Using a Computer Programming Environment and an Interactive Whiteboard to Investigate Some Mathematical Thinking

Merilyn Taylor\textsuperscript{a,\ast}, Ann Harlow\textsuperscript{b}, Michael Forret\textsuperscript{c}

\textsuperscript{a,b,c}\textit{Faculty of Education, University of Waikato, New Zealand}

Abstract

Scratch is a free graphical programming language designed for children to create their own interactive games, animations, simulations and stories. Scratch provides a virtual space where children use some mathematics ideas in order to build their own animated artefacts. This paper reports on some preliminary findings from a research project where two elementary teachers in an urban New Zealand school introduced Scratch to nine and ten year old children in their classrooms. In each of the classrooms a small number of computers and an interactive whiteboard (IWB) were utilised. This paper uses a case study approach to describe how engagement with Scratch and independent use of the IWB enabled children to work collaboratively to solve design challenges. Initial results indicate that the Scratch program is engaging for children. It created an environment where the children were, by necessity, using problem-solving processes such as goal setting, and generating and testing of ideas. The interactive whiteboard afforded rich opportunities for children to collaborate and share their thinking. Some questions and implications for the learning and teaching of elementary school mathematics are explored at the conclusion of the paper.

© 2010 Elsevier Ltd. Open access under CC BY-NC-ND license.

Keywords: Elementary mathematics; Interactive whiteboard; Computer programming

1. Introduction

There is an expectation in New Zealand schools that children will be offered opportunities to explore ways in which information and communication technology (ICT) might provide new ways of learning (Ministry of Education, 2007). It is also anticipated that children will learn subject specific knowledge and develop “capabilities for living and lifelong learning” described as “key competencies.” These key competencies are identified as: thinking; using language symbols and text; relating to others; managing self, and participating and contributing (Ministry of Education, 2007). 21st century learners are expected to find out about and understand a range of concepts (including mathematical concepts) and learn to problem-solve, work collaboratively and represent, negotiate and communicate ideas in creative and critical ways (Ministry of Education, 2006).

The three aspects, (mathematics, key competencies, and ICT’s) need to be connected by teachers’ planning (Hunter, Keown & Wynyard, 2010). Recent research into interactive whiteboard use shows that it is the teacher’s...
orchestration of the learning environment and the ways the teacher integrates the use of the IWB features into a student-centred pedagogy that is the key to the development of pupil competencies (Harlow, Cowie & Heazlewood, 2010). The blending together of mathematics learning, key competencies, and ICTs brings challenges for both teachers and children. Children can be expected to engage in cognitive and social challenges and have control of learning in ways that would not be possible without each component (Dockett, Perry & Nanlohy, 2000; Zucker, 2008). Thus, within a digital environment, it is the available hardware and software that frame the nature of the learning in distinctive ways (Calder & Taylor, 2010).

ICT tools can help children to design and develop representations, refine and interpret their thinking, and evoke dialogue in varied ways as a task is engaged in and reflected upon. An interactive whiteboard (IWB) can provide the focus for group collaborative work, provided children can and will support each other, understand the nature of what the task expects of them, and have a collective responsibility for the task itself (Warwick, Mercer, Kershner & Staarman, 2010). An IWB enables children and teacher to have access to, and be able to interact with, all the functions of a desktop computer (Murcia, 2010). The benefit of the large screen is that it enables a physical and cognitive space for collaborative problem solving in which information can be easily shared and discussed in a public way (Wegerif & Dawes 2004). Although an interactive whiteboard is not designed specifically to foster collaborative learning, it has the potential to aid collective thinking and learning (Warwick, Mercer, Kershner & Staarman, 2010).

Scratch is a free interactive graphical programming tool (http://scratch.mit.edu/) created by Media Lab at the Massachusetts Institute of Technology (MIT). It has been developed from the ideas and work of Seymour Papert, who was instrumental in the development of the Logo programming language. The design of Scratch underpinned by the view that children are active builders of their own intellectual structures (Papert, 1980). One of its key aims is to provide “tinkerability.” Child programmers can put together, take apart, and recombine programming building blocks to build whatever they choose. In so doing, children learn mathematical and computational concepts that support the development of creative and systematic thinking. The inventors of Scratch tried to ensure that the programming language would allow people easy access and offer opportunities to create increasingly complex projects over time, as well as supporting many different types of projects so people with different interests and learning styles can become engaged (Resnick, Maloney, Monroy-Hernandez, Rusk, Eastmond, Brennan, Millner, Rosenbaum, Silver, Silverman & Kafai, 2009).

The Scratch environment is based on a collection of graphical programming “blocks” that children snap together to create programs. As with Lego bricks, connectors on the blocks suggest how they should be put together. Children can start by simply tinkering with the bricks, snapping them together in different sequences and combinations to see what happens. Scratch blocks are shaped to fit together only in ways that make syntactic sense, thus helping the user to avoid many programming errors.

Scratch could be described as a “cognitive technology” tool in that it responds to a user’s commands, and makes their actions apparent (Zbiek, Heid, Blume & Dick, 2007). The programming involves the creation of external representations of the problem solving process (Resnick, Maloney, Monroy-Hernandez, Rusk, Eastmond, Brennan, Millner, Rosenbaum, Silver, Silverman & Kafai, 2009). It offers complex layers of opportunities for investigation and children may choose to include measurement and geometric concepts such as length and coordinates to develop their desired movements and effects. Scratch does not facilitate learning in any one particular mathematical area, but it can enable each child to process their mathematical activity through a digital medium so the understanding that emerges is shaped in alternative ways (Calder & Taylor, 2010). What is learned therefore, will be different for each child.

2. The Research questions

The questions that formed the focus of the larger study were as follows:

1. What is the potential of Scratch to enhance mathematical and technological thinking?
2. How does the use of the IWB assist in the management of the learning through activities, dialogue and scaffolding?
3. How can the use of the IWB/Scratch enhance the development of the key competencies?

This paper focuses on the first research question to investigate the use of Scratch within an elementary school’s mathematics programme.

3. Background

This is an ongoing study that involves two teachers, three researchers and 60 children. In December 2009, the researchers and three teachers from a state, culturally mixed, urban, midrange New Zealand city school spent a day together to explore some of the potential of the Scratch program and to work out the research protocols and intentions and processes. In Term 1, 2010, the research began in the two classes of nine and 10 year old academically diverse children.

3.1 The classroom settings

Each classroom was equipped with an interactive whiteboard and four computers. The children in both classes were split into smaller ability groups for their daily mathematics program. The teachers rotated the groups so children would have regular teacher attention. In both classrooms there was an expectation that children would be able to help each other, and share resources and responsibility for managing themselves. The available technologies (the computers and the IWB) were there as tools to support learning and were not regarded as the preserve of the teacher. All children had access to these tools and some knowledge of their operation.

In the first classroom, the teacher, Leo (pseudonym), introduced all children to Scratch by demonstrating some of its features on the IWB. Tasks were formally outlined and displayed on a wall - children were expected to “create a sprite, make a sprite move diagonally, make it move in a square, construct a re-set button or key, and save your work in a folder.” (Observation notes). During the first week, one group of children per day was given the opportunity to become familiar with the Scratch environment on the desktop computers and/or the IWB. After this orientation, each group of up to nine ability-grouped children was able to work individually or in pairs with the desktop computers. The children were able to explore the Scratch environment in any way they chose, and in doing so could work out some of its capabilities and effects to try and achieve these tasks. Children were able to freely converse with others in the group to share the effects they found and ask questions of each other.

In the second classroom, initial introduction to Scratch was intended to be similar, although with a smaller group. However, on the first teaching day there were technical difficulties with the IWB, so the teacher, Donna (pseudonym), decided to have children “program” her instead. Donna pretended to be a robot and elicited help from the children to give her instructions to help her move to her desk, pick up a calendar, return to the place she started and put the calendar back down on the desk. After the exercise, Donna asked the children what mathematical language and instructions they had used. Various children responded with answers such as angles, degrees and clockwise indicating there was some appreciation of geometrical ideas within the class. She then set this group some introductory challenges – to make a sprite move around a square, a triangle and a circle.

Both teachers wanted to ensure that the children were familiar with Scratch. They wished the children to work relatively independently while they were involved with instructing other groups in more formal mathematics. After the familiarization period, the children were given the task of making a game. There was to be a group game made using the IWB with a different pair of children in the group working on this project each week. At the same time each child or pair of children in the group would be using the computers to make an individual game. A design brief outlining the plan for the games was to be completed at the outset, and for the group game each group had to negotiate, decide, and record who the character(s) were in the game, what they wanted their player(s) to do, what the character(s) were not able to do, a description of the game, obstacles/challenges in it, and if there were levels of difficulty what those levels would be. Every iteration of work on either the IWB or the desktop computers was to be saved.
4. Data collection and methodology

Data was collected using a mixed method approach that included direct observation written reflections by three researchers, digital video recordings, digital photographs, examples of the children’s work, children’s reflective statements about their learning, blog entries made by the teachers and the researchers and teacher interviews.

Data has been analysed through a socio-cultural lens, drawing on the notion of the role that tools play in the mediation of human activity (Vygotsky, 1978). It is the tools that provide opportunities to create new kinds of activity, but the users of those tools develop thinking in alternative ways (Wertsch, 1998).

A case study approach was used to investigate how engagement with Scratch and independent use of the IWB enabled children to work collaboratively to solve Scratch challenges. We utilized a process of “noticing” to try and ascertain how individuals processed complex situations (Jacobs, Lamb & Philipp, 2010). This approach was taken to try and focus attention on the mathematical thinking and strategies. It was an attempt to attend to, and interpret the children’s actions as they engaged in working either collectively or independently on a Scratch challenge afforded by a desktop computer and the IWB.

5. Results and Discussion

5.1 A synopsis of three case studies

Three case studies are reported here. Group 1 comprising of Hamish and Jason (Year 5) and Charles (Year 6) are described as “high mathematics achievers” who preferred to work alone, are in Donna’s class. A second study is of Group 2; five children in Leo’s class, and the final two are of individual children, one from each class, Callum and Hemi. Callum was identified as a child with advanced learning abilities, and a dislike of formal mathematics who generally exhibited poor social skills. The other, Hemi, had been assessed as a child with low capabilities and understanding with respect to numeracy and literacy when measured against traditional testing tasks and his peers’ achievements. He had not displayed any particular academic ability or leadership skills. Time was spent with the groups and individuals in an attempt to capture the talk and thinking, and to note the ways the children managed to collaborate.

The groups in both classes were given the same introductory challenges. These were to get a sprite to walk in a square, a triangle and a circle, and to save the work on the class hard drive. The Group 1 boys worked well together taking turns at the computer, with the IWB pens, and to make suggestions for solving the challenges. The first challenge of making a sprite walk in a square took 25 minutes to complete, the second, walk in a triangle, took 30 minutes and they began the circle challenge but after 5 minutes had not decided on a strategy (they may have taken less time had the equipment been more receptive). They did not appear to see possibilities to extend these challenges such as changing the direction that the sprite walked in, making it stop, or go forever. The two completed challenges were saved into the class folder.

5.2 Reflecting on children’s progress with the challenge

The impact the initial choice of block makes on subsequent progress and types of solution may be worth considering. Children who began by choosing the ‘glide to’ block to work on the task were not really involved with angles at all. They became engaged with trying to work out how to draw using the coordinate system. This was about trying to describe a path in the language of x and y. Having chosen to use the glide to block in the first place, and they could see that this would work once they sorted out the correct values of x and y, they continued to work within the affordances of that type of block.

Children who began by choosing the move and turn blocks were subsequently very involved in thinking about angles. The move of a certain number of steps was quickly accommodated while the angles needed for the required shape were more challenging. Although the task of drawing a square remained the same, the type of thinking and solution afforded by beginning with these blocks was quite different to that of using the glide to block.
5.3 Strategies the group used included:

- Square and triangle – used a move block to move so many steps and a turn block to turn a certain way a certain number of degrees
- About 40 minutes into the exercise Hamish (Y5) had the pen and chose to use a glide block, i.e. glide 5 seconds to \( x = \ldots \) and \( y = \ldots \)
- All used the pen to hover over a point to determine where \( x \) and \( y \) were on the stage.

5.4 Difficulties overcome:

- How to get the sprite to move further – increased the number on the move block from 10 to 100 steps.
- What to do if the sprite moved too fast – inserted a wait block in the script
- What the perimeter of a square/triangle/circle meant – they drew a square/triangle/circle on the stage
- How to work out the degrees of the triangle – get a protractor and measure the angles.
- How to keep the sprite from going off the stage – use the go to block to reset the \( x \) and \( y \) coordinates of the Sprite
- What to do when something does not work – remove the instruction blocks (script) and start again
- How to speed up the procedure for the second challenge – keep the script from the previous challenge and alter it for the new shape.

5.5 Making a car go around a track (Group 2)

In this case, a group of five children (of similar maths ability) worked on a challenge provided by one of the research team. The beginnings of the challenge were already set up and this was downloaded to the class computer. The challenge was to make a car go around the track so that it:

- is always going forward i.e. does not go sideways or backwards
- did not go off the track i.e. does not touch the sides
- starts and finishes at exactly the same place

The researcher explained the challenge to the group and showed them where to find information about the car’s \( x \) and \( y \) position and direction. He suggested to the group that using the blocks that manipulate the \( x \) and \( y \) settings of the car might be helpful for this challenge. He also explained that, because the car had to come back to its exact starting point, it might be useful to record its starting \( x \) and \( y \) position.

The group set about the challenge and began by writing the car’s \( x \) and \( y \) positions on the normal whiteboard. They then made a reset script using the \( x \) and \( y \) values so that the car could be returned to its start point after each trial run. The group was unsure where to go after this other than to use the glide to block to move the car. However, one boy, Thomas, seemed to quickly realise that the mouse could be used to find out the \( x \) and \( y \) position they wanted the car to move to and that these values could then be put into the glide to block. Thomas took control and led the group to use his idea and, after a bit of trial and error, was able to get the car to glide to the bottom right corner. Shortly after this, someone came to the class and asked for Thomas to go somewhere and the rest of the group carried on.

Without Thomas’ guidance, the group was much less clear how to proceed and began trying a range of values in the glide to block. The focus was on trying to get the correct values of \( x \) and \( y \) but numerous trials failed to get the car to the desired position with the car invariably going diagonally up the stage rather than straight across. The researcher asked the children to consider how the \( x \) and \( y \) values they were putting into the block related to the car’s position on the stage and, although initially unsure, one of the group, Billy, later showed that he understood that \( x \) values related to across and \( y \) values to up and down. Although the boys working on the task did seem to understand the connection between the \( x \) and \( y \) values and the car’s position, it soon became clear that they did not understand the negative value. In fact, although they were identifying and using the correct coordinates they only used positive
numbers. It was as if the ‘-’ sign in front of the coordinates did not exist or, at least, they did not see it as part of the number they were using. Once the negative sign was pointed out, the solution to get the car to go to the bottom corner was quickly found.

Interestingly, the reset script they had created at the start worked as they had used the correct coordinates in the negative sign. The initial solution they had for the car to move to the bottom right corner had been direct. Thomas, and once he left, the group did not build on what they had done earlier. At some point after Thomas left, they actually deleted the original script that had successfully moved the car to the bottom right corner, losing the ground that had been gained.

5.6 Reflecting on the group dynamics

In this case, a great deal of time was spent due to non-cooperation and inattention within the group. Get individuals were self-centred and when they were not in control of the pens or the pad, they became disinterested and somewhat disruptive. One girl, Miranda, took no part in the group task and when pressed to have a go, IWB seemed to have no idea what to do. She kept to herself, but did not contribute nor disrupt.

When focusing on the task, individuals made quite good progress and seemed able to get to grips with the programming particularly with some guidance. However, they only seemed to work on what they were doing and trying at little account of what others had tried earlier. This was probably because, in some cases, they had paid little attention to others while others were working at the IWB. Although they had successfully got the car to move to the bottom corner, this particular script was subsequently ignored and eventually deleted. It then took about three quarter hour to get back to this point.

5.7 The case of Hemi

After the initial introduction to Scratch, the teacher, Donna, was on leave for several weeks. When she returned to the classroom, she asked a group of seven children what they remembered about Scratch. Hemi’s response was “making games with it.” Hemi then stated that he knew about the x and y co-ordinates, and that number goes higher as the cursor goes up,” and “when you move the mouse the x and y numbers change.” The teacher seized the opportunity to explain co-ordinates, and after some time politely listening, Hemi quietly stood and demonstrated how it was possible to work out positions on the IWB screen and explained that “the minus show you how to get to zero and where the minuses are.” Later, while working with his group to make a game, he seemed to quickly grasp the syntax of programming in Scratch. He demonstrated his understanding of how to a sprite and program its movement and position to achieve the effect that was desired by the group. Hemi realized that the repeat control block could be used to encompass other blocks and later, when the group’s script did not work as intended, he was able to explain how to use control blocks to make the script work properly.

Another boy in Hemi’s class explained to the researcher that he had been helping to make a Scratch game spare time and that it had six characters and two levels and was a maze-like activity. He explained that the game had been Hemi’s idea and that other boys had joined in to help make it. When working on the project in class, the other ‘extra curricula’ Scratch projects, Hemi was reading and writing Scratch programmes that required use sophisticated thinking and to deal with multiple variables. He was working on five self-generated projects with some other children before school and during school if time was available. Hemi explained that the project contained “different levels, and if you passed a level you get another point.” Within his class, Hemi was seen as an expert. He had established a fluency that involved mathematical ideas such as understanding of length, and how x and y co-ordinates could be used to control sprites’ movement and position. “I learn you can do anything on Scratch. You can make cool screensavers. Putting the script together and making it a work was the hardest thing to do.” (Hemi, recorded notes, 12/07/10)

5.8 Callum’s case

Video and observational data indicated that Scratch proved to be intrinsically motivating and challenging to Callum. He developed proficiency in composing his own scripts and also became adept at reverse engineerin
ready-made scripts to learn how they worked and to find ways to achieve his design brief goals. He was interested in the appearances of the screen and spent much more time on programming sprites for action. Like Callum, had also noticed that it was possible to use x and y co-ordinates and the glide to block to move a sprite to a particular place on the screen. Prior to this realisation, his strategy had been to use trial and error, changing co-ordinates almost randomly. Once he understood how to use the glide to block he was able to explain this to others and help them solve some of the design problems they were experiencing.

Callum began to be consulted by other children to help program their games but also began to be open to ideas. He commended another child when he was offered a different perspective on a problem with which he was grappling. Callum was able to assess and use deductive reasoning to recognize the shortcoming in his knowledge and could perceive the worthiness of another child’s suggestion. The Scratch context and the display of his programme provided opportunities and motivation for Callum to collaborate with and learn from others; these were not his normal pattern of behaviour.

5.9 Reflecting on the effect of working with Scratch on Hemi and Callum

The data shows that these two children (Hemi and Callum) had the disposition to tackle conceptually difficult challenges within Scratch. They both demonstrated perseverance, were motivated to problem solve, and responded to exploring Scratch with behaviours that were not usually evident in their regular classroom programme. Callum demonstrated that he was now able to successfully contribute to a group, and Scratch has increased his involvement with other children in the class.

Scratch proved to be an engaging context for both children, so much so that each teacher reported that available time before or during other school activities, the two children spent time on their personal projects or worked on group tasks. They developed a facility to read scripts quickly and offered suggestions for improvement both publicly and privately to other children or groups. Neither attempted to take over or program for other children, but each was regularly consulted by other children as “approachable experts”. He demonstrated leadership qualities within the classroom that had not been evident before as he helped others.

Scratch offered each child progressive layers of investigation that involved a range of programming mathematical ideas such as the use of conditional and recursive functions, and geometric concepts such as angles, the use of co-ordinates, and the unit circle. Both children were able to take advantage of the “low (easy to get started) and “high ceiling” (potential for complex, sophisticated outcomes) attributes embedded in Scratch (Resnick et al, 2009). We suggest that the two children displayed resilience (Johnston-Wilder, 2010) when working with Scratch, as they sought to explore and deepen their understanding of how to resolve the problems that arose.

6. Emerging themes from the data

6.1 Reflecting on the mathematics

This research indicates that children can explore and use quite sophisticated mathematical and programming ideas when they are embedded in a creative environment like Scratch. What is not quite so certain is the mathematical content knowledge that each of the children learned. Scratch is not specifically designed to facilitate construction thinking of a particular set of mathematical ideas, but has important mathematical ideas embedded within it. Children learn to program in Scratch, they also begin to appropriate the mathematical concepts that underpin the functions of the blocks.

There are many choices that can be made when designing and creating a project. Scratch offers a learner many pathways for exploration, for example with choosing sprites, the background, stage, sound or one of the many options. Seldom is there only one way to solve a problem. Scratch affords learners multiple pathways to success and multiple opportunities to support preferred learning styles.
One of the questions raised for us is whether the mathematical activity and understanding that may develop is dependent upon the type of actions a child chooses to programme. For example, if a child begins a project by selecting the glide to block then they embark on a problem-solving pathway that requires them to understand how to use x and y co-ordinates to describe positions on the stage. If they opt for move and turn blocks then this requires thinking in terms of angles and distances with no need to consider co-ordinates. Each starting point in their problem solving sets up a different pathway and involves different mathematical concepts.

6.2 Reflecting on mathematics learning and the IWB

The teachers and the children were familiar with using computers for word processing. Until this study, the teachers and the children tended to use IWB as a notice board or as timing device for recording basic mathematical facts written in individual workbooks. The teachers discovered through the Scratch project that learning could be shared and developed collectively with other members of a group or class when an IWB is utilised. The characteristics of Scratch and the IWB afforded children particular learning possibilities and the contexts which the children were part of were also influenced by the physical, cognitive, and cultural contexts within which they were set. Working at the desktop computers provided a private space for the children to explore their ideas, but with the large screen the display feature of the IWB was accessible to more than one child. Without the IWB, many of the benefits of group work and sharing would not have been possible. The IWB provided the potential for participating, correcting, for thinking and reflecting, and for guiding further direction (Kennewell and Beauchamp, 2007).

The children in this study used the IWB space to co-construct knowledge as they participated in socially shared cognition (Hennessey, Deaney, Ruthven, & Winterbottom, 2007). The IWB was pivotal in supporting the development of task-related talk for the children, where their reasoning and justifying was supported with the artifacts and programmes that were being created. There is evidence to suggest that the Scratch software helped participants to construct and/or co-construct dynamic representations of their original plans. In most cases, there was a definite sense of co-ownership between the children and respect for what other children contributed.

6.3 The role of the teacher

Just as Scratch and the IWB have their own characteristics and therefore offer particular possibilities, any learning that occurs is also influenced by the physical, cognitive and cultural contexts within which they are set. As Lewin, Somekh and Steadman (2008) suggest, when IWB use becomes embedded in teachers’ pedagogy, it serves as a mediating artefact for their interactions with their pupils, and pupils’ interactions with one another. Changes in pedagogic practice became apparent. It was evident that the teachers had set up their classroom learning environments and modelled behaviours to encourage a culture of listening to and respecting others’ views. They also trusted the children to work independently at the computers and the IWB and offered the children the power and responsibility to make their own decisions and to learn from each other.

The teachers stated they were impressed by the positive social changes in particular for two of the case study children, which they attributed to their exploration of Scratch. However, neither teacher was convinced that Scratch strongly supported the development of mathematical content knowledge, although the children had to utilise measurements of time and distance with formal units, use positional language to estimate angles and employ co-ordinates. The teachers suggested Scratch had provided opportunities for the children to problem solve, make sense of language symbols and texts, to think more deeply and explore some mathematical ideas freely rather than within a prescriptive format.

7. Conclusion and implications

This research found that Scratch provides opportunities for collaboration in a classroom and school setting and beyond. We are left wondering if using hardware and software that requires alternative ways of thinking also requires us to consider changes in assessment practises. As the enactment of the Scratch projects demonstrated, the learning through the medium of the computers, the IWB, the social attributes acquired, and any mathematics learning all seamlessly merged.
There are implications for teaching and learning when children who have been identified as having "low" mathematical understanding are able to develop complex computational thinking and utilise sophisticated mathematical ideas. There remains the challenge of describing the different types of thinking that a child such as Hemi, placed in a low ability mathematics group, was acquiring as he led a group of other children to create projects with children who had been assessed as having much greater mathematics and problem solving capabilities. The value of the social benefits of increased involvement and interaction cannot be underestimated. However, as mentioned at the outset, this study is ongoing, and analysis of data is only just beginning. There is a myriad of information yet to be explored, so any indicators here have to be treated tentatively. Scratch and the IWB do appear to have helped the children in our study to enhance their problem solving strategies, to think creatively, reason systematically and to work collaboratively. What impact Scratch is has had on mathematical thinking is yet to be fully explored.

Acknowledgements

Grateful thanks to the school, the teachers and the children who are involved in this project.

References


