Teaching the Unexpected Mathematics: How Digital Technologies Unlocked Incidental Primary Mathematics Concepts

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Diminishing duplication and finding connections between the *Australian Curriculum: Mathematics* and *Digital Technologies* were a focus of the revision to version 9. This emphasis has provided enhanced opportunities for integration of these learning areas. In this exploratory multiple case study, interviews with teachers following teaching an integrated task identified connections to other mathematical concepts that had not been considered during planning. These findings indicate that integrating mathematics and digital technologies can potentially provide opportunities to deepen and consolidate learning in mathematics through connections beyond the initially intended concepts.

An emphasis on reducing duplication of content has meant that the Australian Curriculum (AC) version 9 was written to make the connections between learning areas more explicit (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2021). These connections emphasise the shared focus on data and computational thinking across *AC: Mathematics* and *AC: Digital Technologies* (ACARA, 2022a). Now, definitions and content in computational thinking and data collection, analysis, and representation are shared. Previously, there was insufficient alignment between the learning areas to develop synergies (Larkin & Miller, 2020). *AC: Technologies* is intended to be taught through integration with other learning areas, and this shared content provides clear opportunities for teachers to integrate.

In this project, professional development (PD) focused on integrating mathematics curriculum and technological content knowledge to demonstrate connections between version 9 of the *AC: Mathematics* and *AC: Digital Technologies* in the primary years. The effective integration of this content poses a challenge for generalist primary teachers (Larkin & Miller, 2020). The project aimed to support teachers in developing integrated tasks and learning experiences for their students through professional development and mentoring. The professional development focused on seamlessly integrating mathematics and digital technologies, teaching and assessing both curriculum areas in a single task. The tasks teachers developed were trialled in their classrooms, and their reflections were the focus of mentoring sessions. The mentoring sessions supported teachers' exploration of students' mathematics and digital technologies learning experiences during the task and determining the next steps for effective integration.

The project aimed to investigate the integration of the *AC: Mathematics* and *AC: Digital Technologies*, with a specific focus on diminishing duplication and uncovering connections between the two disciplines. This paper explored instances of unplanned teaching where connections emerge spontaneously when teachers leveraged their *knowledge of content and curriculum* to identify opportunities for establishing mathematical connections.

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Literature

Curriculum Perspectives and Conceptual Threads

Curriculum integration allows teachers to weave learning experiences across subject boundaries to apply transdisciplinary skills for learning (Ross & Marshman, 2023). An integrated approach to teaching is often complex. Teachers can spend hours of planning time considering the curriculum to find threads that draw together learning areas (Ross & Marshman, 2023). Sometimes, these threads provide successful opportunities for learning. However, the challenge arises from developing these connections at age-appropriate curriculum levels.

While the teachers' plan describes the concepts and purposeful sequencing of learning experiences that they intend, the developed plan is not necessarily followed precisely in the enactment process (Ross, 2024). During the lesson, a teacher may take an unplanned detour to consider student questions or adjust the pitch of the content they are teaching. Further, there may be incidental topics that can be covered, i.e., topics covered that were not planned to be covered during that lesson or sequence. Srinivasa et al. (2022) described incidental learning as the unintended, unplanned, or additional learning that can occur because of other activities. Incidental learning may be additional content that needs to be taught to support a gap in student knowledge, or concepts that are beyond those intended for the lesson, or perhaps student-directed exploration or questioning beyond the scope of the planned lesson. In recognising these incidental teaching moments, the teacher needs deep knowledge to see the potential and capitalise on the learning opportunities (Nayler, 2014).

The Importance of Making Mathematical Connections

Ball et al. (2008) developed their six domains of mathematical knowledge for teaching by building on Shulman's (1987) content knowledge and pedagogical content knowledge (PCK). *Subject matter knowledge* is the mathematics knowledge that most people have. *Specialised content knowledge* is the mathematical knowledge and skills unique to teaching and may include "looking for patterns in student errors" (Ball et al., 2008, p. 400), identifying nonstandard approaches and unpacking mathematical ideas to make them more accessible to students. *Horizon content knowledge* is an awareness of where mathematical topics go in future learning. *Knowledge of content and students* includes anticipating students' thinking and responses to tasks, what they will find confusing, and the level of challenge, the language that students will use with "emerging and incomplete thinking" (p. 401) as well as common conceptions and misconceptions of the mathematical content. *Knowledge of content and teaching* includes knowledge of how to sequence the content and the usefulness of different representations, methods, and procedures. The final category, *knowledge of content and curriculum*, includes knowledge of both the mathematics and the pedagogical underpinnings of the curriculum including understanding the underpinning sequence of mathematical concepts.

Rowland et al. developed the knowledge quartet to describe the categories of knowledge needed to teach mathematics. *Foundation* is the knowledge, understanding, and beliefs acquired during initial teacher education; *transformation* is the ability to transform content knowledge so that it is accessible for students including the choice of resources and activities; *connections* include the sequencing of topics and the connections between different areas of mathematics; and *contingency*, sees a teacher responding to unexpected student responses. Contingency refers to the teachers' capacity to make *in-the-moment* decisions to decide whether to pursue their predetermined plan or to deviate to follow the student's introduced line of thinking. during teaching and learning (Rowland et al., 2009).

In this paper we explore teacher's *knowledge of content and curriculum* in *AC: Mathematics* and *AC: Digital Technologies*. We focussed on definitions and content in computational thinking and data collection, analysis, and representation. Teachers' capacity to select digital resources to teach mathematics using their pedagogical content knowledge can enhance students' mathematical learning (Loong & Herbert, 2018). Teachers are often provided with the technologies in primary mathematics classrooms and expected to integrate these technologies without the necessary PD support (Attard, 2013). Teachers can struggle to understand how the technology can be integrated (Perienen, 2020), and there is a need for further training to integrate digital technology into their mathematics teaching (Attard, 2013; Perienen, 2020) to enhance student learning opportunities.

Research literature has long emphasised that making mathematical connections between facts, procedures, and relationships is essential in constructing mathematical understanding (e.g., Eli et al., 2011) and between learning areas and the real world (e.g., National Council of Teachers of Mathematics, 2000). This is reinforced in one of the aims of the *AC: Mathematics*, "make connections between areas of mathematics and apply mathematics to model situations in various fields and disciplines" (ACARA, 2022b). The curriculum also identifies the role that integrated STEM learning can play in building these connections, "Interdisciplinary STEM learning can enhance students' scientific and mathematical literacy, design and computational thinking, problem-solving and collaboration skills." (ACARA, 2022b). The research presented here investigates how an integrated mathematics and digital technology task can create opportunities for making mathematical connections beyond the initial learning intention. The research question was: *How can teachers best use knowledge of content and curriculum when integrating mathematics and digital technologies?*

Research Design

Context

This 6-month study is part of a larger study. This smaller study focused on the initial experiences of teachers from two schools. Their data has been included in the analysis, and pseudonyms used. All teachers in the project attended a professional development (PD) day focused on developing an understanding of task design and integration. The PD event provided examples of integrated lessons using digital technologies to teach and consolidate mathematical concepts focused on statistics. After a trial period for the teachers with their integrated classroom task, they were offered a mentoring session to discuss the task and its enactment. An exploratory multiple-case study design (Yin, 2009) used mixed methods for collecting data, including surveys and a semi-structured interview protocol during the mentoring session.

Participants

This paper describes case studies of teachers in the study from two different schools in the Moreton Bay region in Queensland. Case study one shares the experiences of an early-career teacher from a designated special school, while Case study two reflects a team of two teachers (one early-career and one mid-career) from a government primary school. Both schools planned teaching and learning using the early primary levels of the *AC: Mathematics* integrated with *AC: Digital Technologies*.

Data Collection

The teachers completed a pre-PD survey to ascertain their starting beliefs and participated in a mentoring session once they had trailed a task in their classroom. The survey included questions from the Technology Beliefs and Barriers to Creating Technology-Enhanced, Learner-Centred Classrooms sections of An and Reigeluth's (2012) survey. Additional questions included beliefs about and barriers to integrating *AC: Mathematics* and *AC: Digital Technologies*.

The mentoring sessions were held through Teams and recorded. The discussion prompts used during the mentoring sessions were based on Rolfe et al.'s (2001) framework for reflective practice, asking the teachers to describe the integrated lesson the teacher had completed, including aspects that worked well and challenges (what); highlighted aspects that the teacher found interesting or surprising (so what); and outlined what they planned to do next (now what). Teachers were asked to recall the enactment of their integrated mathematics and digital technology tasks. They were asked to highlight what happened and encouraged to provide details about the nature of the task and the students' responses. The teachers were also asked to reflect on and analyse the event, including anything the students did that interested or surprised to them. These answers gave rise to several key examples of incidental mathematics learning.

Data Analysis

Data were analysed thematically using Braun and Clarke's (2006) six phases of thematic analysis. Researchers each analysed the data they had collected for individual schools, including survey responses and transcripts of mentoring sessions. Through a comparative discussion between the researchers presenting the data sets they were familiar with; emerging themes were used to code the transcripts of the mentoring sessions. This paper draws on data from one clear theme from mentoring sessions' data: the incidental mathematics the teachers recognised and taught that arose from the integrated mathematics and digital technologies task.

Findings

Case Study 1

David is formally an early career teacher; however, he has come from a career in teaching in another education-related field. He works in a special school where his students are developing their mathematical knowledge at a Preparatory (Foundation) level. In his task, David planned to explore mathematical concepts related to position and location in mathematics. To explore these concepts, he used the Bee-Bots and integrated the activity with digital technologies by considering data representation with his students. The students were tasked with moving a Bee-Bot with a small photo of them on it, through a maze representing the school to several pre-determined destinations (e.g., from the classroom to the library). While enacting the task, David noticed opportunities to explore other aspects of mathematics crucial to the students' capacity to complete the task:

> One thing that came up was that one-to-one correspondence is really helpful and that it wasn't planned. But the fact that they have to hit the button on the Bee-Bot and count as 1, 2, 3 is something that I sort of, I guess overlooked. And then [I] realised as they were doing it. Oh, yes, there is some underlying skill here that needs to be worked on. Yeah. So that was eye opening... [if] I had my time again, I would have just let them play with the Bee-Bot first. Yeah, just go nuts and push all the buttons that you want to push and make it do whatever you want it to do. And then I'll do the one-to-one correspondence.

David recognised the importance of the incidental mathematical concept of one-to-one correspondence as essential to the students being able to use the Bee-Bot buttons to program the robot. Without this knowledge and skill, David's students could not complete the task. Consequently, this aspect would need to be incorporated into future iterations of this lesson sequence. Further, David saw the opportunities in the incidental mathematics concept for one of his students:

> I was just like, basically counting breaking down the steps ... And he was struggling a lot with the one-to-one correspondence and the fact that he had to slow down and there was like a tangible goal, I think really helped him.

David describes a student racing through counting activities and other mathematical tasks. In the student's haste to finish, he was making errors. David felt that using the Bee-Bots meant the student had to slow down to ensure the correct entry of data, and this helped reinforce the one-to-one correspondence that the student was lacking. David also saw the students finding further opportunities to use this concept creatively in more complex coding patterns:

> This student did something that was shockingly creative. At first, I didn't know what he did ... they just installed a new spinner [at school]. So, he sent it [the Bee-Bot] to the spinner [on the map]. And then he made it spin. And at first when he did it, I didn't get it. And I was like what did you want it to do? Like I thought he made a mistake. And then he did it and I was like floored. (David)

The student programmed the Bee-Bot to leave the classroom on the map and head straight for the new spinner in the playground. Using the left turn button, he programmed the Bee-Bot to turn in a circle like the students would when using the spinner in the playground. David was excited by the student's capacity to quickly pick up the coding skills and the mathematical concepts that allowed for the creative expression of this mathematical knowledge.

Case Study 2

Vera was a young, early-career teacher and Sarah, an older, very experienced teacher from a government primary school. Together, they designed their integrated lesson to explore the mathematical concept of symmetry, which was shared with the other Year 3 teachers at their school. Their lesson used Pro-Bots to draw the mirror image of a symmetrical drawing, asking Year 3 students to "draw or follow instructions to draw the other side of the symmetrical item" (Vera). The task required students to follow and implement simple algorithms linked to learning in digital technologies. The teachers were aware that students had not done any programming previously, so gave the students a pre-lesson, "That I had like a pre-lesson on them just playing with the Pro-Bots before getting them to set a task because they've not done any sort of robotic stuff up into this point or any coding" (Sarah).

The teachers acknowledged that the activity included more mathematics than just the symmetry they planned to address. In their discussion of the activity, they explained the incidental mathematics that the students used in the lesson, which included the need to consider what angles to turn the Pro-Bots in the intended direction, directions (turning left or right), measuring how far the Pro-Bot travelled to set up grid references and ensure the Pro-Bot went the correct distance, patterning and mirroring, and inverse relationships, which they connected with addition and subtraction (*connections*). During mentoring, Sarah and Vera reported opportunities for developing directional language, including clockwise, anti-clockwise, quarter turn, and half turn:

Vera: It was not just good for their symmetry, but as well their directions, and actually realising which way was which and then, you know, we'd lift up the paper, and they go, "Oh, I actually went left instead of right. I didn't follow the instructions properly".

Vera: I think getting them to realise that it's not just forward because we had the Pro-Bots not Bee-Bots. So, actually, having the angle and making the angle first and then moving forward. That got them a few times. ... It was that directional language. It was measurement. It was symmetry, which the lesson was based around. Grids, as well, it had tons [of mathematics].

Sarah: Because the measuring was pretty tricky. ... they could work out that it had to be part of the grid system. You know, your turns that we talked about earlier in the year, where we're going clockwise, anti-clockwise, quarter turn, half turn, and then technology-wise, it being a specific pattern and code. Yeah, that had to be followed. Otherwise, it [Pro-Bot] wasn't going.

Vera: All that sequence. So, you're patterning that … And then mirroring.

Sarah: Mirroring. Yeah. With your symmetry. Yeah. So, then you had to reverse it. You had to think the opposite.

Sarah: Yeah. And so … you put that into the relationship of add and take away … they're the opposites of each other. So, you sort of make that connection. They're doing this and your turns are the opposite. Yeah. I mean, that's the same amount of steps, but just the direction is slightly different.

The teachers also identified that they could extend the task and incorporate a map and grid references as they moved into the next school term's learning and assessment:

Sarah: And I think it led into this term when the first maths assessment was looking at grid references in their assessment. So, I think they got really good at direction and giving directions from that

> [integrated task] as well...we could've maybe incorporated that with more of a map situation like we had on the day that we were playing. Yeah. With the grid and things like that. More of that.

Discussion

This study focused on the initial experiences of teachers from two schools and the incidental mathematics the teachers recognised and taught, which arose from the integrated tasks they designed. Analysis of the case studies provided insight into how integrating learning in mathematics and digital technologies supported the teaching of incidental mathematics and strengthened teachers' *knowledge of content and curriculum*, allowing *connections* to be made.

The activity in Case 1, focused on location and direction. Students programmed Bee-Bot using a series of arrows (forward, backward, left, and right) to visit areas of the school on a floor map and describe the robot's position relative to items depicted on the map. David recognised the incidental mathematical concept of one-to-one correspondence as essential to students being able to use the Bee-Bot buttons to program the robot before exploring concepts of position and location.

In Case 2, Vera and Sarah had planned their lesson to focus on symmetry using Pro-Bots. When teaching the lesson, they recognised that the use of the Pro-Bot provided an opportunity to consolidate previous learning in mathematics. This incidental mathematics included directions and directional language, angles, measurement, and patterning and mirroring. There was also an opportunity to discuss inverse relationships with the students, which they did by connecting with addition and subtraction.

The teachers, in both cases, leveraged their deep understanding of content, curriculum, and pedagogy to design and deliver an integrated mathematics and digital technologies task, demonstrating some *knowledge of content and curriculum* (Ball et al., 2008). They used their comprehensive knowledge of the subject matter to identify key mathematical concepts that could be effectively taught using robotics and computational thinking skills. Teachers were also willing to respond to students' needs and deviate from their original plans (*contingency*) and help students make *connections* (Rowland et al., 2005). The teachers chose technologies such as Bee-Bots for foundation years and Pro-Bots for primary years to enhance students' mathematics learning (Loong & Herbert, 2018). Thus, demonstrating an understanding of the pedagogical underpinnings of the curriculum and how both learning areas are connected.

Robotics provide students with tangible programming outcomes and an interactive context to apply mathematics and digital technologies concepts. Of interest to the study was the incidental mathematics that occurred due to the integration and use of these robotics in a task. In Case 1, David's knowledge of the concepts that underpin the understanding required to complete the task meant that he recognised that his students also needed to learn one-to-one correspondence, even though it is not listed in the developmental sequence in mathematics. One-to-one correspondence is an essential part of learning to count and is assumed knowledge at the Prep level. The need for one-to-one correspondence demonstrated how an integrated task using digital technologies can help bring up the students' level of mathematics and develop other mathematical concepts not in the original task design. David's ability to identify the connection between digital technology and mathematics enabled him to enhance the learning opportunities for his students. David realised during the lesson that he needed to draw on further *knowledge of content and curriculum* (Ball et al., 2008) that he had not considered whilst planning the lesson.

Teachers need a solid understanding of curriculum to integrate (Ross & Marshman, 2023). For Vera and Sarah (Case 2), it was only after they began teaching the lesson that they recognised the incidental mathematics underpinning the task. Programming robots to move involves understanding geometry and spatial reasoning. In Case 2, the teachers reported how concepts such as angles, distances and measurement were incidentally taught; for students to succeed in the task, they needed to use these concepts in a tangible manner to control the robot's movement. The integrated task using a Pro-Bot included more mathematics than just the symmetry they planned to address; it provided an opportunity to make mathematical connections between facts, procedures and relationships, an essential component in constructing mathematical understanding (Eli et al., 2011). Whilst teaching this integrated task Vera and Sarah realised that they too needed to draw on further *knowledge of content and curriculum* (Ball et al., 2008) not considered during lesson planning.

The incidental mathematics learning in the cases outlined was unplanned, underscoring the importance of teachers possessing understanding of both the mathematics and digital technologies curriculum content to design integrated tasks and optimal learning opportunities. Evident also in the cases was how integrated applications of mathematical skills and concepts required students to demonstrate a deeper understanding of mathematics than simple memory of formulas and procedures. In these examples, the integrated task allowed students to see connections between different mathematical concepts and the relationship between mathematics and the real world.

Conclusion

This paper provided a small snapshot of data analysed from a larger study. The paper serves to highlight the incidental mathematics that arose for teachers from two participating schools during teaching of integrated mathematics and digital technologies tasks. While the scope of the paper is confined to the experiences of these two schools, their insights serve to demonstrate the broader connections across mathematical concepts that can emanate from across diverse educational settings if the teachers see the conceptual connections.

The deliberate focus in version 9 of the Australian Curriculum to establish connections between mathematics and digital technologies has enriched the possibilities for seamless integration in these learning areas. As highlighted in the two case studies, the incorporation of digital technologies into mathematics education has unveiled opportunities for incidental mathematical learning. Making mathematical connections is an essential component in the construction of mathematical knowledge, and this study indicates that teachers need to possess *knowledge of content and curriculum* (Ball et al., 2008). Specifically, an understanding of both *AC: Mathematics* and *AC: Digital Technologies* curriculum content, and an understanding of the pedagogical underpinnings of the curriculum and knowledge of how both learning areas are connected, to create integrated learning experiences. Emphasising connections between the two curriculum areas and promoting a holistic view of mathematics lays the foundation for students to apply a range of mathematical concepts in real-world situations using digital technologies. Further, more sustained research across a broader range of contexts would be useful to further analyse the range of connections teachers are able to find from integrated contexts.

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