24 questions and was delivered electronically to participants at the conclusion of the eight weeks. The questionnaire was mainly qualitative in nature and involved a series of open-ended response questions. Free text entries from the participant data were read repeatedly to enable the coding and categorisation of responses. This qualitative data analysis method was informed by the work of Boyatzis (1998) and Bogdan and Biklen (2003).

Reflective Journals

To facilitate reflective practice, scaffolded reflective journals were used in this study to help teachers reflect on the integration of the humanoid robot within their classrooms. The reflective journals used in this study provided participants with the means to move beyond focussing on skill development in digital technologies by providing scope for challenging existing beliefs and about pedagogical practices that promote deep student learning (Koszalka, 2003); about how their class engaged and interacted with the robot; the benefits for students; and any frustrations and concerns that occurred with the technology. The participants were also asked to provide suggestions and sample activities for other teachers exploring ways to integrate humanoid robots within the Australian Curriculum.

Interviews

Semi-structured interviewing was used in this study for the purpose of collecting teachers' responses for this research. During the interviews, teachers were encouraged to discuss their experience working with the humanoid robot in the classroom. Questions were developed to act as an initial guide in framing the interview but also allow for the teachers to discuss their experiences from using the humanoid robot with their students (Kvale & Brinkmann, 2009). A response to one of the questions often raised other questions, which the interviewers then pursued. The questions, served as a guide to ensure similar ground was covered in each interview. The benefits of individual interviews allowed for self-disclosure and for the participants' views to be clearly articulated (Fontana & Frey, 2000). Interviews ranged from 45 to 60 minutes.

Results & Discussion

At the end of the first year of our three-year research project, a number of emerging themes became evident, *curiosity*, *challenge*, *collaboration*, *communication*, *critical thinking*, *creative thinking*, *computational thinking* and *coding*. The themes have led to the development of our *4plus4* Model in Figure 1 and it is these themes that are the focus of this paper.

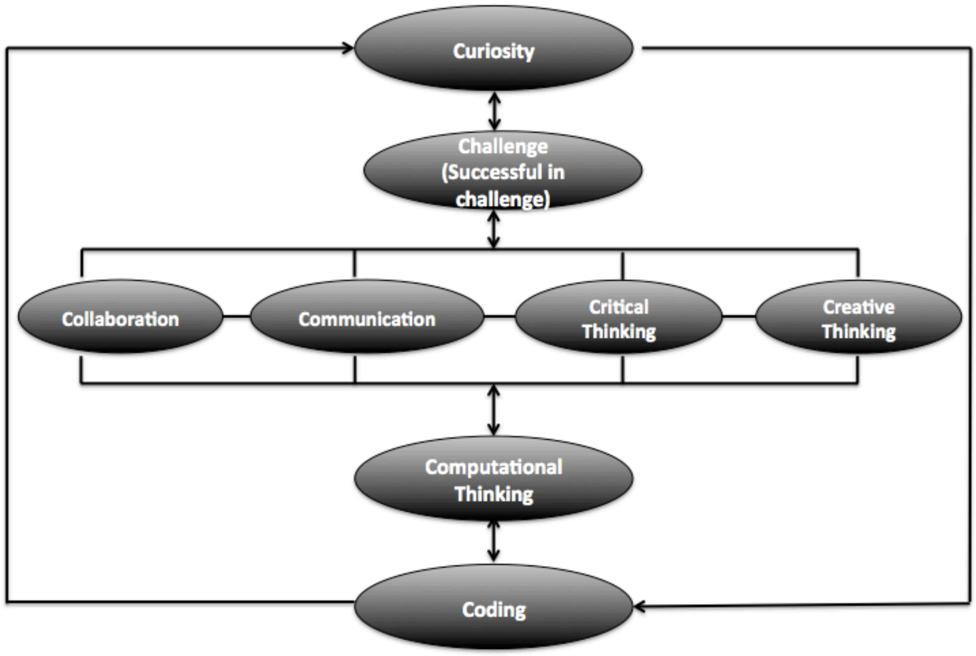

Figure 1: 4plus4 Model

The *4plus4* Model highlights that *curiosity* arises from the engaging nature of technology and is a powerful motivator to explore and develop new ideas. This natural curiosity inspires students; however, *curiosity* on its own does not foster deep learning. *Curiosity* is enhanced by the complexity of the task and, combined with the *challenge* of solving complex open-ended learning tasks, can facilitate deep learning. The 4Cs supports students with complex challenges by getting them to *creatively* and *critically* look at problems in new ways, through the *communication* of ideas, and *collaboration* to develop solutions to the task. Through the 4Cs, *computational thinking* is supported as it allows students to collaboratively develop procedural thinking by breaking complex challenges into smaller tasks that can be solved. When *computational thinking* skills are developed, *coding* skills are expanded, as students build on their own and others' ideas. The *4plus4* Model highlights how students can achieve success in computational thinking and coding by incorporating the 4Cs and combining their natural curiosity in solving complex challenges.

Curiosity

Curiosity was a pivotal theme that became evident in both teachers and students who engaged with the humanoid robot. This curiosity arose from the "irresistibly engaging" nature of the technology and this irresistibility is described by Fullan (2015, p. 6) as the first of the five elements essential for deep learning. The human like characteristics of the technology sparked an unexpected emotional connection with the device even though there was a conceptual recognition from the 4 years olds through to the 15 year olds that the robot was really just programmable hardware.

> The children have surprised me with the level of empathy they have shown Thomas. I was impressed that when he fell over....they all quickly said, *Are you OK Thomas*? They have treated him like a human from the start. (Sylvia, ELC teacher of 4 year olds)
>
> One thing that emerged was that they saw P!nk as their robot friend- some (students) even said she was like their little sister. (Shannon, Year 8 Maths teacher)

Curiosity about this human-like friend was identified by the teachers as an important motivational factor that underpinned the acceptance of the robot in the classroom. The intentional human like design of the robot, and the mimicry of particular human traits made the technology seem familiar and led the students to quickly accept the robots. In all the case studies, the students developed a relationship with the robot and personified the robot by referring to it by its given name of P!nk or Thomas, or the appropriate gender based pronoun. Almost immediately, all interactions with the robot were fuelled by the students' curiosity about their new friend.

> Initially some students were wary of her, but a small group immediately went to the robot and wanted to engage. When asked at the end of the project why they did this, they said that they were curious. (Shannon, Year 8 Maths teacher)

As part of developing computational thinking skills in Shannon's Year 8 Maths class, students were asked to develop a program for P!nk. Curiosity was a strong motivator for the students. Maud, one of the Year 8 students was curious about the degree to which she could control the robot's behaviour. The teacher reported that curiosity inspired Maud to create a game to be enacted by P!nk that required the student to learn how to use a range of complex, unfamiliar software such as voice recognition and to embed sound files of famous cartoon characters into flow charts. The game Maud created required embedding branching into her coding. Maud was continuously motivated because she could instantaneously assess the efficacy of her program through P!nk's interaction. This instant feedback fuelled her curiosity, which led to the ongoing refinement of her code to achieve her goal.

Challenge

One of the most significant findings from the NAO humanoid robot project is the interdependent relationship between curiosity and complexity. Teachers claimed that the sophistication of the robot challenged students to master the software, thereby fostering deep learning.

Teachers reported that through their initial curiosity, students were intellectually engaged with working with the robot. They developed strategies to enable them to solve problems and then created and refined code to make the robot behave according to their plan. Most students chose projects that were very challenging and the successful execution of their intended robot behaviour necessitated significant, new learning.

> The girls then moved on to advanced manual coding. They worked individually …. and used complex software to successfully develop their own coding sequence, creating their own boxes. Each of the girls had a goal they wanted Thomas to achieve and developed their own coding program to achieve this. They used a virtual robot to trial their sequence until they had achieved mastery and were ready to trial it on Thomas. (Amelia, Year 3 Class teacher)

Students were highly aspirational in the design and development of their projects and chose tasks that had higher degrees of difficulty than their teacher would have set. Inspired by their natural curiosity and motivated by the challenge, students were highly engaged in working closely with their humanoid robot as seen by the following examples.

> A key theme of the work with the NAO - curiosity, persistence, engagement and self directed learning. (Shannon, Year 8 Maths teacher)

> The persistence that I saw students demonstrate during our coding lessons was incredible. I believe that this was the greatest benefit for the students in my class. (Amelia, Year 3 Class teacher)

Interestingly, some teachers commented on students who persevered with working with the robot as they were intrigued about how they could make the robot emulate the tasks they had designed.

Differentiated Learning

One of the most surprising findings was the provision of differentiation. The ability for the teacher to adjust the content and complexity of the tasks gave students confidence in their interactions with the robot. It afforded students the ability to extend their learning and challenge their skill level. The accompanying humanoid robot software provides a range of entry points for students from 4 years of age to Year 10.

> It would vary for each individual - but there has certainly been a depth of learning that has been evident. (Melanie, Foundation Class teacher)

Even more intriguing, is the evidence that within each class group there were multiple approaches by which students could engage with the robot and be challenged. Teachers stated that the robots provided a classroom where differentiated, self-directed learning took place.

> The fact that each child could interact [with Thomas] at their own level was amazing. (Melanie, Foundation Class teacher)

The challenge of the open ended learning task permitted students to create programs that stretched their intellect while remaining within their zone of proximal development (Vygotsky, 1962). Another unexpected insight from teachers was that the robot differentiated learning by providing particular benefits for some learners. Sally commented:

> One theory has been floated that the students who struggle in school have had lots of experience getting things wrong and don't fear mistakes - either way this skill has definitely benefited them when coding robots. (Sally, Primary ICT teacher)

Sally expanded on this concept and highlighted how the robot not only extended learners with the particular skill sets of creativity and risk taking, but also leaves hanging some questions about the attributes traditionally encouraged in students:

> It seems the creativity and risk taking when coding with NAO [humanoid robot] plays to the strengths of these students [not traditionally academic]. It's lovely to see these students become recognised experts for their peers and have their time to shine. (Sally, Primary ICT teacher)

Shannon, a Year 8 Maths teacher, felt that high achieving students also needed to be encouraged, especially with complex tasks.

> The other benefit is that it really stretches those students who excel in conventional education. They get frustrated and can have a tendency to give up because instant success just doesn't happen. If encouraged and given a chance to think things through they will recover their equilibrium and give it another try. (Shannon, Year 8 Maths teacher)

Martha and Amelia, both primary school teachers, agreed that when students engaged with the humanoid robots they learnt new insights about their students:

> I don't yet understand why, but some students who struggle in other subject areas pick up programming easier than others. Maybe some students prefer ordered thinking. (Martha, Primary school educator)
>
> Having the NAO [humanoid robot] will show you more about a student's way of thinking, abilities and strengths than any test will ever reveal. (Amelia, Year 3 Class teacher)

Amelia, Martha, Shannon and Sally believed that engaging with the humanoid robot not only led to differentiated learning, but also provided a unique lens for the teacher to gain powerful new understandings about the learning strengths of their students. These important new insights provided teachers with the knowledge to accurately tailor learning opportunities that challenge and extend students. For Shannon, there was a moment towards the end of P!nk's time at her school that she realised that the students in her Maths class were very different from students she had taught in previous years. This insight made her realise she needed to change her pedagogy to provide a stimulating environment for learning and discovery. She needed to turn to her students to understand how she could encourage and stimulate their learning.

> I had a moment, I had an epiphany, where I lay there and I just went, *I thought I got it, but I really, really didn't, now I do*. These little darlings [the students] are very, very, different, in a good way and we need to harness this and we need to be responsible in the sense of saying *You guys, you've got creativity, you understand technology, you've got originality and curiosity, how do we help you use that in ways to make things better*?
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> To me it just feels like an opening up of what I believed, but much bigger...This [epiphany] would not have happened without P!nk in the classroom. (Shannon, Year 8 Maths teacher)

The importance of revising pedagogy is emphasised by Fullan and Langworthy (2013), who argue that only through pedagogical innovation will technology be able to "achieve its potential to impact learning" (p. 21).

Collaboration, Communication, Creativity, Critical Thinking

Teachers also identified other skills developed with integration of the humanoid robot in their classrooms; collaboration, communication, creativity and critical thinking. These skills, grouped together are also known as 21st century skills (AMA, 2010; AT21CS, 2012; Keane et al., 2014; MCEETYA, 2008).

> The open-ended opportunity presented by NAO [humanoid robot], combined with the high engagement has meant the *21st Century skills* -creativity and innovation, critical thinking and problem solving, communication, digital literacy, collaboration and leadership- are presented by students. (Sally, Primary ICT teacher)

The study found that embedding innovative technology such as the humanoid robot into the classroom encouraged both teachers and students to communicate their ideas and understanding, creating a more collaborative classroom. Teachers in this study described how everyone became part of a learning community where the learners brought various skill sets to the community. It changed the relationship in the classroom between the teacher and students and provided further understanding of the impact of innovative technologies on new roles for teachers (Fullan & Langworthy, 2013).

> Often the sequence would not run as the girls wanted it to and I was amazed to witness the conversations and problem solving that took place. Often peers would be able to help problem solve and offer suggestions to get the program to run effectively. (Amelia, Year 3 Class teacher)

As humanoid robots are relatively new to ELC-12 classrooms, teachers have not had the body of knowledge from their own experience or the ability to learn from other teachers' experiences. Teachers were exploring how to use the robot whilst working alongside their students. Teachers reported that when the humanoid robot joined the class and questions arose about how to program a particular robot behaviour, the students and teachers quite naturally crowd-sourced possible solutions from everyone present.

Our preliminary findings support Fullan's (2015) view that the very nature of disruptive technologies often changes the teacher's pedagogy, and our data provides evidence of teachers actively promoting in their classroom and beyond a collaborative community of learners. An unexpected finding from this project has been the depth of collaboration between educators within schools and across schools.

> Collaboration between educators was also extremely beneficial throughout the project work. It was also important to document every phase. This helped to take the project to a deeper level. (Sylvia, ELC teacher of 4 year olds)

To develop their programming ideas into actuality students needed to problem-solve to extend existing NAO [humanoid robot] routines and to pursue the more complex ideas they wanted to include. Students' ideas and coding skills expanded, as they experimented with programming the humanoid robot by building on their own and others' ideas.

> Creativity and originality were key for the students - they saw some of the routines that the NAO [humanoid robots] could perform and that gave them ideas for their own projects. However, they didn't want to copy the code or routines but make their own. (Shannon, Year 8 Maths teacher)

Teachers reported being surprised by the high level of creative and critical thinking that the students brought to the task. Students were successful in creating programs for the humanoid robots, critically evaluating ideas and refining them to accommodate their expanding coding skills to constantly improve the functionality.

> The students were able to demonstrate their ability to be both creative and innovative through their experiences with the NAO humanoid robot. They were able to design individual sequences to teach, play and do chores. (Malcolm Year 3 Class teacher)

Computational Thinking

21st century skills identified as collaboration, communication, creativity, and critical thinking (4C's), are important skills, combined with computational thinking. According to Wing (2008), "computational thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science" (p. 33). The connection of thinking skills to computer science was also evident in this study.

> The NAO humanoid robot promoted computational thinking…[the students were] able to solve problems, design sequences, and understanding robotic behaviour that draws on concepts fundamental to computer science…this will assist them to be computational thinkers which is a fundamental part of the way people think and understand the world. (Malcolm Year 3 Class teacher)

Teachers identified a number of skills that students adopted related to computational thinking including: problem decomposition, algorithmic thinking, problem solving, designing sequences, and testing and debugging. The students represented their solutions as computational steps and algorithms.

> Those who were programming the robot did engage deeply with algorithmic thinking and had to consider the necessary steps to achieve the desired outcomes in terms of movement, synchronized speech and the listening functions. All of which required multiple tests and adjustments. (Aaron Language and Robotics teacher)

The skills identified by the teachers in this study are similar to the computational thinking concepts identified by Yadav, Mayfield, Zhou, Hambrusch, and Korb (2014). These computational thinking concepts are based on Papert's (1993) work on Logo programming language and the idea that computers can allow children to develop procedural thinking through programming.

Coding

The Students' curiosity in engaging with the humanoid robot extended to using the humanoid robot's drag and drop programming software and in some cases students used Python to code. Python is a high level programming language used by many professional programmers. Most of this coding was done without prior knowledge of robotics and limited knowledge of coding. The students developed a deeper understanding of coding as they experimented with the software and Python, engaging in real-world tasks and pursuing their own interests. Even the very youngest students in this study learned how to program the robot by pasting paper based, instructional icons onto a sheet of paper. The students then used string, wool or felt pen to connect the icons as a visual representation of their flow chart.

> They worked with a buddy to design their own coding sequence on paper using string to join the sequence together. At the end of the lesson we programmed Thomas to complete some of these sequences and had some sharing time. My girls loved this experience and enjoyed having the opportunity to share their knowledge with others and be the teacher. (Amelia, Year 3 Class teacher)

As students engaged more with the robot, they tried more complex programming and took risks as they tried to achieve their vision of what they wanted the robot to accomplish.

> High levels of risk taking in both male and female students - whatever they could imagine doing with the NAO was what they wanted to try. They imposed few limits on what they wanted to try which is entirely the point of having students learn to code. The fact that their work came to life in front of them gave them more encouragement to keep trying. (Shannon, Year 8 Maths teacher)

The teachers in the study reported that their students found the humanoid robot to be very engaging and it sparked the students' interest in coding and robotics. Being able to code and problem-solve with robotics and other technologies are important 21st century skills that need to be developed. One teacher commented:

> I see humanoid robots having an important role in schools. I believe that an exposure for all students from ELC to Year 12 is important. I believe that coding and robotics should become a part of the school curriculum. Humanoid Robots' role in our world is constantly evolving. The students in our care have a right to be exposed to this type of technology. (Amelia, Year 3 Class teacher)

Conclusion

This research paper is part of a three-year study investigating the impact that humanoid robots have on student learning and engagement. The use of humanoid robots in schools has been recent and our findings confirm previous research conclusions that technology engages students in their learning. While this finding is neither new nor unexpected, our study has shown that engagement with humanoid robots promotes curiosity, challenge, critical thinking, creativity, collaboration and communication. Our early findings have identified that curiosity and challenge foster critical thinking, creativity, collaboration and communication and that enables the development of high level skills in computational thinking and coding as described in our 4plus4 model.

Humanoid robots were deployed in a variety of school settings to investigate the most appropriate contexts to promote deep learning. Our initial findings suggest that humanoid robots had an impact on the learning of students from ELC-Year 10. Students embraced the humanoid robot technology with relative ease and initiated challenging, self directed projects typically without any prior knowledge of robotics and limited knowledge of coding. Teachers reported that the complexity and sophistication of computational thinking and coding surpassed their expectations and made them see their students in new and different ways. This finding challenges not only long held assumptions about students and their learning potential but also teaching strategies and methods. The use of humanoid robots in the classroom allowed for differentiated learning and provided the opportunity for students to personalise their learning. Teachers noted that student learning extended well beyond the expected skill level for their age in computational thinking and coding. Interestingly, for some students, their motivation was so high that they self taught Python, a high level programming language.

As humanoid robots are integrated into the Australian Curriculum our findings indicate an increase in student engagement, differentiation of student learning, self directed learning, deep learning, and a fostering of the 4Cs (creativity, collaboration, communication, and critical thinking). These transformative classroom practices enable students to use the technology in ubiquitous ways and through this use, unlock their potential to engage in complex computational thinking. The next stage of this research will consist of applying the 4plus4 model in a variety of school settings and investigating the use of robotics across a range of learning areas. As such, the prospective study will continue to build on our understanding of the impact of innovative technology in this rapidly changing educational landscape.

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