Young Children's Understandings of Clocks at the Start of School

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Time is an essential construct for understanding our everyday lives and the wider world; however, it is commonly seen as a difficult topic by teachers and children throughout primary school. There is limited research into children's learning about time, and in particular, concerning young children's understandings of clocks. This study examines the extent to which children are able to draw the structural features of a clock at the start of school. The drawings were produced by 132 Kindergarten children in their first six weeks of primary school. The drawings showed that the majority of the children started school with the ability to represent the structural features of a clock (numbers, hands, partitioning). Moreover, unlike previous studies, our analysis suggests that children's ability to represent clock structure does not progress sequentially. Rather, the drawings suggest that different children attend to different features of clocks, and thus have different developmental journeys.

Time is an essential construct for understanding our everyday lives and the wider world, however it is a complex and abstract concept (Levin & Zakay, 1989). It is also commonly seen as a difficult topic by teachers and children throughout primary school (Burny, Valcke, Desoete, & Van Luit, 2013). Despite its importance, and its difficulty to teach and learn, there is limited research into children's learning about time (Burny, Valcke, & Desoete, 2009). In particular, there is relatively little research around young children's understandings of clocks. A seminal study was that of Pengelly (1985), who asked children aged three to seven years of age to create a clock face using a range of materials. Pengelly suggested that children's understanding of the clock face progressed through a step-wise developmental sequence. More recently, Smith and MacDonald (2009) examined the clock drawings of four- to six-year-old children and noted, in particular, a fixation on the role and movement of the hands of a clock. This finding challenged Pengelly's developmental sequence, which did not include a focus on hands, flagging a need to more closely examine young children's development of their understanding of clocks.

Despite the demonstration of children's early understanding of clock faces in these studies, Australia's national curriculum for Mathematics (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2017) only expects children to be reading clock faces at the conclusion of Year 1, when aged six to seven years. There is no mention of clocks in the curriculum for the first year of schooling, just a requirement to sequence familiar events in time.

This study examines the extent to which children are able to use drawings to represent the structural features of a clock at the start of school. Specifically, this study considers three key structural features – numbers, hands, and partitioning – and the sophistication with which children are able to represent these features in their mathematical drawings within the first 6 weeks of primary school. It examines how the representation of each feature is associated with the representation of each of the other two structures, and also considers what children's drawing narratives reveal about their understanding of the structure and function of clocks as they begin primary school. The article is a significant expansion of an earlier conference paper (MacDonald & Murphy, 2018).

Background

Time is an element used to structure and understand our world. We use time to order events, to measure their duration, and to gauge the intervals between them and the rate at which they occur (Burny et al., 2009). Time is used to regulate our days, to organise our work lives and social interactions, to monitor our society, to plan our futures and to track our histories. The precise measurement of time is essential for the technologies that facilitate our economy, our communication, and our navigation. Given its central role in human life, time has been explored by many, including scientists, philosophers, historians, theologians, archaeologists, mathematicians, and psychologists (Burny et al., 2009; Levin & Zakay, 1989). Due to its central role, time is seen as a key concept for instruction throughout primary school (Burny et al., 2009).

Time is a complex and abstract notion (Levin & Zakay, 1989). Time progresses at a steady rate (at least in our everyday experience), and this progress is quantifiable (Levin & Wilkening, 1989). Like length, weight and other measurable aspects of our world, the units ascribed to measurements of time allows it to be represented and modelled mathematically. However, unlike length and weight, the units used to measure time having no physical manifestation. Instead, units of time, including formal units like seconds or minutes, can be seen as representing a constant, known rhythm (Levin, 1989). The complex and abstracted nature time as a concept may go some way to explaining why time is a difficult topic for primary school teachers and students alike (Burny, Valcke, Desoete, & Van Luit, 2013).

Despite the importance of the concept of time, and the difficulties associated with education about time, there has been limited systematic investigation into teaching and learning time in primary school (Burny et al., 2009). Initially, this field was dominated by a psychological exploration of children's natural development of an understanding of time. It has only been since the turn of the century that the research literature has emphasised instruction and learning about time-related competencies. This work suggests that systematic instruction has the greatest influence on children's mastery of the topic of time. Further, children's understanding of time depends on their development of other skills including literacy, numeracy and spatial abilities (Foreman, Boyd-Davis, Moar, Korallo, & Chappell, 2008). While the weight of evidence highlights the important of instruction, there is scant research into effective instruction to support the development of children's time-related competencies (Burny et al., 2009).

Analogue clock reading is one time-related competency, and is "the most exclusive time-related subject in primary school, playing a role in nearly every grade" (Burny et al., 2009, p. 485). Similar to research into the development of time-related competencies, research into the acquisition of clock reading skills is relatively limited. One research synthesis of three American studies suggested that 10% of four year olds can read an "o'clock" time, with 45% of five year olds able to do this, and by age seven all children can read an "o'clock" time on an analogue clock (Williams, 2012). The precision of clock reading progresses through the grades until most children can read an analogue clock to the nearest minute by age 10 (Burny et al., 2009).

One research strategy used to understand young children's skill development in this area is to investigate how young children represent analogue clock faces. Mulligan and Mitchelmore (2013) explored young children's drawings of clocks as part of a broader program of research investigating pattern and structure in early mathematical development. They noted potential problems with fine motor coordination in young children as a limitation in studies using children's drawings, and highlighted importance of collecting children's narratives about what they have drawn to assist in interpreting this data. They showed that the grade one (six-seven year old) children in the study vary widely in their ability to represent clock faces. Some offered “pre-structural” representations, with a suggestion of numbers somewhere on the face, or some marks on the perimeter. Others offered advanced structural representations including the numbers one to twelve evenly spaced around the perimeter, differentiated hands, and in at least one case, minute interval markings.

Pengelly (1985) investigated the ability of younger children (aged three to seven years old) to build clock faces using a variety of material. Using her findings, Pengelly suggested that children’s understanding of clock faces progresses through a sequence of five stages: 1. Early impressions of a clock; 2. Awareness of the numerals on a clock; 3. Awareness of the importance of the twelve numerals; 4. Partitioning of the twelve numerals becomes significant; and 5. Recognition of minute markers. More recently, Smith and MacDonald’s (2009) study of the clock drawings of four to six year olds flagged a challenge to Pengelly’s developmental sequence. They observed a strong interest in the role and movement of the hands of a clock, where Pengelly’s stages did not include a focus on hands, and suggested this may be a promising way of exploring time with young children.

Method

Methodological Approach

This study utilises children’s representations in the form of drawings and accompanying narratives to ascertain children’s understandings of the structural features of an analogue clock. Goldin and Kaput (1996) describe *representations* as symbolic configurations that “usually belong to highly structured systems, either personal or idiosyncratic or cultural and conventional” (p. 398). Vygotsky (1978) emphasised the critical role of representation in young children’s concept development. Indeed, activities such as drawing helps to bring children’s ideas to the surface (Woleck, 2001), in a form that is “accessible to observation by anyone with suitable knowledge” (Goldin & Kaput, 1996, p. 400).

Increasingly, children’s drawings are being recognised as an appropriate and effective methodological approach for researching with young children (MacDonald, 2013). Drawing is an activity that is, for most children, familiar and non-threatening (MacDonald, 2009), and a medium that enables children to explain ideas with precision and detail (McArdle, 2012). This study uses a “drawing-telling” approach (Wright, 2007; Smith & MacDonald, 2009), whereby children are encouraged to draw as well as provide an accompanying narrative for their drawing. The narrative elements is critical, because: 1. It enables the child to draw attention to key features within the drawing; 2. It provides the opportunity to highlight features or ideas that may not be immediately obvious in the drawing; and 3. It reduces the risk of misinterpretation of the drawing by the researcher/viewer, as they child themselves has had the opportunity to describe the meaning and intent of the drawing (MacDonald, 2013).

Data Gathering

This study was part of a wider project undertaken with 132 children who had just commenced Kindergarten (first year of school) at two primary schools in regional New South Wales (NSW), Australia. A Kindergarten class typically contains children aged between 4 years, 6 months, and 6 years. Children in NSW start school in late January, and the data were collected within six weeks of the children starting school. The children were simply asked to “draw a clock”; no further instructions were given. Once the drawing was completed, children were invited to explain what they had drawn and the drawings were annotated with this narrative. Only two children chose to draw digital clocks, with the rest of the sample drawing analogue clocks.

Data Analysis

The analogue clocks were initially analysed according to the features as represented in the drawings – independent of the accompanying narrative. The coding was based on three structural features of an analogue clock: numbers, hands, and partitioning. The drawings were coded according to the degree of sophistication of these three features evident within the drawing, as shown in Table 1. Descriptive statistics where used to analyse the relative prevalence of single and pairs of structural features in the children's drawings. Spearman rho correlation coefficients were calculated to further explore the relationship between the sophistication of representation of the various pairs of structural features.

126 of the 132 children offered a narrative to accompany their drawing when invited to explain what they had drawn. These narratives were analysed for statements about clock structural features and clock function, as well as commentary about each child's ability to complete the task. 33 narratives offered no such statements. Several of these described the type of clock, for example "This is a Batman clock" or "This is a rainbow one". Others identified where the child had encountered a clock, such as "I've seen one on the telly" and "I have a clock on my watch". One offered the sound a clock makes, "Tick, tock", and a few presented a creative narrative for their drawing, for example "The monsters are taking the clocks away". All of these narratives were excluded from the analysis. The remaining 93 narratives were analysed according to statements about clock numbers, hands, and the relationship between the two. The narratives were coded according to the degree of sophistication of these three aspects, as shown in Table 2.

Table 1
Coding of the Structural Features of an Analogue Clock Represented in Children's Drawings

Numbers	Hands	Partitioning
1. No number representation	1. No indications of hand(s)	1. No partitioning
2. Some number representation	2. Indication of hand(s)	2. Developing partitioning
3. Numbers in sequence	3. Two equal length hands	3. Partitioning
4. Numbers 1-12 in sequence	4. Two (or three) differentiated hands	

Narratives were further analysed for statements about the relationship between clocks and daily routine, time-telling, and the child's capacity to draw a clock. Finally, each child's drawings was compared to the narratives they offered to identify where narratives suggested greater knowledge of clock structure than the child's drawing indicated.

Table 2
Coding of References to the Structural Features of an Analogue Clock in Children's Narratives

Numbers	Hands	Relationship between Hands and Numbers
1. No mention of numbers	1. No mention of hand(s)	1. No mention of a relationship between numbers and hands
2. Some mention of numbers	2. Statement implying hand(s) (e.g. "arrows")	2. Statement implying relationship between hands and numbers
3. Explicit mention of the number 12	3. Explicit mention of the term "hands"	3. Statement indicating two hands that point to numbers

Results

Analysis of Clock Drawings

The analysis revealed that the majority of children represented one or more structural features of a clock. Only 14 children (10.6%) were classified as not representing any of the three features. Of these 14, one drew a digital clock (but with no numbers represented), and one chose to draw a cuckoo clock. The remaining 12 drew a vaguely circular form, but with no clearly discernible structural features of a clock. 22 children (16.7%) represented, to some degree, one of the features. 46 children (34.8%) represented two features, while the other 50 children (37.9%) represented at least some indication of all three features.

Representation of Numbers

Only 17 children (12.9%) did not make some representation of numbers in their drawings. Two of these children did, however, represent the hands of the clock (Figure 1). 42 children (31.8%) represented numbers in some form; usually through the use of dots or dashes (Figure 2), or through identifiable numerals. The majority (57 children; 43.2%) not only represented numerals, but also represented these in a sequence (Figure 3). Often these sequences extended beyond the number 12. Finally, at the highest level of sophistication, 16 children (12.1%) clearly represented the numerals 1-12 on their clock face (Figure 4).

Figure 1. No representation of numbers.

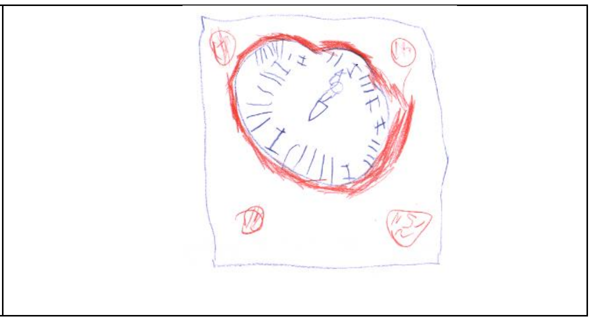

Figure 2. Representation of numbers.

Figure 3. Representation of a number sequence.

Figure 4. Representation of numbers 1-12.

Representation of Hands

The majority of the children gave some indication of clock hands in their drawing; although, 45 children (34.1%) did not represent hands in any way (Figure 5). Of those who did represent hands, most (37 children; 28.0%) used marks to indicate the position of at least one hand; sometimes more than three hands were evident (Figure 6). 20 children (15.2%) represented two hands of the same length, with no differentiation between hour hand and minute hand (Figure 7). Nearly a quarter (30 children; 22.7%) of the drawings clearly represented dimorphic hands (Figure 8), with some children also including a seconds hand.

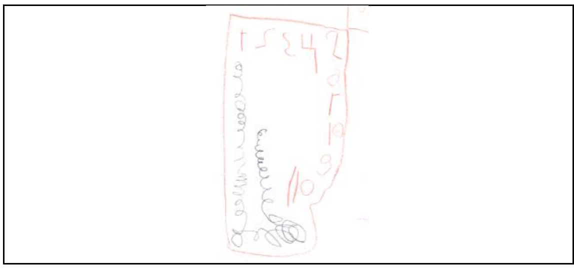

Figure 5. No representation of hands.

Figure 6. Indication of hands.

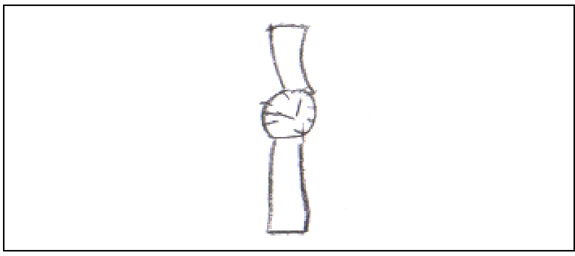

Figure 7. Two equal-length hands.

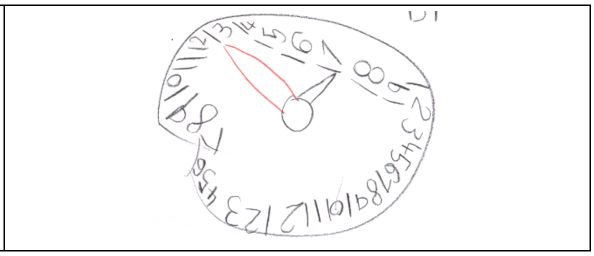

Figure 8. Two (or three) differentiated hands.

Representation of Partitioning

Drawings were classified as having no partitioning evident if the numerals/marks were placed haphazardly, or around an arc of the clock face (Figure 9). This was characteristic of most of the drawings, with 70 children (53.0%) coded as not representing partitioning. Inversely, partitioning *was* evident in nearly half of the sample. 48 children (36.4%) showed a developing sense of partitioning. Drawings were coded as “developing” when there was an attempt to evenly place numerals/marks around the clock face (Figure 10). Some responses also showed a need to “fill the face”, i.e. have numerals/marks all the way around the clock face. In instances where the children stopped at 12 (or another number, i.e. 19), attempts were made to “fill the gap” with scribbling, colouring, or the placement of the hands in the space left over. Finally, there were 14 children (10.6%) who clearly represented partitioning of 12 numerals/marks around the clock face (Figure 11).

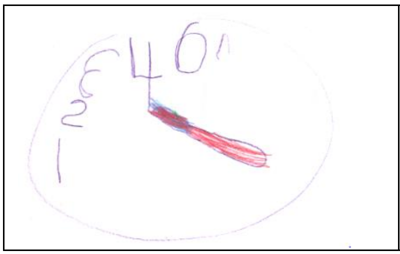

Figure 9. No partitioning.

Figure 10. Developing partitioning.

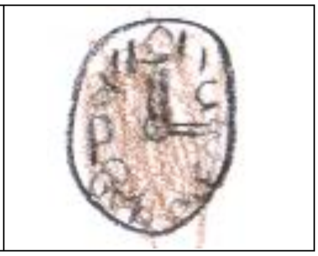

Figure 11. Partitioning.

Representation of Structural Features Considered Together

Table 3 shows the coding of number representation versus partitioning for each drawing. 17 drawings (12.9%) included no number representation so therefore could not show partitioning. Of the 42 children (31.8%) who used only number representation, 27 showed no partitioning, 13 showed developing partitioning, and only two showed partitioning. The 57 children (43.2%) offering a number sequence were most likely to show developing partitioning (N = 31), with 23 not showing any partitioning and only three showing full partitioning. Only the 16 children who used numbers 1-12 most frequently demonstrated the most sophisticated level of partitioning (N = 9), though some children using the numbers to 12 demonstrated no partitioning at all (N = 3). There was a moderately strong linear correlation between the sophistication of number representation and the sophistication of partitioning (rho = 0.49, $p < 0.01$). While the data suggests that increased sophistication in number representation is accompanied by increased sophistication in partitioning, this was not so in all cases.

Table 3

Coding of the Representation of Numbers versus Partitioning in Children's Drawings of an Analogue Clock

	No partitioning	Developing partitioning	Partitioning	Total
No number representation	17 (12.9%)	NA	NA	17 (12.9%)
Number representation	27 (20.5%)	13 (9.8%)	2 (1.5%)	42 (31.8%)
Number sequence	23 (17.4%)	31 (23.5%)	3 (2.3%)	57 (43.2%)
Numbers 1-12	3 (2.3%)	4 (3.0%)	9 (6.8%)	16 (12.1%)
Total	70 (53.0%)	48 (36.4%)	14 (10.6%)	132 (100%)

Table 4 shows the coding of number representation versus hands representation for each drawing. The children not representing numbers were unlikely to include hands in their drawings either. Of the 42 drawings (31.8%) offering number representations, 26 included some representation of hands, though most of these were of a low sophistication. Where a number sequence was included, hands were drawn to varying levels of sophistication in relatively equal proportions, 29 no hands or indications of hands, and 28 two hands, either equal size or differentiated. Nearly half the children who included the numbers 1-12 also drew differentiated hands. There was a moderately strong linear correlation between the sophistication of number representation and the sophistication of hands representation (rho = 0.41, $p < 0.01$). Again, the data suggests that increased sophistication in number representation is accompanied by increased sophistication in hands representation, however this was not so for all of the drawings.

Table 4
Coding of the Representation of Numbers versus Hands in Children's Drawings of an Analogue Clock

	No indication of hand(s)	Indication of hand(s)	Two equal length hands	Two (or three) differentiated hands	Total
No number representation	14 (10.6%)	1 (0.8%)	1 (0.8%)	1 (0.8%)	17 (12.9%)
Number representation	16 (12.1%)	15 (11.4%)	7 (5.3%)	4 (3.0%)	42 (31.8%)
Number sequence	13 (9.8%)	16 (12.1%)	10 (7.6%)	18 (13.6%)	57 (43.2%)
Numbers 1-12	2 (1.5%)	5 (3.8%)	2 (1.5%)	7 (5.3%)	16 (12.1%)
Total	45 (34.1%)	37 (28.0%)	20 (15.2%)	30 (22.7%)	132 (100%)

Table 5 shows the coding of the representation of hands versus partitioning for each clock drawing. It demonstrates that partitioning is not required for children to draw clock hands at the highest level of sophistication, however there are some patterns of note. Of the 70 children showing no partitioning, 56 included no hands or only an indication of hands. 17 of the 48 children demonstrating developing partitioning drew differentiated hands, with nine drawing equal length hands, and 11 each indicating hands or including no hands at all. Half of the children showing full partitioning drew differentiated hands. There was a moderately strong linear correlation between the sophistication of partitioning and the sophistication of hands representation (rho = 0.42, $p < 0.01$). This indicates that increased sophistication in hands representation is accompanied by increased sophistication in partitioning, however, once again, this was not the case for all children's clock drawings.

Table 5
Coding of the Representation of Hands versus Partitioning in Children's Drawings of an Analogue Clock

	No partitioning	Developing partitioning	Partitioning	Total
No indication of hand(s)	33 (25%)	11 (8.3%)	1 (0.8%)	45 (34.1%)
Indication of hand(s)	23 (17.4%)	11 (8.3%)	3 (2.3%)	37 (28.0%)
Two equal length hands	8 (6.1%)	9 (6.8%)	3 (2.3%)	20 (15.2%)
Two (or three) differentiated hands	6 (4.5%)	17 (12.9%)	7 (5.3%)	30 (22.7%)
Total	70 (53.0%)	48 (36.4%)	14 (10.6%)	132 (100%)

Analysis of Narratives

Six children offered no narrative at all. In some of these cases teachers noted that the students were English as a Second Language (ESL) students. Only 93 of the 126 children who provided a narrative commented on the structure or function of a clock. Of these, 82 mentioned numbers, with statements such as "Clock has 1, 2, 3, 4" and "I'm drawing numbers around the outside". Seven of these children explicitly mentioned the number twelve, for example, "It has a bird in it that comes out when it gets to 12", and "It goes up to 12".

37 narratives mentioned hands in some way. 29 alluded to hands, using alternate terminology with statements such as "Goes up to 11. The time goes around and around and around", or "It has numbers on it and arrows. The arrows tell you what the time it." Eight explicitly used the term hands, for example, "It has numbers - go up to 10. I have Barbie Clock that stays at 3. It has 2 hands", and "It has numbers and hands".

In all but two of the 37 narratives indicating the presence of hands, numbers were also mentioned. 19 narratives suggested some relationship between the hands and the numbers. The majority of these (N = 15) described a relationship in a way that was inaccurate or vague, for example, "One hands pointing to the 10 and the 2. The other hand's pointing to the 4 and the 10. Numbers go up to 10 and keep going around", and "It has a strap on it and numbers. The things in the middle tell the time by going around the numbers. Watches help you tell the time. Mum has a watch to tell the time." Four narratives described the relationship between hands and numbers accurately and specifically, though they may not have shown an accurate understanding of the significance of the relationship, such as, "It has things to know what numbers. It's pointing at a 1 and a 2", and "It has numbers up to 10. It is pointing to 10 and 8. I don't know what time that is. The big one is pointing to 10 and the little's pointing to 8 - means its eight o'clock".

In the majority of the 93 cases, the narrative given by the child did not offer any more insight into their understanding of clock structure than their drawing gave. However, it is significant that 10 (10.7%) narratives did reveal that the child had a more sophisticated understanding of clock structure than their drawing indicated. One child who drew none of the three structural features being researched on their clock stated: “It tells the time. The point things turn around and point to the numbers. It goes up to 12.” Another child drew no numbers in their drawing but explained: “No numbers but you can tell the time because you know where the numbers should be. It would be 12 o'clock.” In four narratives children spoke about an inability to write numbers, potentially impacting on the level of sophistication of their clock drawing, for example, “These are pointers. There are more numbers, but I don't know how to write them.” These examples illustrate that the clock drawings may not reveal the full understanding a child has of clock features.

Narratives have the capacity to show a child’s understanding of the function of clocks that is more difficult to represent in a drawing. 16 of the 93 narratives suggested a relationship between the clock drawing and daily routines, for example: “It has numbers and hands that point to the numbers. It shows when they have to go out of the meeting”; “I have a rainbow clock. When its point to the 2 and the 8 that means its breakfast time”; and “They go bing, bing when it is time to wake up. The numbers tell me when the time is breakfast, or morning, or play time.”

Some of the narratives reveal children’s early attempts at telling the time. In some cases, narratives mimicked the form of time-telling without suggesting a real time, for example, “The time is half past thirteen”, and “The time is 11 and a 2”. In eight cases these children just beginning primary school accurately named the time that they have represented in their drawing, for example: “It is four o’clock”; “It is 10 o’clock. These are special pointers that point very fast”; and “There are numbers and arrows. It dings so I can wake up. It is 8 o’clock.” In all these instances the child was representing a time on the hour.

Discussion and Conclusion

This study explored the extent to which children just beginning school represented three structural features – numbers, hands and partitioning – in their drawings of an analogue clock. It analysed both children’s clock drawings and the narratives they offered about these drawings for evidence of their understanding of the structure and function of clocks. It also interrogated the relationship between the representation of the different features of a clock to gain some insight into the development of children’s understanding of these structures.

The results showed that the majority of children start school with some ability to represent the structural features of a clock (numbers, hands, partitioning), with 117 children (89%) representing at least one structural feature in their drawing, and 50 children (37.9%) representing all three structural features studied. It was logical that the 14 children who did not represent numbers in any way were also classified as not representing partitioning. 115 children (87.1%) represented numbers in some way, while 62 (47.0%) children demonstrated at least some partitioning. 87 children (65.9%) represented hands and 37 children discussed hands or hand-like structures in their narratives, consistent with Smith and MacDonald’s (2009) finding that many children recognise the hands as a feature of clocks. Encouragingly, five children represented all three features at the highest level of sophistication.

Our analysis suggests that children’s ability to represent clock structure does not progress sequentially, as posited by Pengelly (1985). While some form of number representation is necessary to demonstrate partitioning, some children showed partitioning without any number sequence. Some children demonstrated clock hand differentiation without any number representation, while others represented the numbers 1 to 12 without drawing hands or demonstrating any partitioning. There were numerous examples of children drawing one or two features are the highest level of sophistication, while the remaining feature(s) where at a lower level of sophistication, or even not present. The drawings suggest that different children attend to different features of clocks, and thus have different developmental journeys. The fact that there was a moderately strong correlation between the sophistication of each pair of features suggests that as children increase their ability to represent one feature of a clock, so does their ability to accurately represent the other features. None of the clock features appear to have developmental primacy of any other. This challenges Pengelly's suggestion that children's ability to represent clock structures develops through five successive stages (Pengelly, 1985).

Analysis of the narratives accompanying the drawings provided important insights into children's thinking about clock structure and function, as well as how they went about fulfilling the requirements of the task. Given this, it is telling that 6 children chose not to offer a narrative about their drawing. Of those that did, 10 children revealed a deeper understanding of clock function than their drawings demonstrated, and four children raised concerns about their capacity to write numbers limiting their ability to complete the task. This serves as a caution to researchers and educators alike about the potential limitations of drawings for conveying children's understandings. Further, 16 children's narratives demonstrated some understanding of using a clock to signal daily routines like breakfast time or time to get up, and eight children's narratives revealed that they know how to draw a specific time. The richness of these narratives supports Smith and MacDonald's (2009) argument that both the drawing and the child's story about the drawing must be attended to.

This study demonstrates that many children arrive at school with a sophisticated understanding of clock features; yet, the Australian Curriculum for Mathematics (ACARA, 2017) makes no explicit mention of clocks for children just beginning school. This is consistent with international research that indicates a mismatch between the intended mathematics curriculum for the first year of school and children's mathematical ability when starting school (Perry, MacDonald, & Gervasoni, 2015). This presents a risk of these students becoming bored or disengaged with mathematics upon school entry.

The children's drawings present a number of opportunities for mathematical development in the first year of school. For example, clock drawing as means of supporting children's writing of number sequences in a meaningful context. Children can also be supported to develop skills in partitioning and spatial representation. These skills also lend themselves to the representation of other mathematical concepts, such as division and fractions. The "draw a clock" task could easily be utilised in Kindergarten classrooms as a means of ascertaining a foundation for further mathematics learning in the first year of school.

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