

# Exploring the Multimodality of Young Children's Coding

**Karen Murcia**

Curtin University, Australia

**Kok-Sing Tang**

Curtin University, Australia

*Computational thinking, which includes foundation skills such as matching, sequencing and decomposing, is increasingly becoming an educational focus with young children (Strawhacker, Lee, & Bers, 2018). This research focusses primarily on the nature of young children's play with tangible coding technologies (TCTs) and the role of multimodal representation in their development of computational thinking. The methodology aimed to 1) engage young children with authentic and integrated technology learning and; 2) qualify multimodal representation demands and opportunities evident in young children's play with digital coding technologies. Children demonstrated computational thinking through a task where they learnt to code a robot called Cubetto. Results showed the tangible interface of the device facilitated children's development of multimodal digital literacies. Few studies before this have focused on young children's' development of computational thinking through coding, therefore this research is of prime importance to the ever-growing knowledge base of digital technologies and young children.*

## **Introduction**

Early childhood is a critical time for developing the foundation capabilities and dispositions of STEM (Victoria Department of Education and Training, 2016). When observing young children, it is evident they are engaged and developing fundamental STEM skills and general transversal competencies (Bers, Seddighin, & Sullivan, 2013; UNESCO, 2015) through play-based learning. Children are engaging with the T in STEM and developing the fundamentals of computer science when tangible coding technologies (TCTs) or ‘robots’ are incorporated into their hands-on play. Playful learning with tangible objects supports concrete ways of thinking, reasoning and problem solving. Play based learning with TCTs generates authentic and developmentally appropriate computational learning opportunities such as patterning and sequencing. Purposeful and reflective learning conversations integrated with the play, assists children to clarifying their thinking, try out ideas and represent their ideas using multiple modes or representations while coding. Young children collaborate and communicate while problem solving and negotiating actions with a TCT. As such, positive social and emotional outcomes are evident in inquiry-based STEM learning environments that effectively integrate TCTs (Berson, Murcia, Berson, McSporran, & Damjanovic, 2019).

The current research reported here focused on the nature of young children’s play with TCTs and the role of multimodal representation in their development of computational thinking. Specifically, the aim of the research was to identify and document how young children develop computational thinking while coding tangible technologies in an emergent child-centred STEM curriculum. This research was timely due to the national and international focus on STEM education and the national quality standards in early childhood education. In this current climate, the role of digital technologies in early childhood is increasingly discussed and negotiated in learning centres. Educators are wanting support in understanding how young children can be creators of technology (digital coding) and not simply consumers of products. Research evidence is required to inform and meaningfully shape public debate, policy and also the STEM teaching and learning practices occurring in Early Childhood Learning Centres.

Multimodal analysis of the data collected and educators’ reflective practices will provide the evidence needed to inform policy and effective pedagogy in Early Childhood Learning Centres. The research will provide empirical research evidence to inform public and professional debate regarding the role of digital technologies in early childhood education.

## **Coding and computational thinking**

Digital technologies are an increasingly important aspect of early learning. However, for some educators there is an issue understanding pedagogical use of technologies in a setting that values play-based learning. There is ongoing debate around play-based learning and a perceived threat from technology to children’s imaginative play. It is apparent that how children learn to use technologies through play is not well understood. Bird and Edwards (2015), acknowledged ‘research into technological play either problematizes technologies as negatively impacting the quality of children’s play or works to identify newly emerging forms of play’ (p. 1158). Coding is regarded as one of the most powerful aspects of educational technology and is building children’s programming literacy (Strawhacker et al., 2018).

Computational thinking which underpins coding, has many definitions and encompasses a broad range of analytic and problem-solving skills, dispositions, habits and approaches used in computer science. It involves the ability to recognise how computational instructions cause computational behaviour while also developing the ability to identify potential ‘bugs’ or errors (Sullivan & Bers, 2015). The Australian curriculum defines computational thinking as a “problem solving method that is applied to creative solutions that can be implemented using digital technologies. It involves integrating strategies, such as organising data logically, breaking down problems into parts, interpreting patterns and models and designing and implementing algorithms” (ACARA, 2015, p. 8). Computational thinking starts in early childhood with matching, sequencing, patterning and decomposing which are integral to early coding skills and the foundations to future programming capabilities (Murcia, Campbell & Aranda, 2018). These processes involve young children taking actions of the following nature:

- Matching: Identifying objects that have a common attribute.
- Sequencing: An extension of comparing and involves sequencing three or more items or events according to a specific attribute.
- Patterning: A repetition of a sequence of items or events.
- Decomposing: Breaking a large problem into smaller parts for analysis or actions.

Computer programming instruction is viewed as a ‘paradigm shift’ in technological education as it allows learners to think about problems in a qualitatively different way. Learning to develop ‘computational thinking’ that is the set of skills, practices and attitudes around procedural solutions to information-processing challenges is recognised as important across the globe and increasingly an educational focus with young children (Strawhacker et al., 2018).

The use of robotics in early education is growing and children’s understanding of how and why these tools work the way they do is emerging as a new priority area of research. Researchers Sullivan, Elkin and Bers (2015) suggest that robotics and computer programming offer a way to playfully engage children with the process of how motors, sensors and electronics work. They begin by stating ‘robotics offers a playful and tangible way for young children to engage with technology and engineering concepts during their foundational early childhood years’ (p. 1). A range of TCTs and robotics kits for young children (e.g. Bee-Bots, Cubetto, KIBO) are now commercially available. For example, the latest version of the KIBO robotics kit arguably allows young children (aged 4 to 7) to become ‘engineers’ by constructing robots using motors, sensors, and craft materials. Children may also become programmers by exploring coding sequences, loops and variables. Developers of this product claim it teaches technology and engineering to young children in a developmentally appropriate way.

Researchers Sullivan et al. (2015) concur with these claims and state ‘robotics and computer programming in early childhood can support the development of a range of cognitive and social milestones’ (p. 1). These may include number sense, language skills, and visual memory. They also proposed that changes to children’s working memory between the ages of three and five enabled them to learn new content, including following multi-step instructions and retelling familiar stories in correct sequence. They suggest that using a TCT or ‘robot’ strengthens children’s working memory skills as they learn to sequence increasingly complex programs. Arguably, play involving the manipulation of physical objects with symbolic meaning assists children explore more complex symbolic thinking, which is key to coding and future programming. Case study research conducted in both the US and Australia (Damjanovic & Murcia, 2019) explored the affordances of a range of digital technologies and through

observations of children in Preschool classrooms (3 & 4 years of age) playfully learning with a range of digital coding technologies (e.g. Sphero, Cubetto, Bee-Bots and iPads). This study identified multimodal affordances offered by TCT's that potentially assist children to think computationally and develop foundation coding skills. For example, Cubetto is an innovative tangible coding technology yet it incorporates traditional play elements such as patterns, colour recognition and shape sorting. It is a tangible coding tool with a physical programming interface that facilitates young children's engagement with foundation coding principles. Similarly, Bee-Bots have a tangible, mechanical push button, coding interface and alternatively iPads have a touch screen interface for children's play with coding apps.

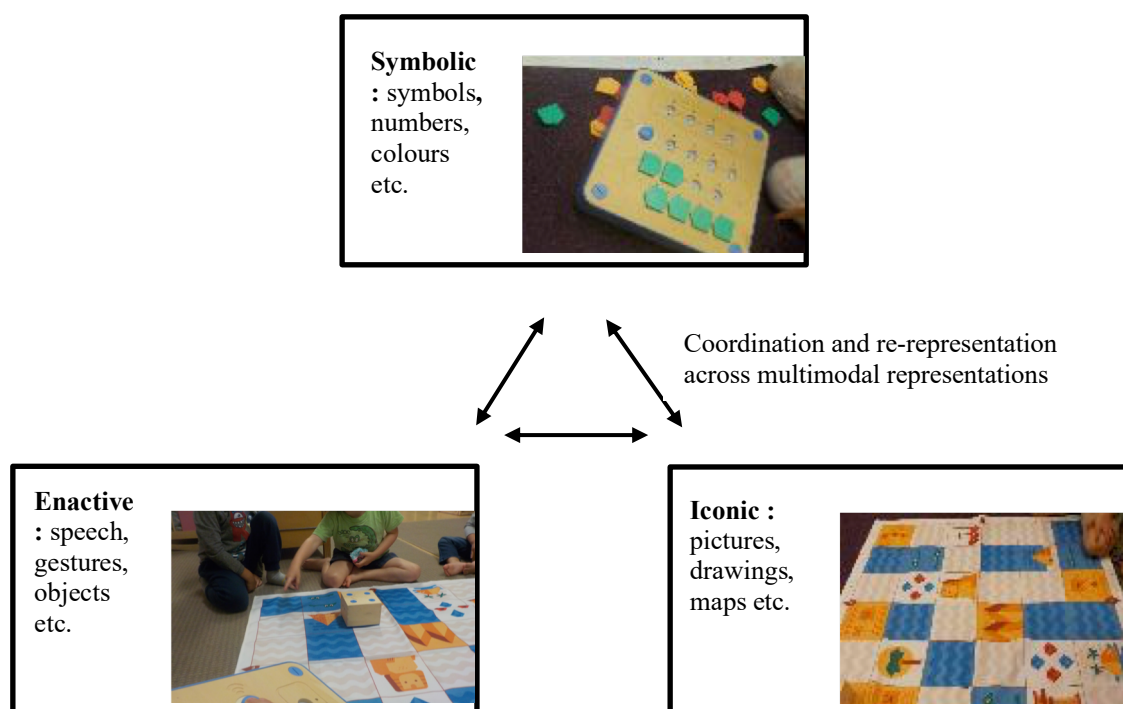
### **Coding as Multimodal Representations**

The theoretical basis of this research is informed by a social constructivist view of the role of language and representation in cognitive development. Drawing on Vygotsky's (1986) insight on the mutually constitutive relationship between language and thought, there is a parallel analogy where coding can be seen as the language equivalent of computational thinking. On one aspect, coding is an outward manifestation of computational thinking in terms of what a person can do that is publicly visible (e.g., writing a code). At the same time, it is only through the action of coding (using symbols and other resources like TCTs) with adults and peers in a social space that computational thinking can be developed and become internalised (Vygotsky, 1986) for young children within a zone of proximal development.

As a form of language, coding is not simply a piece of written code. Instead, it is a unique semiotic system that has been developed by computer scientists to enable our interactions with computers and robots. This perspective of language is drawn from Halliday's (1978) social semiotics which posits language as a set of communicative resources that is developed by a community and over time becomes an indispensable semiotic tool that mediates a specific way of thinking and interaction within that community. In addition, coding, like every language, is not limited to words but it also includes a range of representational modes such as mathematical symbols, images, gestures and physical objects. Fraillon, Ainley, Schulz, Duckworth and Friedman (2019) suggest a visual coding environment is accessible to novice users, and it decreases confounding keyboard errors because no typing is involved. These multimodal representations are crucial to the way we learn and make meanings (Kress & van Leeuwen, 2001).

Building on this idea of language development, Bruner (1990) argues that learning often occurs through three different stages of thinking with the use of representations: enactive, iconic and symbolic. The enactive stage is a concrete hands-on mode that involves the use of tangible objects and accompanied by speech and gestural actions. The iconic stage is a visual mode that involves images resembling or modelling the situation enacted in the enactive stage. The symbolic stage is an abstract mode that involves symbols (e.g., words, signs) representing the objects or ideas through social conventions. Studies have found that abstract ideas in the STEM areas are best learned through a progression from enactive to iconic to symbolic modes of representation (e.g., Tang, 2016). In the context of computer programming, we posit that learning how to code should not be confined to just text-based scripting (symbolic), but it needs to be built on concrete interactions with the objects or physical actions to be coded (enactive) and the visual interface that mediates the human-computer interaction (iconic).

The innovative framework used to understand how children learn coding and develop computational thinking through hands-on play with TCTs, is shown in Figure 1. This framework captures the multimodal representations used in the various modes (enactive, iconic, symbolic) and how they are coordinated to enable children make various mathematical and computational meanings. For example, by using a map (iconic) to visually locate where Cubetto should move to, the children count orally with their fingers (enactive) the number of steps in different directions. The directions and counting are then re-represented into coloured chips (symbolic; e.g., green for forward, yellow for left turn) to be inserted onto an interface board, which would then transform the symbolic ‘code’ back into the physical movement of Cubetto on the map (enactive and iconic). The coordinated movements requires re-representation occurs across multiple modes. Young children interact with symbolic representations on the tangible coding board through shapes, numbers and colour as an iterative processes across the various modes in order to give command to a robot is the beginning of basic programming.



*Figure 1.* Framework showing the coordination and re-representation across the symbolic, enactive and iconic modes.

## Research Design

This project was a collaboration with Researchers and Educators from the University’s Early Childhood Centre located on the metropolitan campus. The Early Years Centre provided long day care and education services to the children of University staff and students. There were four Educators participating, who worked as a pair in each of the Centre’s two kindergarten rooms. For the purpose of the research, the Educators selected eight children, four in each of

two focus groups (ages 3 and 4) from their kindergarten program based on parents return of a signed ethics consent form and children's interest and engagement with the TCT's during the six month research period. To support educators development of technological pedagogical content knowledge and to build their confidence we used action research methods and introduced a user friendly TCT Cubetto.

Questions underpinning the study were:

1. How do educators engage young children with authentic and integrated learning that incorporates tangible coding technologies in the learning environment?
2. What are the multimodal representation demands and opportunities evident in young children's play with digital coding technologies?

Action research methods informed the design and protocols for working with the Educators and positioned them as practitioner researchers. Action research was established by Kurt Lewin (1946) as a term describing the integration of action (implementing a plan) with research (developing an understanding of the effectiveness of this implementation). This approach valued the classroom expertise of the Educators as they partnered with the Researchers in understanding the impact of TCT's and pedagogy on children's learning and development. The Educator's planning, acting, observing and critically reflecting on children's learning occurred in two cycles of action research. Importantly, learnings from each cycle informed the planning of the next.

To elaborate, each stage in an action research cycle contained the following activities:

- Planning: Identify an issue or interest specifically relevant to the kindergarten classroom and focus group of children. Develop questions for exploring, propose a hypothesis and develop a plan of approach.
- Acting: Trial the proposed change by following the plan. Implementing planned ideas, resources and pedagogical strategies.
- Observing: Monitor carefully and purposefully, collect and collate evidence of impact (data), and discuss with co-researchers and peers for interpretation.
- Reflecting: Re-visit and question the implementation process and critically analyse the collected evidence to determine the impact of the implemented action or activity. Evaluate outcomes and options for going forward into the next cycle of action research.

The initial task for the Educators was to design and guide learning experiences that were developmentally appropriate and meeting the play and learning needs of the children. An assertion of the research team was that TCTs should sit integrated across the learning areas and create provocation for children's inquiry, development of computational thinking and coding capabilities.

Critical reflective practice was used throughout the action research cycles. The model of reflection used was based on the Harvard Visible Thinking strategy, I see, I think, I wonder (Lowe, Prout, & Murcia, 2013). This model provided a structure and expected depth in the Educators' critical reflection during team research meetings as they debriefed their actions, observations and learnings. Digital photographs were taken by the Educators of the children playing and learning with the TCT. These photos were deidentified and used as further



evidence to inform the observational notes and checklists made by Educators during the action research cycles.

Educators also wrote reflective learning stories about the children's engagement with the TCT. Learning stories were a normal part of practice in this Centre and required Educators to focus on an individual child's experience. In the learning story Educators described 'What' happened in the learning experience, followed by 'So what' was significant in this observation, and then 'Now what' in terms of how learning from the experience could be used to inform activities going forward.

Critical reflection on the outcomes of cycle one informed the Educators second cycle planning. The following data was collected during each cycle:

- Digital photos of the activities and learning stories about focus children.
- Researcher site visits, field notes and photographs.
- Briefing and debriefing activities in each centre (cluster meetings with educators: talking circles), sharing practice, building shared language and understanding.

Through researcher site visits, educator observations of children's play, shared collegial reflection and review of educator generated learning stories, evidence emerged regarding the multimodality of the children's learning. The data was examined for multimodal representations and evidence of children's computational thinking. Firstly, critical incidents were identified and learning episodes were extracted that illustrate the modes of representation or semiotic resource being used by the focus children. This included text-based scripting (symbolic), concrete interactions with the objects or physical actions to be coded (enactive) and the visual interface used by the children in their interaction with the TCT (iconic).

## **The Learning Story: Cubetto's Adventures in Space**

### **Introduction**

The children had been learning to code the robot called Cubetto. They had been exploring a range of environments as they played with Cubetto on grid mats supplied with the device. During their play it was evident they understood the cause and effect of the coding shapes and the sequencing required to direction Cubetto's movement to set locations. They were using directional language such as forward, left and right. In an initial activity, the educator found that allowing open-play access to Cubetto enabled two focus group children to demonstrate their sequencing and coding skills with minimal prompting from herself.

As additional children joined them to form a larger group the educator asked, 'If we did our own adventure map for Cubetto what could we put on it?'. The children were discussing their ideas, creating stories, finding photos online and drawing their plans, for Cubetto's adventures into space. The children were encouraged to 'write' their code on to a paper story board so other children could program Cubetto and share in the same adventures. Table 1 demonstrates the multimodal analysis of children's coding.

Table 1

*Multimodal analysis of children's coding*

Learning Episode	Multimodal Representation
<p><b>E1: Getting to know Cubetto</b>            (Educator 1): "I wonder how we make Cubetto move?"            (M): "He needs the Board" (D): "Needs chips".            (O): "He goes do do do doo". (M): "If you put two chips in and press the button he moves"            (D): "Wheels move him"            (Educator 1): Looking at the map, "I wonder if you can see some letters"            (J): "I can see E", pointing to the compass on the map            (Educator 1): "E is for the east direction, W is for the west position, S is for the south direction and N is for the North" While pointing and turning in the direction.            (O): "Green goes forward." While pointing in the direction, "I want to go to the rocket ship"            (Educator 2): "How many squares are there for Cubetto to go to the rocket ship?". "Let's count together",            (O): Pointing to each square and counting with the educator, "One, two, three, four, five; five green." The child puts the five green chips onto the coding board and presses the button setting Cubetto off in response to the coding sequence. He smiles "Cubetto's at the rocket!"</p>	<p>E: The children are pointing in the directions for movement and in addition they are doing one to one correspondence for counting. The children observe the physical movement of Cubetto which is also a form of representation for them. The educator is leading a purposeful learning conversation and the children are talking about cause and effect between the chips and the movement and also direction i.e. "Green goes forward."</p> <p>I: The map is an iconic spatial representation of the journey to be taken by Cubetto. The board provides a concrete visual representation of the coded sequence. This interface is enduring and provides a permanent record for the children's coding actions.</p> <p>S: The coloured chips are a symbolic representation of direction. When the children place a sequence of chips they are symbolically representing the movement or algorithm for the journey. In this episode the children also translated from the compass point symbols to a direction</p>
<p><b>E2: Scaffolding Orientation and Direction</b>            (Educator 3): The child (M) was having a turn, working through the book that came with the space mat. On his first go he was a little confused with which way Cubetto was going to go when he put the coding chips onto the board.            (M) was excited saying, "I know" as he placed each colour of chip onto the sides of the board in the direction it would make Cubetto move. This made it a lot easier for (M) to figure out</p>	<p>E: The children did engage with some trial and error. They coded and re-coded in response to observations of Cubetto's journey.            In this episode the children grappled with orientation and were observed moving and turning their whole body to match their orientation in relation to Cubetto's position and journey.</p>



<p>where Cubetto would go and he was much quicker at putting the coding chips onto the Board.</p> <p>Then to match the Board and scaffold the children's ability to orientate, I placed the coloured chips on top of Cubetto facing the direction each coded for a movement. This also seemed to make it a much quicker process and (M) was able to manipulate the resource with ease and understand exactly what he would do with each coloured chip.</p> <p>(Educator 4): Later I laminated photos of Cubetto with chips placed on top showing the direction of movement each caused. These photos were included in the play-kit and were made available so the children could work out Cubetto's orientation and the direction needed in a coding sequence.</p>	<p>I: With the educator, the children were reading the book, seeing the pictures in the story and relating this to the icons on the map.</p> <p>The child placing the coloured chips on the side of Cubetto was an iconic representation of direction. This was a visual aid for assisting him in understanding the orientation and direction for turning Cubetto.</p> <p>The subsequently created photo capturing Cubetto with the coloured chips on top served as a scaffold. This tool was to help children to work out direction, as orientation had been a problem.</p> <p>S: The child being able to put the red chip on the right side demonstrated a symbolic representation of direction.</p>
<p><b>E3: Making an Adventure Map for Cubetto</b></p> <p>The children were exploring the planets by looking at books and searching the internet with the educator.</p> <p>(Educator 3): "If we made our own adventure map for Cubetto where would he go? Not surprisingly the children responded with "To Space".</p> <p>Before starting to create the new mat we placed one of the original mats on the floor to look and see how it was designed. When asked how we could make the squares the same size, so Cubetto would go the right distance, (S) replied "Measure it" and left to find the ruler we had been using earlier.</p> <p>We started by measuring the squares on the first mat and then drew this onto a piece of card as a template. Other children joined and used the template to draw the square (unit) onto coloured paper. Children drew pictures of the planets and these were glued onto the new mat.</p>	<p>E: The measuring of the size of one square was an indication that the children were relating this standard unit to one step of forward movement coded by a green chip.</p> <p>I: The children's drawings of the planets became iconic representations included on their new map.</p> <p>They also were making a visual comparison for the movement of Cubetto to the size of each square on the map.</p> <p>S: The children were demonstrating understanding that each chip was a symbolic representation of a unit of movement.</p>
<p><b>E4: Cubetto's adventure stories</b></p> <p>(Educator 4): Today (S) was asked to plan an adventure for Cubetto on the new space map. He talked about setting off from the sun and going to each planet in order. Firstly, he worked out how to get Cubetto to Mercury. He used the scaffold photo of Cubetto to help find the chips he needed for the coding sequence.</p>	<p>E: The child's story telling was an enactive representation of the proposed coded journey.</p> <p>The children observed the movement of Cubetto and compared this to the sequence of chips placed on the coding board.</p>

<p>Once Cubetto landed on Mercury I asked him “How can we draw instructions for someone else to take Cubetto on the same adventure. What would we write down for them to get Cubetto to get from the Sun to Mercury?” He replied, “We can draw the chips”. He looked at the coding board and took a green pen. He proceeded to draw the shape and colour of each chip in the coded sequence. When it came to Cubetto needing to turn right or left, he would say a red or yellow chip was needed. I would ask each time “Which way does the red/yellow chip go, right or left? He replied correctly each time Red-Right or Yellow-Left. He continued this recording on a story board for all the planets in the solar system (see Figure 2).</p>	<p>I: The scaffold photo tool was used as a visual aid by the child for orientation and finding the directional chips needed for the proposed journey.</p> <p>S: The child re-represented the coding sequence by drawing the shape and colour of each chip needed. The story board became a symbolic recording of the coded journeys.</p>
<p><b>E5: Reading code</b> (Educator 3): I took out the adventure story boards from last week and I asked (L) to show me how the recording worked. She easily identified and explained that the colour and shape drawn represented a chip and that the sequence was to code the journey. She counted out-loud the number of chips in each colour, placed them on the board and then counted the next number (e.g. 2 green, 1 red, 2 green). The child was matching and grouping the chips based on their colour and her understanding of the direction they represented. When I asked her, what was going to happen she said “Cubetto is moving from the sun to this planet”. Pointing at the picture drawn on the map as she couldn’t remember the name of the planet.</p> <p>Other children then coded Cubetto from the symbolic sequence recorded on the story board and matched and talked about the adventure he was taking.</p>	<p>E: The child was using verbal language to re-represent the coding sequence from the story board symbols to a journey for Cubetto</p> <p>The child observed the movement of Cubetto and compared this to the coded sequence. She was pointing in the direction for movement and in addition she was recognising the number of chips and relating this to the squares on the map.</p> <p>I: She was observed looking at the pictures on the map and relating these to the sun and the journey to the planet.</p> <p>S: The child was interpreting the symbolic representation of the journey recorded on the story board.</p>



*Figure 2. A Coding Storyboard with Cubetto in Space.*

## Discussion

Throughout the Space learning journey educators were intentionally introducing resources into the children's environment to provoke their curiosity and playful learning. There was a keen interest from the children to learn about the planets in the solar system as a result of playing with Cubetto on the space map. As described in Table 1: E3, the resulting STEM project where children searched the internet with their educator, looked at pictures and talked about what it would be like to visit each planet was driven by the children's interest. Extending the play with Cubetto in this way created authentic mathematical reasoning opportunities and supported children to develop measurement, location and orientation capabilities as they created their own map and adventure stories. The space journey was playful and children were observed using their imagination and creativity. Consistent with previous studies, it was evident that the collaborative nature of the play encouraged children to demonstrate positive social and emotional outcomes such as communication, problem solving and negotiation of actions (Berson et al., 2019; Bers et al., 2013).

Educators questioning strategies and openness to listening to children's ideas was also observed as a factor influencing the depth of children's engagement and the time they spent learning about and with the TCT. The inquiry questions posed by the educators were prompting children to explore coding of the TCT as they were challenged to explore their created map of space. Newhouse, Cooper and Cordery (2017) found children were unlikely to demonstrate meaningful uses of robotic toys without explicit scaffolding (tightly scripted activity) from educators. Similar to findings from researchers Murcia, Drury and Davies (2017) it was evident in this study that the range of open inquiry questions used by educators and directed towards exploring and reasoning require children to use higher level cognitive skills in responding. The reported learning conversations through all episodes were dialogic in nature as educators encouraged children to contribute and listened to their ideas.

The coding activities that children engaged with supported their development of a range of cognitive capabilities including mathematical reasoning, language skills, and visual memory. It was evident through each episode of the space learning story that the children were learning new science and mathematics concepts and importantly, increasingly using their working

memory to follow multi-step instructions and retelling Cubetto's space adventures through a coding sequence. This was particularly evident in Table 1: E4 and Table 1: E5 as the children were representing a coding sequence with symbols and later reading it back to code Cubetto. Like Sullivan et al. (2015) we observed children learning to sequence increasingly complex programs as they played and explored with Cubetto.

The children's play required the manipulation of physical objects with symbolic meaning to plan and conduct a Cubetto journey. The scaffolding tools and strategies used by the educators assisted the children to explore and demonstrate increasingly complex symbolic thinking. The educators encouraged children to use whole body movements in Table 1: E2 to experience and understand orientation and its effect on direction when coding. The educators and children were often gesturing to indicate direction and also pointing to assist with counting. Again, in Table 1: E2 the educators were responsive to the children's learning needs and created laminated photos of Cubetto with chips placed on top showing the direction of movement each caused. These were made available throughout subsequent episodes in the learning to assist children in working out Cubetto's orientation and the direction needed in a coding sequence.

The analysis of the learning episodes has unpacked the children's coding sequence in terms of the multimodal coordination that arose from the use of enactive, iconic and symbolic representations afforded by Cubetto. Enactive representations in the form of speech, gesture, body movement and orientation, tactile manipulation and Cubetto's physical movement are arguably the most intuitive modes of representation that the children spontaneously used without much intervention from the educators. The provision of these enactive "hands-on" resources was one reason why TCTs appeal to young children in learning coding through play, as opposed to other programming tools, such as Scratch, that do not have much enactive affordances. However, to progress towards basic coding skill and computer thinking will require the re-representation of the enactive representations to iconic and eventually symbolic representations. In this respect, iconic representations, such as Cubetto's board, map (including the embedded squares and icons), drawings and photographs, provide a crucial transition to help the children visualise firstly, the steps they took in the enactive representations and secondly, how to represent those actions symbolically. For instance, the spatial displacement of Cubetto on the map in Table 1: E1 and the visual comparison between the size of each square on the map and Cubetto's step in Table 1: E3 facilitated the children to count and measure the number of chips that were required in their coding sequence.

The use of symbolic representations is essentially the key to understand how the programming in Cubetto works in terms of the sequence of the coloured chips and the logic of that sequence. As symbolic representations are abstractions based on rules and conventions, they present the most challenging demands for children's play with TCT. The analysis in all the five learning episodes has shown that the use of the symbolic representations did not occur in isolation from the enactive and iconic modes, but was instead frequently mediated by and re-represented from those modes. This implies that young children do not learn coding from the abstract and they will need to harness the multimodal opportunities provided by the enactive and iconic representations afforded by Cubetto. This mutual dependence among and transition across the enactive, iconic and symbolic representations is a recurring theme that we saw from all the five learning episodes.

As the children learned basic coding by interacting with the multimodal representations afforded in Cubetto, they also correspondingly developed computational thinking. Some degree of computational thinking such as matching, sequencing and decomposing were evident from the learning episodes. For instance, the student in Table 1: E5 was able to identify and group the colours and shapes from the story board according to their common function. This demonstrated matching in terms of re-representing a visual storyboard to the symbolic sequence required in the code for Cubetto's journey. In terms of sequencing, this occurred in most learning episodes but was most visible in Table 1: E4 when the children translated Cubetto's movement to the sequence of chips on the coding board. This outward performance implied that the children could breakdown Cubetto's analog journey in the real-world as a sequence of discrete events and subsequently assign each event to a symbolic attribute (i.e. colour). This ability also demonstrated decomposing in terms of breaking a larger problem (e.g., Cubetto's journey) into the smaller parts of discrete actions. Lastly, for the computational thinking of patterning to occur, this will require the children to perform a looping function on Cubetto. As patterning is a repetition of a sequence of events, this is a higher level of computational thinking that builds on the skill of matching and sequencing. Thus, although patterning was not observed during the learning episodes, the prerequisite to do so was sought when the children learned the necessary computational thinking required for patterning to develop further.

## **Conclusion**

An important outcome of this research project is the new knowledge gained and understanding of computational thinking developed in children's play with tangible coding technologies. Furthermore, this project benefits research focussed on the semiotic resources drawn on by young children who are developing computational thinking as they create coding solutions. Although there has been a surge of interest in the role of digital technologies in early childhood, past research in this area tends to narrowly focus on children as consumers of digital tools such as iPads and educational apps. As few have focused on young children's' development of computational thinking through coding, this research makes a unique and novel contribution to early childhood learning and development in a knowledge-based economy, which is increasingly characterised by inquiry, creativity and STEM learning opportunities.

Researchers observed the TCT Cubetto being used as a playful bridge to integrate curriculum content with meaningful projects emerging out of children's play. However, achieving this outcome required professional learning for the educators. The effect of teacher preparation and instructional style on children's learning outcomes when engaging with new technology is an increasingly significant research focus. Importantly, it is noted that the success of programming curricula in the early years is not so dependent on the availability of technology as it is on appropriately designed learning activities and supporting materials integrated into learning environment's by well informed and prepared teachers (Bers et al., 2013; Murcia, et al., 2017).



## References

- Australian Curriculum, Assessment and Reporting Authority (ACARA) (2015). Australian Curriculum-Technologies F -10. Retrieved from <https://www.australiancurriculum.edu.au/f-10-curriculum/technologies/digital-technologies/rationale/>
- Bers, M., Seddighin, S., & Sullivan, A. (2013). Ready for robotics: Bringing together the T and E of STEM in early childhood teacher education. *Journal of Technology and Teacher Education*, 21(3) 355-377.
- Berson, I. R., Murcia, K., Berson, M. J., McSporran, V., & Damjanovic, V. (2019). Exploring young children's play and creativity with tangible technologies in early childhood classrooms in Australia and the United States. *Kappa Delta Pi Record*, 55(2). <https://doi.org/10.1080/00228958.2019.1580986>
- Bird, J., & Edwards, S. (2015). Children learning to use technologies through play: A Digital Play Framework. *British Journal of Educational Technology*, 46(6), 1149-1160.
- Bruner, J. S. (1990). *Acts of meaning*. Cambridge, Mass: Harvard University Press.
- Damjanovic, V., & Murcia, K. (2019). Pleasure of Play with Innovative Technologies: Moving Away from the Dominant Discourse of Achievement and Access. Conference presentation at RECE, New Mexico.
- Fraillon, J., Ainley, J., Schulz, W., Duckworth, D., & Friedman, T. (2019). International Computer and Information Literacy Study 2018: Assessment Framework. Retrieved from [https://research.acer.edu.au/cgi/viewcontent.cgi?article=1016&context=ict\\_literacy](https://research.acer.edu.au/cgi/viewcontent.cgi?article=1016&context=ict_literacy)
- Halliday, M. A. K. (1978). *Language as social semiotic: the social interpretation of language and meaning*. London, England: Arnold.
- Kress, G., & van Leeuwen, T. (2001). *Multimodal discourse: the modes and media of contemporary communication*. London, England: Arnold.
- Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues*, 2(4), 34-46.
- Lowe, G. M., Prout, P., & Murcia, K. (2013). I see, I think I wonder: An evaluation of journaling as a critical reflective practice tool for aiding teachers in challenging or confronting contexts. *Australian Journal of Teacher Education (Online)*, 38(6), 1-16.
- Murcia, K., Drury, S. & Davies, S. (2017). Talking STEM: Inquiry questioning in early childhood education. ESERA conference presentation, Dublin, Ireland. Retrieved from <http://esera2017.org>



*Australian Educational Computing*, 2019, 34(1).

Murcia, K., Campbell, C., & Aranda, G. (2018). Trends in early childhood education practice and professional learning with digital technologies. *Pedagogika*, 68(3), 249-264.

Newhouse, C. P., Cooper, M., & Cordery, Z. (2017). Programmable toys and free play in early childhood classrooms. *Australian Educational Computing*, 32(1)

Strawhacker, A., Lee, M., & Bers, M. U. (2018). Teaching tools, teachers' rules: exploring the impact of teaching styles on young children's programming knowledge in ScratchJr. *International Journal of Technology and Design Education*, 28(2), 347-376.

Sullivan, A., & Bers, M. (2015). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education*. Online First.

Sullivan, A., Elkin, M., & Bers, M. (2015). KIBO robot demo: Engaging young children in programming and engineering. In Proceedings of the 14th International Conference on Interaction Design and Children (IDC '15). ACM, Boston, MA, USA. Retrieved from  
<http://ase.tufts.edu/DevTech/publications/IDC%20KIBO%20Demo%20Complete.pdf>

Tang, K. S. (2016). The interplay of representations and patterns of classroom discourse in science teaching sequences. *International Journal of Science Education*, 38(13), 2069-2095. <https://doi.org/10.1080/09500693.2016.1218568>

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2015). Asia Pacific Education Research Institutes Network (ERI-Net) Regional Study. Transversal Competencies in Education Policy & Practice. Retrieved from  
<http://www.unesdoc.unesco.org/images/0023/002319/231907E.pdf>

Victoria Department of Education and Training. (2016). STEM in the Education State. Retrieved from  
[http://www.education.vic.gov.au/Documents/about/programs/learningdev/vicstem/STEM\\_EducationState\\_Plan.pdf](http://www.education.vic.gov.au/Documents/about/programs/learningdev/vicstem/STEM_EducationState_Plan.pdf)

Vygotsky, L. (1986). Thought and language (Translation newly rev. and edited / by Alex Kozulin ed.). Cambridge, Mass: MIT Press.