Coding and learning mathematics: How did collaboration help the thinking?

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This paper reports on two teachers' perceptions as part of a project examining the learning that took place when 9 and 10-year-old children used *ScratchMaths* in their programme. The project used design-based methodology, which incorporated video-recorded classroom excerpts, teacher interviews, and teacher analysis and review of their practice. The teachers identified the students' problem solving, collaborating using explicit mathematical and coding language, and being cognitively engaged. They also recognized that their own practice evolved into a more faciliatory role, while their understanding of coding processes grew through learning beside, and through, their students.

In 2020, the new Digital Technology Curriculum (DTC) became a mandatory part of the New Zealand (NZ) Curriculum but research indicates that NZ teachers and schools will find adopting and implementing DTC challenging. This is because it encompasses proficiencies such as coding that are outside the expertise and experience of many NZ primary teachers' current understanding of digital technologies (Crow et al., 2019; ERO, 2019). Crow et al. (2019) indicated a gap in the availability of resources that are specifically situated in curriculum contexts, which would practically assist engagement with coding. They also advocated that teachers and schools develop unique implementations. This paper reports on a small research project that examined teacher practice with coding through the use, evaluation and adaption of University College London's *ScratchMaths* resources, and the associated student learning. The project also aimed to enhance teachers' coding and computational thinking-based pedagogies and student learning while simultaneously addressing the limited resources available for teaching coding in NZ.

Some NZ research has evaluated similar curriculum implementation at high-school level (Johnson et al., 2017) and international research has examined some aspects of DTC (e.g., Falkner et al., 2014; Johnson et al., 2014). However, none of this research specifically examined the affordances and implementation of DTC in the NZ primary-school context. There has been very little research on the use and influence of coding in NZ schools, hence the implementation of the DTC would benefit from being analysed by a collaborative partnership of teachers and researchers, as teachers consider how, when and where it will best be integrated into existing classroom practice, and explore how to support student learning.

Scratch is a free-to-use graphical programming environment that provides opportunities for creative problem-solving. It is a media-rich digital environment that utilizes a building block command structure to manipulate graphic, audio, and video aspects (Peppler & Kafai, 2006). Studies have shown its potential for developing computational and mathematical thinking in an integrated way, particularly in geometry and algebraic thinking (Calder, 2018). *ScratchMaths* aims to integrate computing and mathematical thinking effectively. Mathematics is used as a context and gives purpose for developing computational thinking, while the process of coding, particularly with *ScratchMaths*, is identified as being influential on the development of mathematical thinking (Benton et al., 2018) and the understanding of mathematical ideas such as algorithms and the 360 degree turn (Benton et al., 2017).

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However, the *ScratchMaths* resources, while well-tested and effective resources, are structured, with small incremental steps to be undertaken by students individually, whereas in NZ learning is seen as a more collaborative, creative process (Ministry of Education, 2007). The project examined how the *ScratchMaths* resources might evolve to be more conducive for learning in the NZ context. For instance, the development of collaborative student-led projects in *Scratch* (e.g., Calder, 2018), which might also emerge with *ScratchMaths*, would be conducive to collaborative problem solving.

Collaborative Problem Solving

In the consideration of collaborative problem solving, collaborative learning is first discussed, together with its potential to improve learning and understanding. Ways that collaboration supports learning when digital technologies are used and the influence of both in facilitating problem solving are next briefly identified. The connection between collaborative problem solving, the use of digital technologies, thinking, and student engagement is then considered. Collaborative learning occurs when two or more students are engaged in an activity, interacting with each other and learning together (Dillenbourg, 1999). This perspective of learning in mathematics repositions learning more as participation in a social practice then as an acquisitional process (e.g., Cobb & Bowers, 1999; Sfard, 1998). Educational collaboration associated with problem solving has been connected to academic success. For example, Mercer and Sams (2006) showed how students collaborating while engaged in an online task produced enhanced learning outcomes in mathematics. Other studies have illustrated how the collaborative use of digital technologies can support students in developing more flexible approaches to problem solving (e.g., Mercier & Higgins, 2013).

Mercer and Littleton's (2007) definition of collaborative learning goes beyond the sharing of ideas and task coordination to "reciprocity, mutuality and the continual (re)negotiation of meaning" (p. 23). Collaborative learning in line with this definition involves the utilization of individual understandings and expertise, with the collaborative interaction influencing the thinking of at least one participant in the interaction, even if there is only a minor adaption, coupled with a repositioning of the learners' perspective and understanding. When students work collaboratively on a task there is frequently a coordinated approach to the sense making and the approach taken when engaging with the task. The joint coordination of a task enables students to communicate and negotiate in order to support decision-making (Zurita & Nussbaum, 2004), and, as such, they are involved in "a coordinated joint commitment to a shared goal" (Mercer & Littleton, 2007, p.23).

In general, digital technologies can enable opportunities to explore and organize data or mathematical phenomena in ways that might facilitate mathematical thinking, and to see patterns and trends more quickly in mathematical situations that might otherwise be too complex to do so. With coding, this offers potential to learn through the iterative process of engagement with the coding process, and reflection on the output that the coding generates. The coder can try something and instantaneously identify the effects of the new coding, enabling them to generalize coding attributes and refine their approach. With a visual environment such as *Scratch,* where the coding and output screen sit side by side, these relationships are even more easily identified (Calder, 2018).

Computational thinking can be considered a collection of problem-solving skills that relate to principles of computer science (Curzon et al., 2009). At times, computer science involves creating applications to solve real-life problems using computational thinking, an analytical, computing approach for problem solving, modeling situations and designing systems (Wing, 2006). Abstraction, allied with logical thinking, innovation, and creativity, is considered central to the constitution of computational thinking (Wing, 2006). These elements also resonate with mathematical thinking and problem solving in mathematics. *ScratchMaths* appeared to be an engaging and relatively easy to use space for problem solving.

Research has indicated that students become more engaged when using digital technologies, with enhanced mathematical learning also evident (e.g., Attard & Curry, 2012; Bray & Tangney, 2015; Pierce & Ball, 2009). In educational settings, engagement is recognized as more than the student being interested or participating positively, but as a complex, eclectic relationship between the student and classroom work (Fredricks, et al., 2004). They perceived it as being multi-faceted and operating at cognitive, affective and behavioral levels. With regards to using mobile technologies in the process of learning mathematics, Attard (2018) concluded that they do improve student engagement at operative, cognitive, and affective levels.

Additionally, studies have indicated that *Scratch* was an effective medium for encouraging communication and collaboration (e.g., Calder, 2010, 2018). This paper considers teachers' observations and perspectives of the students' problem solving, collaboration and engagement as they undertook coding tasks using *ScratchMaths.*

Research Methodology and Design

Using a design-based research methodology, with the teachers as co-researchers, the project examined two teachers and their 9 and 10-year-old students' use of the *ScratchMaths* resources. This methodology, designed by and for educators, endeavours to enhance the impact and implementation of educational research into improved classroom practice (e.g., Anderson & Shattuck, 2012). It can illuminate the challenges of implementation, the processes involved, and the associated pedagogical and administrative elements (Anderson & Shattuck, 2012). Design research necessarily comprises multiple cycles, which involve a number of different design and research activities. Nieveen and Folmer (2013) divide these activities into three distinct phases: the preliminary research phase; the prototyping or development phase; and the summative evaluation phase. These three phases, involving the teachers and including videoing of their classes, were implemented through iterations of use, reflection and modification of the resources and the associated pedagogy.

The research design was also aligned with teacher and researcher co-inquiry whereby the university researchers and practicing teachers work as co-researchers and co-learners (Hennessy, 2014). Allied to this was an emphasis on collaborative knowledge building. The research design was based on a transformational partnership arrangement that aims to generate new professional knowledge for both academic researchers and teachers (Groundwater-Smith et al., 2013).

The *ScratchMaths* resources identified by the teachers to use initially were from module one and included: Moving, turning and stamping, and creating circular rose patterns. The *ScratchMaths* resources and existing projects were used as starting points for the lessons, with the "unplugged" activities also incorporated into the sessions. Some of these class sessions and individual groups working on the tasks were video recorded. There were two iterations of the review and design process with videoing of classes each time, followed by co-researcher meetings to examine the classroom practice. One element of these meetings was the analysis of classroom video recordings. Discussions in the meetings were recorded, as were the teacher interviews.

The research question related to this paper was: *In what ways might the use of coding embedded within a mathematics curriculum context, influence teacher practice and children's coding and mathematics engagement?*

Results and Discussion

The paper reports on teachers' perceptions of how using *ScratchMaths* facilitated the learning process in four key areas: problem solving, collaboration, mathematical thinking and the teachers' pedagogical approach. The teachers consistently commented on how using *ScratchMaths* fostered a problem-solving approach as the students found solutions to unfamiliar problems in mathematical contexts, through a variety of approaches. For example:

> Annie: The children were problem solving, risk taking and learning from failure

> Marama: It's massive (problem solving). For some activities there are no instructions for how to get them from there to there, they just had to work it out.

The students use of *ScratchMaths* within the problem-solving process at times led to enhanced engagement. The process of debugging code was a particular aspect that some students became immersed in. This is a part of computational thinking that involves reviewing the code through trialing and when it didn't produce the desired output, collaboratively problem-solving possible solutions. It might also involve the output unexpectedly stopping or going into continuous loops. While the aspect of debugging was highlighted by the teachers at times, usually students were self-motivated with this process through wanting the script to be consistent with their expectations of the output. Marama commented on the student engagement consequential of the debugging process:

> There would not be many things that would have them that focused on what they're doing so intensely. They would be doing debugging the whole time.

The teachers identified that the students not only appeared more cognitively engaged but that the process facilitated enjoyment and a sense of fun.

> Marama: They're having a laugh as well you know... it's not all serious... even though it's heavy duty problem solving. They're having fun, they're smiling and enjoying working with each other too.

> Marama: Well, it's not quiet in our classroom but it's not off task noise, it is completely on task noise. It's talking about what they are doing and it's excited talk.

The students interacted with each other in a relatively natural, seamless manner as they explored potential solutions and then collaborated to make their codes more efficient. As they worked to design the scripts and subsequently make the codes more efficient, they shared ideas and potential solutions using language that used coding terminology, or was related to the mathematical or coding processes that they were discussing. The teachers noted this in the interviews. For instance, Annie indicated how the collaboration fostered their shared understanding of language, and hence from her perspective, their mathematical and computational thinking:

> Annie: It supported students' learning through communicating with friends, problem solving, increasing their mathematical knowledge and mathematical and coding language, bringing that all into the norm of how we can talk about coding.

> Annie: So, then we can look at different ways of how children create a script to get to an end product and look at just simplifying the script.

Marama identified instances when students found efficient ways to code that were valued by other students, enhancing their mana (respect) within the class. Sometimes this wasn't the students who were usually perceived as being more capable in mathematics so it readjusted those perceptions.

> Marama: There are kids that are capable but then someone quietly just comes up with this really simple code to do something that someone else has taken a long time to do and they think they're good so it's kind of just levelled everyone out

This also indicated how using *ScratchMaths* facilitated collaboration. Collaborative learning can be perceived as going beyond the sharing of ideas and task coordination to the ongoing negotiation of perspectives and meanings (Mercer & Littleton, 2007). Collaborative learning in line with this definition was identified:

> Annie: So, it gives a context for social interaction to happen where they're learning to code and learning maths.
>
> Marama: They're definitely getting extended in their maths but also that social side of it, working together collaboratively like that and not... someone not (always) taking a lead role, they're all in different roles all the time, sometimes they're teachers, sometimes they're learners.

While the ongoing negotiation and evolving perspectives are indicated here, this also indicates that the students' roles were flexible and contingent on their personal, and the group's understandings. Observational data also suggested that there was contestation of ideas during the collaborative work. Not only did the students interact through the ongoing dialogue as they problem solved to find solutions, students did at times became leaders of learning.

> Marama: One of the girls solved this thing that really no-one else was managing to do and she managed to crack it. Well the whole class was whoosh over there, so that's fantastic that she's having to explain it and off they go all excited.

Much of their work involved mathematical thinking. Further, the interview data revealed that at this later stage, for one teacher, the activity focused on the mathematics to begin the task. So, the coding in some instances was a way to enact the mathematical ideas. This was the perception of one of the teachers:

> Annie: It's the maths first and then the coding.

After several weeks they decided to make the work with *ScratchMaths* an integral part of their mathematics programme, so one of the classes usual mathematics sessions became the session using *ScratchMaths.* The teachers also found that the mathematical thinking related to both concepts and processes arose more naturally within the *ScratchMaths* activities. For instance:

> Annie: I think because maybe the opportunities with this program and what it's actually focused on with the angles and the measurement side and the negative numbers – we've been going through this for three terms so it's that continual weekly learning of that that's probably been more cemented than what it could have been if we had been teaching it in isolation.

While the teachers made the mathematical thinking explicit to the students by referring directly to the mathematics and using mathematical language, some of the mathematics emerged through attempting to solve and accomplish the tasks, and the collaboration on the coding aspects. In this way, some of the mathematical thinking and learning was more incidental as the need arose, and outside the usual curriculum level for that age group.

> Annie: It was just-in-time learning around the maths concepts. The use of angles was very in-depth. They used negative numbers, degree turns and always mathematical language.

For instance, negative numbers were not part of the curriculum for this particular age group. In a later discussion they identified some of the other mathematical thinking that occurred: Relationships, exploring variations, precision with language, methodical thinking, and strategies for problem solving. Their spatial awareness, understanding of angles, and positioning sense through the use of coordinates, were all engaged to varying degrees. There was also evidence of relational thinking as the students made links between their input, the actions that occurred on screen, and the effect of specific variations of size in coding procedures. They discussed how the students came to conclusions and gave explanations of what they had done.

The fourth aspect reported here is the teachers' pedagogical approach, which varied from their usual approach when teaching mathematics.

> Marama: I don't know that I need to know everything. Most of the time it's the kids that are the ones that solve things. They are learning off each other a lot more, they're going to each other a lot more, they're talking a lot more.
>
> Annie: The classroom approach is to explore, but the mathematics and coding objectives are explicit. At times (we) start with *ScratchMaths* for say, angles. There is a purposeful context for the learning.
>
> Marama: The teachers' role is facilitating learning – actively scaffolding processes and content.

The teachers were consistent in their belief that positive student learning had occurred and also regarding students' collaboration and engagement when problem solving. They articulated their personal learning regarding coding processes, while acknowledging that their role in the classroom had evolved.

Conclusions

Although findings are presented as four separate aspects, they were mutually-influential elements that the teachers perceived had contributed to student engagement and learning. The work with *ScratchMaths* simultaneously influenced teacher practice, moving them towards a more faciliatory approach and greater understanding of coding processes. The students' mathematical thinking and learning in coding were tied to their solving of both mathematical and coding problems, while the explicit language of both contributed to the communication of processes, concepts and solutions. Students at times became leaders of the learning.

Much of the conceptual understanding and thinking related to the Geometry and Measurement strand of the NZ curriculum, in particular, angles and spatial perception. However, the process the participants undertook more directly facilitated mathematical thinking through the creative problem-solving process it evoked, and the development of logic and reasoning as they responded to the various forms of feedback.

While the findings were limited by the size of the project and the particular context in which they were enacted, they nevertheless give insights into the ways learning in both mathematics and coding might be enhanced through the *ScratchMaths* resources. The research is ongoing, with more schools and a broader range of classes and teachers now involved, and there is still analysis of the data to be completed, but further research into a broader range of contexts and some assessment and analysis of students' mathematical and computational thinking is anticipated and will give clearer, more comprehensive insights.

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