Early Childhood Education Journal (2025) 53:891–902
https://doi.org/10.1007/s10643-024-01634-8

# Informal Assessment of Preschool Children's Concepts of Zero

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Accepted: 16 January 2024 / Published online: 26 February 2024


**Abstract**

There is growing interest in mathematics learning progressions in early childhood education. Counting is a skill usually developed early in life. The application of the counting principles in early childhood typically entails counting objects. This poses challenges for learning about zero. Indeed, the word "zero" is seldom used in the context of early childhood education. Early childhood educators could purposefully introduce children to zero as a concept and facilitate children's understanding that zero is a number and more than just the absence of something. "Zero" is introduced in school, but little guidance is provided to teachers within the Australian Curriculum for Mathematics in the Foundation year. This study contributes to a small corpus of research that has investigated preschool children's understanding of the concept of zero. Unlike other studies, the method employed to elicit children's knowledge was informal and more similar to educator-child conversations that occur within a playbased curriculum and contribute to formative assessment. Data are presented from 20 children, aged from three to five years, participating in a regional early learning centre. Six children demonstrated familiarity with the symbol for zero ("0") and/or the concept that zero describes a numerical quantity. Asking a follow-up question encouraged children to share their thinking. The importance of early childhood educators purposefully supporting children's familiarity with the word zero along as well as the concept of zero is proposed.

**Keywords** Zero · Early childhood · Preschool · Assessment · Learning progressions

## Introduction

The mathematical thinking of children in the years before school entry has been the focus of research over many years and it is well-established that children's number knowledge when they start preschool is shaped by early exposure to number talk in the home environment (Gunderson & Levine, 2011; Niklas et al., 2015). This variability predicts levels of ability in the early years of school (Levine et al., 2010). Research attention has also focused on children's mathematical argumentation (Nergård, 2023) and progressions in mathematics learning (Clements & Sarama, 2021; Early Start University of Wollongong, 2013; The University of Melbourne Assessment Research Centre, 2008; UNESCO Institute for Statistics (UIS) & ACER's Centre for Global Education Monitoring (GEM), 2018). In addition, a large body of literature has addressed the critical role of educators in recognising and supporting children's mathematical thinking (Cohrssen & Pearn, 2019; Cohrssen & Tayler, 2016; Cutting & Lowrie, 2023; Franzén, 2021; Ginsburg, 2010; Ginsburg et al., 2008; Gunderson & Levine, 2011; Hedge & Cohrssen, 2019; Knaus, 2021; MacDonald, 2013, 2015; MacDonald & Murphy, 2021; Ryoo et al., 2014). Mathematics learning is cumulative: early learning impacts on later learning and academic achievement (e.g., Clements & Sarama, 2021; Duncan et al., 2007; Jordan et al., 2010; Krajewski & Schneider, 2009b).

Much of the research on children's number knowledge in particular has included a focus on their application of the counting principles (Gelman & Gallistel, 1978). Play provides an ideal vehicle for the rehearsal and consolidation of counting skills as children spontaneously count, classify, and order objects during play. Children's knowledge of sequential relations between successive numbers supports ordinal number knowledge (Xu & LeFevre, 2016). Krajcsi et al. (2021) have suggested that children need to develop an understanding of numbers and counting in order to grasp the notion of zero as an empty set. Applying the counting principles implies that there is something to be counted and

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when children count objects, they tag physical objects with natural[1] number words. These numbers differ from zero in that zero is not used as a counting number as it is not tagged to a physical object. Consequently, the trajectory for emerging understanding of zero may differ from the trajectory for mastering rational[2] numbers (Merritt et al., 2009) and lag behind children's understanding of other small numbers (Wellman & Miller, 1986). Despite this, many three-year-old children represent zero as the absence of something and four-year-old children may represent zero as accurately as they do small whole numbers (Sarama & Clements, 2009).

It is, thus, necessary for early childhood educators to purposefully introduce children to zero as a concept and to progress their understanding of zero from solely representing the *absence* of something to understanding zero as a number; that is, treating the concept of nothing as a numerical quantity. This is complex thinking as it requires children to understand both the concept of an empty set *and* the concept of zero as a number (Kazima et al., 2023). One strategy for early childhood educators to explore the concept of zero may be the use of five-frames and concrete manipulatives as these provide opportunities to rehearse the counting principles as well as to notice visual representations of numbers from zero to five (McGuire et al., 2012). Indeed, it has been argued that the concept of zero is not acquired by children until they have mastered the cardinal principle (Hartmann et al., 2022; Nieder, 2016).

In the context of growing interest in learning trajectories in early childhood mathematics, considering children's emerging understanding of the concept of zero is timely. Wellman and Miller (1986) identified three phases in this progression. First, children become familiar with the name and symbolic representation of zero ("0"). However, recognising and naming 0 ("zero") does not mean that the child understands the meaning of zero as a quantity. Second, children develop an understanding that zero describes a numerical quantity of nothing or none. At this stage, children continue to regard 1 as less than 0. In Wellman and Miller's third phase, children understand that zero is the smallest number (other than negative numbers). Recent research has reported that preschool children can use empty sets around the time that they can work with positive numbers, arguing that challenges associated with zero are linguistic rather than deriving from difficulty with understanding the concept of zero (Krajcsi et al., 2021). This seems to support Wellman and Miller's finding that exposure to the concept of zero through games and songs that involve counting backwards influenced differences in children's understanding of zero.

Nieder's (2016) description of the emerging understanding of zero as a concept synthesises cross-disciplinary research and proposes three phases in this progression that children achieve at different ages. First, children perceive zero to be the absence of something but not yet a null quantity (which Nieder describes as sensory representation). Second, zero is understood by the child to be a quantity and thus able to be positioned on a numerical continuum. Here, Nieder states, "when faced with symbolic notations of zero and integers (i.e., number words and numerals), children realise that zero is the smallest number in the series of (non-negative) integers by about age 6 years" (2016, p. 835). This emergent – and initially non-quantitative – notion of nothing as an empty set leads to the third progression point when zero is understood to be a quantity and children's ability to reason about algebraic rules using zero increases.

Since 2009, Australian early childhood educators have turned to the Early Years Learning Framework to guide pedagogical practice with children aged from birth to five years (EYLF; Australian Government Department of Education (AGDE, 2022); Department of Education Employment and Workplace Relations (DEEWR, 2009). In the EYLF, mathematics strands are referred to in the definition of numeracy (numbers, patterns, measurement, time, spatial awareness, chance and data, as well as mathematical thinking, reasoning and counting). An early years planning cycle is described in the EYLF that requires educators to plan for learning experiences within the context of a play-based curriculum. The planning cycle starts with educators gathering information about what children already know, drawing on this as evidence to inform the planning of learning experiences that align with children's interests and provide opportunities for their knowledge to be consolidated and extended. The framework does not unpack the elements of each of these strands. However, research-informed learning trajectories published by the Australian Education Research Organisation (AERO) have addressed emergent mathematical thinking from birth (AERO, 2023). Aligned with the EYLF (AGDE, 2022), these set out learning progressions that dive more deeply into children's demonstrations of mathematical thinking and are intended to support educators' pedagogical content knowledge (Shulman, 1986). Indeed, opportunities for educators to draw children's attention to the concept of zero within the context of an informal curriculum abound, whether during everyday routines such as mealtimes ("Audrey has four strawberries on her plate, Milo has two strawberries, but Pathmini has none. She has zero because she has eaten hers"), during planned learning experiences such as voting for a favourite under the sea creature ("The jellyfish got zero, didn't it? So, he's not popular!" (Cohrssen et al., 2014, p. 4), or informally measuring continuous quantities ("Minty has a bucket full of sand but Jamie's bucket is empty. He has zero."). However, the AERO Early Childhood Learning Trajectories (AERO, 2023) do not

[1] Positive, whole numbers like 1, 3 and 10.

[2] Numbers that can be written as simple fractions.

address the progressions in children's emerging understanding of zero. In terms of curriculum documents, "zero" is introduced for the first time when children enter school.

## Zero, Within the School Curriculum

Learning occurs within an ecological system (Bronfenbrenner & Morris, 2006), begins from birth, and is shaped by reciprocal interactions in the home environment and early learning settings as elements of the child's microsystem. As children mature, the environment within which formal learning occurs is school.

The Australian Curriculum for Mathematics (ACM) introduces zero in the Foundation year (the first year of school). Children are required to "name, represent and order numbers including zero to at least 20, using physical and virtual materials and numerals" (Australian Curriculum, Assessment and Reporting Authority (ACARA), 2023—AC9MFN01). Evidence of having achieved this would be a child knowing that 0 precedes 1 and recognising the symbolic representation of zero: 0. The child would know that zero describes the absence of a quantity and thus an empty set. Interestingly, as with the EYLF (AGDE, 2022), little guidance is provided to teachers on pedagogical strategies to support learning about zero. However, the ACM does elaborate by suggesting the collection of "a quantity of items" or "reading numerals" and suggests a number track using cards numbered 0 to 20 to describe positions (first, second, third) and so forth. If anything, the suggestion that zero is the first ordinal number could be confusing to children. In Year 2, children learn about the use of zero as "placeholder" (ACARA, 2023 – AC9M2N02). Once again. the relevant Year 2 elaboration merely states that children should be "comparing the digits of a number with materials grouped into hundreds, tens and ones, and explaining the meaning of each of the digits in the materials".

Pedagogical content knowledge requires the teacher to support lateral and vertical integration of knowledge, as well as to anticipate concepts that may be difficult to understand (Shulman, 1986). Since number sense is cumulative (Jordan et al., 2010; Krajewski & Schneider, 2009a), it is necessary for teachers to be familiar with learning progressions in order to recognise what children know already and to scaffold their emerging understanding and capability.

## The Role of Language in the Acquisition of the Concept of Zero

Children's understanding of numerosity is ontogenetic and reflects the neurobiological challenge of conceptualisation of zero (Nieder, 2016). It occurs along individual trajectories (Clements & Sarama, 2021; Jackson et al., 2023) but their emerging capabilities are shaped by everyday reciprocal and multidirectional interactions with people and objects within their environments and over time (Bronfenbrenner & Morris, 2006; Navarro et al., 2020). Here, vocabulary may contribute to the development of the concept of zero.

Kazima and colleagues (2023) draw attention to the importance of teaching children mathematical language and indeed, this is well established in the research literature (Eason & Levine, 2017; Klibanoff et al., 2006; Ramani et al., 2015). The accurate use of formal mathematical terminology has frequently been regarded as indicative of conceptual understanding (McGinn & Booth, 2018). Yet, the importance of children's use of formal versus informal language for mathematical concepts continues to be a topic of discussion (McGinn & Booth, 2018). In typical interactions, a range of words may be used when describing empty sets rather than the word zero: "no apples, nothing to eat, empty glass, vacant chairs, blank spaces" (Hartmann et al., 2022, p. 355) and children may understand the concept but simply not know the word (Krajcsi et al., 2021).

Young children engage with many early mathematical concepts through rhyme and song. Some of those incorporate "zero" or notions of "zero" as a cardinal number below one. For instance, the word "zero" is used in the countdown to a rocket blast-off as the point at which the rocket's engines ignite in popular children's programs such as Peppa Pig and Paw Patrol:

> Ten, nine, eight…three, two, one, zero, blast-off!

However, in some instances, the *concept* of zero may emerge in rhymes and songs, but as Hartmann et al. (2022) state, the *word* zero may not be used. For example, "Five Speckled Frogs" ends with "no green speckled frogs":

> One little speckled frog
> Sat on a speckled log
> Eating some most delicious bugs. Yum! Yum!
> It jumped into the pool
> Where it was nice and cool
> Then there were no green speckled frogs.
> Glub! Glub!

Similarly, children sing "none of the five little ducks came back" in "Five Little Ducks Went Swimming One Day":

> One little duck went swimming one day
> Over the hill and far away
> Mother duck said, "Quack, quack, quack, quack"
> But none of the five little ducks came back.

Educators have the opportunity to follow the song by asking open-ended questions such as: How many ducks came back? Or, how many speckled frogs sat on the log? Children's responses to the questions create the opportunity to assess children's knowledge of the word and the concept and thus inform both the follow-up responses and subsequent planning for learning. Follow-up responses may include emphasising the association between “none” and “zero”, or indeed introducing the word to children.

## Method

Internationally, research that has explored preschool children’s understanding of the concept of zero has often been undertaken using an experimental research design (Bialystok & Codd, 2000; Hartmann et al., 2022; Krajcsi et al., 2021; Wellman & Miller, 1986). However, we set out to assess three- to five-year-old children’s emergent understandings of zero by having their educators ask them open-ended questions – such as those that form part of everyday interactions between educators and children – during free play. We set out to determine whether informal, open-ended questions would elicit children’s understanding of the concept of zero. This approach aligns with business-as-usual practice in Australian early childhood education and care (ECEC) settings as it aligns with the planning cycle described by the mandated EYLF which requires educators to observe, assess, plan, implement, and evaluate children’s learning within the context of an informal curriculum (AGDE, 2022, p. 27).

Full ethics approval was obtained before seeking written consent from primary caregivers for their children to participate in the study. Signed consent was also obtained from three educators providing a program for children aged from three to five years of age at a regional early learning centre rated as ‘Meeting” the Australian Children’s Education and Care Quality Authority (ACECQA) National Quality Standard (ACECQA, 2023). Two educators were diploma-qualified, and one held a Certificate III and was studying towards a diploma. Consent forms were distributed to all families and the first and third authors were present to answer any questions primary caregivers may have. Consent was obtained for 25 children (9 girls; 16 boys) aged from 34 to 66 months.

Rather than using an unfamiliar formal assessment process (e.g., Bialystok & Codd, 2000; Hartmann et al., 2022; Kazima et al., 2023; Wellman & Miller, 1986) such as the ‘give-N task’, we were interested in exploring whether an informal, open-ended inquiry would facilitate children’s individualised responses to questions. This approach takes into account that more open-ended approaches to encouraging children to demonstrate mathematical thinking than experimental designs may elicit unexpected representations of mathematical thinking (Cohrssen & Pearn, 2019; Deans & Cohrssen, 2015; Pollitt et al., 2020). Educators and parents were advised that we were interested in children’s number knowledge, but not that our specific focus was on children’s understanding of zero, in order to avoid priming ahead of time.

Data were collected mid-year. The children’s educators are more familiar to the children than the researchers, and the educators were deemed more likely to elicit an authentic response to questions from children than a formal assessment process (e.g., Bialystok & Codd, 2000; Hartmann et al., 2022; Kazima et al., 2023; Wellman & Miller, 1986). Educators, each accompanied by one researcher, approached children one at a time during free play morning sessions, introduced the accompanying researcher to the children (the first and third authors were already known to the children) and explained that we were interested in how much they knew about numbers. Educators asked each child whether they would let us film them answering two questions about numbers. The children are familiar with being photographed and videorecorded using mobile devices as educators use this as one form of data to inform classroom planning. If a child declined to participate, the educator had a brief conversation with the child before moving to the next child. Those children who declined to participate were approached on two more occasions, after which attempts to include the child were abandoned. If a child assented to answering questions on camera, videorecording began. Data from five children for whom parental consent had been received were excluded for the following reasons: (i) three children declined to participate, (ii) one child provided verbal assent but appeared uncomfortable with the process and oriented their body away from the educator, and (iii) one child for whom caregiver consent was received had not yet reached three years of age. The final sample of 20 children included 8 girls and 12 boys.

First, a question was asked to orient children to numbers and the nature of the question that was of interest to

**Table 1** Demonstrations of knowledge of age-number and zero, by age

| Age in years | Group size | Boys (Girls) | Indication of knowledge of age-number | | | Indication of knowledge of zero | | |
|---|---|---|---|---|---|---|---|---|
| | | | No | Yes | % | No | Yes | % |
| 3 | 14 | 7 (7) | 11 | 3 | 21.4 | 12 | 2 | 14 |
| 4 | 4 | 3 (1) | 0 | 4 | 100 | 1 | 3 | 75 |
| 5 | 2 | 2 (0) | 0 | 2 | 100 | 1 | 1 | 50 |
| | 20 | 12 (8) | 11 | 10 | | 14 | 6 | |

**Table 2** Demonstrations of knowledge of age-number and zero, by child

| Age in months | Pseudonym | Indication of knowledge of age-number | Indication of knowledge of zero | Relevant additional data |
|---|---|---|---|---|
| 36 | Maxine | Uses three as the starting point to count on "four, five" | Not demonstrated | |
| 37 | Lachlan | Not demonstrated | Not demonstrated | |
| 37 | Fergus | Not demonstrated Shows five fingers and says "three" | Not demonstrated; shows five fingers | |
| 38 | Lily | Holds up three fingers and says "three" | Not demonstrated – looks at fingers moving | |
| 39 | Faith | Shows three fingers with prompting | Looks at fingers then says, "zero means you can't see it" | |
| 41 | Daniella | Not demonstrated | Not demonstrated | When prompted to show what five looks like, holds up five fingers |
| 41 | Sarah | Not demonstrated | Not demonstrated | |
| 41 | Terry | Not demonstrated | Not demonstrated | |
| 43 | David | Not demonstrated | Not demonstrated | |
| 44 | Kylie | Not demonstrated | Not demonstrated | |
| 45 | Sadie | Not demonstrated | Not demonstrated | Disregards the question and recounts an experience. Later, accurately counts four fingers for the members of her family |
| 46 | Daniel | Not demonstrated – holds up one thumb and says "four", then starts at 4 and counts on to 7 | Not demonstrated – repeats the word "zero" | Recites number words but not in stable order |
| 46 | Milo | Not demonstrated | Not demonstrated | |
| 46 | Jonathan | Not demonstrated—draws a curve in the air | Draws a circular shape in the air and says, "it's an O" | |
| 48 | Alex | Draws the numeral 5 in the air | Draws a circular shape in the air and says, "It's a circle…Because it's a zero means nothing" | Note: Alex was asked to show/tell what he knows about 5 although he is not yet five |
| 48 | Eliza | Identifies herself as number 4 | Repeats "zero" twice then asks if it's round | "I'm gonna be four for a long time" |
| 51 | Bryan | With encouragement, shows four fingers to indicate four | Counts fingers but then abandons | |
| 57 | Max | Pointing and articulating that 1 plus 4 makes 5 | Repeats zero and moves pencil around the 0 in the puzzle board and says it's "like an O" | Note: Max was asked to show/tell what he knows about 5 although he is not yet five |
| 63 | Sam | With prompting, showed five fingers and counted them correctly | Not demonstrated | |
| 66 | George | Draws an approximation of the numeral 5 with his finger on the table top; counts bullets in his drawing accurately | Draws a zero on the table top; points out multiple circular/oval shapes on this drawing | |

us. Since children are usually familiar with their age, the first question was, "Can you tell us or show us what you know about (child's age: 3, 4 or 5)?" Educators were asked to provide positive feedback on child responses. The second question asked was, "Can you tell us or show us what you know about zero?" If the child provided an answer, the educator asked a follow-up question: "How do you know that?" There is no right or wrong answer to an open question of this nature. Rather, open questions invite children to share their thinking and encourage extended responses (Wasik & Jacobi-Vessels, 2017). This simple protocol was set out on a small card to support consistency in delivery.

While these conversations took place, the first and second authors video-recorded the interactions positioned slightly behind the respective educators in order to capture children's gestures. Educators were asked to avoid using children's names and pseudonyms are used in transcripts of videos. Conversations were transcribed by the first author and analysed to identify children's understanding of the stated number and zero. In the final step, children's responses were compared with Wellman and Miller's (1986) and Nieder's (2016) stages of emerging understanding of the concept of zero. At the same time, data were evaluated for evidence of categories of understanding that did not align with these stages.

## Findings

Three children aged, from 36 to 47 months, demonstrated knowledge of their age number; 11 did not (Table 1). Of the three three-year-old children who demonstrated knowledge of their age number, Maxine used three as the starting point to count on: "four, five". Lily held up three fingers and said "three," as did Faith. Of the 11 children who did not, Fergus said he was three but held up five fingers and Daniel demonstrated knowledge of the number word sequence from four to seven. Of the three three-year-old children who responded correctly to the priming question, only Faith demonstrated some knowledge of zero, responding that "zero means you can't see it".

All four children aged 48 to 59 months responded accurately to the priming question. (In the cases of Alex and Max, the age number prompt was incorrect: both children were prompted with five despite still being four years of age.) Three of the children demonstrated some knowledge of the symbolic representation of the zero (Alex, Eliza and Max). Bryan attempted to find a finger on which to count zero, but appeared to recognise that he did not have a finger for zero and abandoned this strategy. Alex stated that "zero means nothing".

Both children aged from 60 to 71 months demonstrated knowledge of "five" (the priming question). One did not demonstrate an understanding of zero; the second demonstrated knowledge of the symbolic representation of zero.

When aggregated by age, demonstrations of knowledge of age-number were more frequent among older children than younger children and this trend appears to apply to demonstrations of some knowledge of zero (Table 1).

Six children indicated knowledge of zero. Five children referred to the symbolic representation of zero as a numeral (two children aged 3 years, three children aged 4 years, and one child aged 5 years). Eliza is included in the group of four-year-old children as she appeared to be familiar with the shape of the numeral, even if uncertain. Two children described zero as meaning "zero means you can't see it" (Faith, 39 months) or "zero means nothing" (Alex, 48 months). Transcripts of the interactions are provided below to illuminate the data presented in Tables 1 and 2.

| | |
|---|---|
| Educator | Now can you tell or show us what you know about zero? |
| Faith | (Looks at the educator. Looks at her fingers. Raises thumb, index finger, middle finger, starts raising ring finger then looks at the educator.) |
| Educator | How do you know that? |
| Faith | Um. Zero means (inaudible). |
| Educator | (Leans forwards to listen.) |
| Faith | Can't (? very quiet speech) see it. |
| Educator | Pardon? |
| Faith | Zero means that (inaudible). |
| Educator | (Leans back again.) Zero means you can't see it. |
| | *(Faith, 39 months)* |
| Educator | What do you know about zero? |
| Jonathan | (With the index finger of his right hand and starting at the bottom, traces a circular shape in the air.) It's an O. |
| Educator | O. |
| | *(Jonathan, 46 months)* |

| | |
|---|---|
| Educator | It does look like that. Thank you. That's the number 5. Now can you tell us or show us what you know about zero. |
| Alex | Ummm. (Traces a large numeral 0 in the air with his right index finger, starting at the bottom, moving in a clockwise direction.) |
| Educator | What shape is that? |
| Alex | Um. A circle. |
| Educator | A circle. Thank you so much. How do you know that that's what. How do you know if that- |
| Alex | Because it's a zero means nothing |
| Educator | Zero means nothing. You're so clever. Thank you. |
| | *(Alex, 48 months)* |

| | |
|---|---|
| Educator | That's okay. Now what can you tell or show us what you know about zero? |
| Eliza | Zero! (Looks up and smiles at the educator.) |
| Educator | What do you know about zero? |
| Eliza | Zero! |
| Educator | Do you know anything about zero that you can show me? |
| Eliza | (Looks away. Looks at the educator.) Is it round? |
| Educator | Is it round? Yeah! It's round! |
| Eliza | (Puts thumbs and pointing fingers of both hands together to form a round shape.) |
| Educator | (Inhales.) Thank you for showing! |
| Eliza | (Smiles at educator.) |
| Educator | Is there anything else you know about zero? |
| Eliza | (Bites her bottom lip. Nods.) I, I heard (sibling's name) cry at rest time. |
| | *(Eliza, 48 months)* |
| Educator | Yes. Can you tell us what you know about… |
| Max | (Moving pencil in the puzzle board '1' and '2' holes.) Two. |
| Educator | Zero? |
| Max | No. (Smiles.) Nothing. |
| Educator | You know nothing? |
| *Another child, off camera* | I can know. About zero. |
| Educator | Sshh. |
| Max | (Runs his pencil around and around the '0' hole in the puzzle board.) |
| Educator | How do you know zero? |
| Max | Zero. Like a 'O'. (Moves pencil around the '0' hole while smiling at the educator.) |
| Educator | Yeah, how do you know? |
| Max | There's zero like a 'O'. (Moving pencil around the '0' hole. Lifts puzzle board up and looks closely at it.) |
| | So, one (moves pencil up and down in the '1' hole on the puzzle board) plus two (moves pencil up and down in the '2' hole on the puzzle board) equals three (moves pencil in the '3' hole on the puzzle board. Looks up at the educator.) |
| | *(Max, 57 months)* |

| | |
|---|---|
| Educator | Awesome! |
| | Now can you tell us or show us what you know about zero? |
| Sam | (Looking forwards, smiling slightly.) I don't know. Ummm. (Looks down.) |
| Educator | That's okay. |
| | *(Sam, 63 months)* |

| | |
|---|---|
| Educator | Goodness gracious. You're so clever. Can you tell me or show me what you know about zero? |
| George | (Traces a '0' from the top in a clockwise direction on the table top.) |
| Educator | And how do you know that? |
| George | An. I just do. |
| Educator | Cause you just do? You're so clever. High five. |
| George | (High fives the educator.) |
| Educator | Thank you. |
| George | Zero is like that (points to the representation of the sights on his rifle picture). |
| Educator | Zero is like that one. It is. It looks like that's got lots of zeros can you show me the others? |

| | |
|---|---|
| George | This is the (inaudible) (points to a circular shape on the drawing) and that's the (pointing to a shaded-in circular shape) like blood that I got and these (circular gesture) and this is engine and this these are where you pull (pulling gesture) because there's two pull things and this is the this is um what…I know the pully thing and umm (gestures pulling, then nods) |
| Educator | Uhh. So, is the, stayed in your hand? |
| George | (Nods.) Yip. |
| Educator | Awesome. You're brilliant. Thank you so much. |
| | *(George, 66 months)* |

## Analysis and Discussion

Responses to the priming question indicate that this question ("Can you tell me or show me what you know about (child's age?") was understood by the children aged four and five years. Eleven of the 14 three-year-old children did not show us or tell us what they knew about three.

Of the two three-year-old children who demonstrated an understanding of zero, Faith (39 months) described zero as the absence of something: "Zero means you can't see it". This aligns with the first of Nieder's (2016) proposed three-phase progression of understanding of zero in that it can't be seen. On the other hand, it aligns with the second phase in Wellman and Miller's (1986) progressions: Faith appears to understand that "zero" describes a numerical quantity of nothing or none. Since Faith has demonstrated the second phase, the observer may infer that she has achieved the first phase (familiarity with the name and symbolic representation of zero). The educator omitted to ask the follow-up question that may have elicited more information about the child's thinking processes.

Jonathan (46 months) was familiar with the shape of a 0. This aligns with the third phase of Nieder's (2016) progression (symbolic representation). However, Jonathan did not demonstrate understanding of zero as a quantity situated on a numerical continuum (Nieder's second phase). Jonathan's tracing of a circular shape in the air aligns more closely with Wellman and Miller's (1986) suggestion that the first phase in children's understanding of zero is demonstrated by familiarity with the name and symbol for zero but not an understanding of its numerical value.

Both Max and Alex are four years of age, but were asked to show or tell what they know about the number five – which both did. Max demonstrated an understanding of addition, stating that "1 plus 4 (his age) makes 5 (the priming prompt provided to him). Both Max and Alex demonstrated knowledge of the symbolic representation of '0' but like Jonathan, neither demonstrated an understanding of zero on a numerical continuum and consequently, appear to be at the first phase of Nieder's (2016) progression. Alex added that "zero means nothing", demonstrating the second phase in Wellman and Miller's (1986) progression – his familiarity with the symbolic representation of zero (phase 1) reinforces this assessment.

Eliza said, "I'm number 4", and somewhat hesitantly indicated familiarity with the word zero as the name for a shape. This may reflect the second phase in Nieder's (2016) progression. However, putting her fingers together to make the shape of a "0" does not suggest a perception of zero as the absence of something (Nieder's first phase) but it does suggest familiarity with the symbolic representation of "0" which constitutes Wellman and Miller's (1986) first phase. Bryan first shrugged in response to an invitation to show or tell what he knew about four, but when asked how old he was, immediately showed four fingers. It is unclear whether his knowledge of four is wrapped up in his identity (as observed with Eliza). When asked about zero, Bryan counts the fingers on his left hand silently but does not have a finger for zero. He stops moving his fingers and remains silent. This suggests that he understands zero to be a quantity but not that it can be positioned on a numerical continuum (Nieder's second phase). In addition, we see no evidence in his actions that suggests the perception that zero is the absence of something—rather, as a non-counting number, it could not be tagged to a finger. On this basis, he does not demonstrate any of Nieder's phases but he does appear to be familiar with the word "zero" (Wellman and Miller's first phase).

Sam and George are five years of age. Sam appeared uncertain how to respond to the question, "What do you know about five?" but when asked to show five, held up five fingers and counted to five. When asked about zero, he replied that he did not know. This may be attributed to unfamiliarity with the word, "zero" (Krajcsi et al., 2021) and consequently, he may not yet have achieved Wellman and Miller's first phase. George demonstrated knowledge of the numerals for five and zero, and pointed out multiple circular/oval-shaped elements of his drawing that resembled the shape of zero (Wellman and Miller's first phase). Neither Sam nor George demonstrated an understanding of zero as a quantity or positioned along a numerical continuum – Nieder's (2016) second phase—nor as a numerical quantity (Wellman and Miller's second phase). As Sam did not know about zero, no follow-up question was asked. The follow-up question asked of George was, "Zero is like that one. It looks like that's got lots of zeros can you show me the others?" This question, deviating from the protocol, did not encourage deeper thinking on George's part but instead focused on the shape of the numeral and was a missed opportunity to gain deeper insight into the child's knowledge in order to plan for learning.

Nieder (2016) theorised that the third phase is achieved between the ages of six and nine years when children are able to apply simple algebraic rules involving zero, and provides the example that "if you add 0 to a number it will be that number" (p. 836). Interestingly, Max (57 months) came closer to Nieder's third phase than other children by spontaneously demonstrating an understanding of operations ($1+2=3$) but did not use 0 during the recorded interaction.

Wellman and Miller's (1986) third phase is demonstrated when children understand that zero is the smallest number (other than negative numbers). None of the children was observed to demonstrate Wellman and Miller's third phase in understanding zero. Finally, no demonstrations of understanding were observed that did not align with the progressions identified in the literature we reviewed.

Turning to the educators' interactions with the children, it is apparent from the data that the educators had positive expectations of the children, used respectful language, and praised them. The follow-up question. "How do you know?", was important. When asked, it provided insight into children's understanding of zero beyond merely the shape of the numeral. Insights into children's understandings of zero provides more nuanced information that could contribute to differentiated planning for learning. It is unclear from Max's response ("No…Nothing.") whether the use of the word "nothing" was his reply to the interrogative "Zero?" and perhaps missed by the educator in the back-and-forth of the conversation. However, the educator persevered, noticing that he was running a pencil around the "0" hole in the puzzle board. Given that he was observed to recognise the numeral on the puzzle board and continued to demonstrate knowledge of addition using small numbers, this warrants further investigation by the educator in order to assess Max's knowledge more accurately.

Eliza knew about the symbolic representation of zero but in the absence of a follow-up question to ask how she knew this, the opportunity to determine whether Eliza knew zero to be a number was missed. At the educator's request, George identified multiple examples of circular shapes in his drawing, indicating knowledge of the symbolic representation of the numeral but without the question, "How do you know?", the opportunity to demonstrate a deeper understanding of the concept was missed. These examples of missed opportunities highlight the importance of questioning as an intentional pedagogical strategy to elicit the depth and nuance of children's capabilities and knowledge.

None of the educators who participated in this project held bachelor's degrees in early childhood education. Whilst the service is rated as "Meeting the National Quality Standard", researchers have reported differences between National Quality Standard quality ratings and quality when measured with research instruments that focus more closely on pedagogical practice and discipline areas within service curricula such as mathematics and science (Siraj et al., 2019; Sylva et al., 2003). In the current climate of teacher shortages in the ECEC sector, supporting educators with mentoring and targeted professional learning is critical. Indeed, Cohrssen and colleagues (2023) have argued the importance of distributed responsibility for quality through multiple systems such as state and territory accreditation organisations and institutions of higher education rather than placing responsibility for high-quality pedagogical practice solely on the shoulders of educators and teachers.

## Limitations

We set out to assess the efficacy of an informal and open-ended approach to eliciting children's understanding of the concept of zero in a manner that would be more closely aligned with typical formative assessments of children's knowledge and capabilities. It is possible that the informal approach did not authentically elicit what children knew. However, the benefits of educators using follow-up questions as an intentional pedagogical strategy to make children's thinking visible are also apparent in the data. These encourage children to explain their thinking and should form the springboard for differentiated teaching and modelling advanced language.

Sample size precludes generalisations being drawn from the data. However, the informal method employed to elicit children's knowledge was similar to educator-child conversations that occur within a play-based curriculum and contribute to formative assessment.

## Conclusions

Educator-child conversations should inform differentiated pedagogical practice as three-year-old children may demonstrate understanding beyond that of a five-year-old child. Indeed, within our sample, two of the children who demonstrated an understanding of the concept of zero were three years old and one who did not, was five years old. The simple question educators asked children, "Can you show us or tell us what you know about zero?" was observed to elicit a range of responses from children. This highlights that educators – and indeed, primary caregivers – may need to *introduce* the word zero to some children, to *consolidate* numeral recognition and symbolic representation for other children, and overall, to *deepen* children's understanding of the concept of zero as a number and not merely the absence of something.

Faith, who is seven months younger than Jonathan, appears to demonstrate the *second* phase in Wellman and Miller's (1986) progression in understanding, namely the recognition that zero refers to a numerical quantity of none or nothing. Jonathan, on the other hand, appears to demonstrate the *first* phase in the same progression. These differences highlight the individual nature of children's learning and suggest that opportunities to experience mathematical concepts play a significant role in developing understanding. They also highlight the contribution of a learning trajectories approach to differentiated teaching in guiding educators to support children's emerging conceptual understanding as their progression along learning trajectories differs.

Despite the differences in children's responses to the question, none of the participating children fully achieved the second progression within Nieder's (2016) theorised trajectory which describes children as recognising that zero represents a quantity and in addition, understanding that along a numerical continuum, zero is the smallest number. Wellman and Miller's (1986) earlier progression was observed to be a closer fit.

Within an informal curriculum, early childhood educators are required to engage in ongoing formative child assessment to inform contingent planning for learning through play (AGDE,2022). Formative assessment is a critical element of the early years planning cycle ((AGDE, 2022) and as such, sets up opportunities for educators to respond both in the moment, as well as to inform contingent planning for learning, to consolidate and extend children's thinking.

A range of words may be used when describing empty sets: "no apples, nothing to eat, empty glass, vacant chairs, blank spaces" (Hartmann et al., 2022, p. 355) and children may simply not know the numerical word, zero (Krajcsi et al., 2021). Whilst the word "zero" is infrequently used in ECEC settings, children can understand the concept of zero as a characteristic of an empty set. Educators and parents informally supporting children's familiarity with the *word* zero, along with their understanding of the *concept* of zero within the context of playful learning, songs and rhymes would strengthen their progression along mathematics learning trajectories and form a platform for formal mathematics education in school.

The limited guidance for early years educators in Australian Curriculum documentation (e.g. ACARA, 2023; EYLF, 2022; NESA, 2022) is a concern. Without adequate guidance, primary school educators are not alerted to the importance of establishing notions of zero and "zeroness" with children. In the absence of an obvious concrete representation, "zero" is not an easy concept to grasp. However, a lack of understanding of zero has significant ramifications for children's understanding of place value. Here too, informally supporting children's familiarity with the *word* zeroalong with their understanding of the *concept* of zero during conversations and through songs and rhymes would strengthen their progression along mathematics learning trajectories.

Finally, given the growing interest in the development of early childhood learning trajectories to support evidence-based planning for playful learning, there is a need for research to address the progressions in children's acquisition of the concept of zero and for such information to be included in initial teacher education courses.

**Acknowledgments** Not Applicable.

**Author Contributions** Caroline Cohrssen: Conceptualization, Literature review, Methodology, Data acquisition and management, Analysis and interpretation of data, Co-writing of original draft and editing. Jill Fielding: Literature review, Data analysis and interpretation, Co-writing of original draft and editing. Jo Bird: Data analysis and interpretation, Editing of the original draft.

**Funding** Open Access funding enabled and organized by CAUL and its Member Institutions. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

## Declarations

**Conflict of interest** The authors have no competing interest to declare.

**Ethical Approval** The research study that underpins this publication was provided by the University of New England (HREC No. HE23-099) and the research was consistent with national/international standards for conducting research with human subjects.

**Informed Consent** Informed consent was obtained from (1) participating educators and (2) primary caregivers of participating children. Ongoing assent was obtained from child participants. All consenting participants were advised of their right to withdraw (or withdraw their child) from the study at any time.

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