The Role of Gesture in Determining Van Hiele Levels of Geometric Thinking of Young Children

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Children's gestures can be an important thinking and communication tool in geometry but were rarely considered in research on the development of geometric knowledge until recently. This study explored the differences between 4-8-year-old children's development in relation to van Hiele levels, with and without attending to their gestures made about a hidden 3D object. From 172 children, when verbal responses alone were considered, 74% of children aligned with Level 1. However, when verbal and gestural response were analysed, 40% of these children then met Level 2. This finding suggests the value of expanding the van Hiele model to include embodied representation modes.

Introduction

> Nonverbal thinking is of special importance; all rational thinking has its roots in nonverbal thinking, and many decisions are made with only that kind of thought. We observe some things without having any words for them. (van Hiele, 1999, p. 311)

Van Hiele's seminal work (originally conducted in the late 1950's) on the development of geometric thinking has been used for decades in curriculum planning and for interpreting students' levels of thinking in research and education (e.g., Burger & Shaunessy, 1986; Clements, 2003) (See Pegg, 2020 for a summary of the whole model). Despite van Hiele's own evolving views on the nature of 'thinking' in relation to language (e.g., van Hiele, 1999), most research seeking to explicate the van Heile levels across various contexts, has focused on verbal and visual representations as both inputs and outputs in learning processes, with some inclusion of student drawing and actions on physical models such as sorting tasks (e.g., Burger & Shaunessy, 1986). Other studies have utilised test-style tasks that limit students' response modes (e.g. Wu & Ma, 2006). The dominance of a focus on two-dimensional shapes is also notable (Sinclair & Bruce, 2015), as is the focus on secondary students. In recent years, the rapid increase in research on embodied cognition and learning has broadened views on the role that non-verbal thinking, especially gesture, plays in children's spatial reasoning (e.g., Ehrlich et al., 2006; Thom, 2018). However, little research has explored how children express their perception of a three-dimension (3D) object in the absence of visual input, or how their gestural communications relate to the van Heile Model of geometric thinking. The aim of the present study is to explore the potential of adapting the descriptors that characterise the van Heile levels to better identify indicators of young children's progress in geometric thinking, particularly regarding 3D objects.

Various studies have advocated the importance of gesture in children's spatial reasoning (Ehrlich et al., 2006; Thom, 2018), in geometric communication in different contexts (Elia, 2018), and in revealing emerging geometric conceptions (Kim et al., 2011). However, the role of gesture is rarely explained in isolation, but rather as a component of multimodal experience linking action, speech, and/or visualisation in children's sense-making and progress towards abstraction (Elia et al., 2017; Nathan & Alibali, 2021). Both McNeill (1992) and Goldin-Meadow (2025) draw on substantial bodies of research to argue the co-evolution of language and gesture where the two modalities are complexly and dynamically linked, sometimes in harmony when underlying meanings coincide, and sometimes mismatched in a forecast of imminent conceptual change. Gesturing has many functions such as externalising thoughts, reinforcing language, filling gaps in available language or representing non-verbal thoughts and visualisations and therefore offers many avenues of research into children's spatial-geometric

(2026). In N. Berger, M. Thompson, J. Ley & C. Wilsmore (Eds.), *Beyond boundaries: Strengthening futures in mathematics education. Proceedings of the 48th annual conference of the Mathematics Education Research Group of Australasia, Sydney* (pp. 74–81). MERGA.

reasoning (Elia et al., 2014; Thom, 2018), including developing "strategies for using children's gestures to evaluate their knowledge development" in geometry (Kim et al., 2011, p. 235).

Conceptual Framework

It has been argued by some researchers that the van Heile model, with its sequential levels of geometric development and its emphasis the critical role of language in the manifestation of a geometric concepts, does not account for multiple ways in which children 'come to know' geometric ideas (Roth & Thom, 2009; Sinclair & Bruce, 2015). Rather than discard the model, for the exploratory purpose of this study, we propose three adaptations to the model's application that acknowledge the intertwined nature of language and gesture development and enhance its suitability for reflecting early development in young children.

The first adaptation focuses on the first two van Hiele levels[1] and introduces the two sub-levels proposed by Pegg (1997) for Level 2. In *Level 1 Visualisation* figures are identified according to their overall appearance. In Level 2 Description, thinking becomes more analytical with recognition of the parts that compose a figure, beginning with *Level 2A Description – single feature* where figures are identified in terms of a single property, and *Level 2B Description – multiple features*, where more than one feature is recognised but the properties of a figure are considered as being independent of one another. The subdivision of Level 2 also acknowledges that levels appear to "be dynamic rather than static and … continuous in nature" (Burger & Shaunessy, 1986, p. 45).

The second adaptation draws on the work of Ehrlich et al. (2006) that utilised scheme for recognising a broader range of strategies that children may reveal through speech and/or gesture while working on tasks involving combining and separating two-dimensional shapes. While the task context differs from this study, we incorporate Ehrlich et al.'s four strategy categories, *Movement, Perceptual Features, Perceptual Whole, and Alignment* as potential triggers for observing subtle signs of children's attention to different aspects of geometric figures that might otherwise be missed.

The third adaptation focuses on hand movements produced by children "in effortful cognitive activity" (Elia et al., 2014. p.737), and whether the movements are co-speech gestures (aligned in meaning or mismatched), or gestures apparently detached from spoken language. We also incorporate four of McNeill's (1992) gesture classifications that differentiate the function and meaning of gestures: a) *deictic*, pointing to real or visualised objects or locations; b) *iconic*, visual representation aligned with speech; c) *temporal*, highlighting gestures that might be repeated for emphasis; and d) *metaphoric*, representing an abstract idea or object with a more concrete or familiar with meaningful similarity.

The study focuses on the following research questions:

- *RQ1 Is there a connection between children's gesture types and van Hiele levels?*
- *RQ2 Can children's gestures be used as evidence for their developmental level of geometric thinking?*
- *RQ3 What is the impact of considering gestures on classification against van Hiele levels?*

Methodology

In exploring multiple representations children use to communicate their thinking, a qualitative approach allows for the collection of rich, descriptive data that provides insights into learning processes (Bikner-Ahsbahs et al., 2015). Qualitative data was collected from 172

[1] In this paper the first two van Hiele levels are described as Level 1 and 2 (Burger & Shaunessy, 1986)

preschool to Year 2 children (4 to 8-year-olds) from the four Control Schools in Phase 2 of the *Embodied Learning in Early Mathematics and Science* project. The four schools varied in location and student population contexts such as levels of socio-economic advantage, and percentage of students with English as an Additional Language or Dialect (EAL/D). This paper presents data from the Timepoint 1 task-based interviews where students responded to tasks that were specifically designed to elicit embodied modes of communication. The task is based on a task by Roth (2014) and required children to place both hands inside a bag to feel a mystery object (Figure 1). Once they removed their hands, children were invited to 'tell me what you could feel', and often further prompted by the question 'what shape does it feel like'.

Figure 1

Feely bag object

The feely bag task removes visual exploration of the object, encouraging children to use other modes such as touch and hand movement, verbal responses to describe the object, and gestures–movements that 're-presents' (Roth, 2014) the object independent of where it was originally, in the bag. Tasks such as this allow space for "embodied ways of knowing" (Roth & Thom, 2009, p. 46) to be shared. Each interview was video recorded to capture verbal and non-verbal behaviour, and later transcribed.

The analysis process was based on the application of the conceptual framework for the study as a multi-step analysis framework. A deductive micro-analysis approach was taken that followed four distinct analysis steps. First, video data were viewed, transcribing children's verbal and gestural responses. Videos were often paused and rewatched several times to ensure transcription of nonverbal responses were detailed e.g., *hand/arm gesture* (whole hand or arm), *air drawing* (pointing) or *touch tracing* (pointing with surface contact e.g., table). During this process 'everyday' and mathematical vocabulary was noted as well as types of gestures aligned to McNeill's (1992) gesture types (Table 1).

Table 1

Coding of gestures to McNeill's categories

McNeill's gesture types
Iconic–visually represent concrete entities or action, closely related to speech *'curve [draws U]'*
Deictic–pointing movement in space, may describe location *'like this' 'over here'*
Temporal–highlighting gesture, simple repeated movement *'repeatedly air draws an arch shape'*
Metaphoric–represents image of an abstract object or idea (story from real life) '*walking on bridge'*

Second, initial geometric thinking coding commenced where children's verbal responses were coded to Ehrlich et al.'s (2006) representation strategies (Table 2). Responses were then aligned to the van Hiele levels.

Table 2

Representational strategies for geometric thinking

Ehrlich et al.'s Representation strategies
Movement – of figure or parts, location
Perceptual Features – a focus on a particular feature
Perceptual Whole – recognition of the whole figure
Alignment – emerging attention to the location of single feature in relation to the whole

Third, gesture, and co-speech gesture data were then considered "as a single integrated process" (McNeill, 1992, p. 35) coding gestures to Ehrlich et al.'s (2006) representation strategies (Figures 2a, b, and c). Fourth and finally, responses were examined again revising van Hiele level based on both verbal and gestural representations collectively.

Figures 2a, b and c

Examples of gesture types, description linked to Ehrlich et al.'s strategies

2a. Perceptual whole
Iconic gesture 'arch'

2b. Perceptual feature–movement
Deictic–temporal gesture *'like this'*

2c. Perceptual feature–alignment
Iconic gesture *'hole in the middle'*

Results

Gesturers and non-gestures

Analysis revealed 102 of the 172 children used gesture and that 97% of these gesturers used co-speech gesture. Gesturing was spontaneous in 59% of children, whereas the other 41% only gestured after the prompt 'what shape does it feel like'. No distinct differences were noted across grades regarding the use of gesture; all were between 56-62%. Air drawing was the most common gesture noted, followed by hand/arm gesture, then touch tracing.

Verbal descriptions

The most frequent word used to describe the whole object was *bridge*, others included *block, ramp, arch*. Mathematical words were also used to describe the whole or parts (features) of the object e.g., *circle, curve, curved or curvy, rectangle, sides*. Several children also talked about the orientation and positioning of the object *upside down, top, around*. Others indicated 'missing' aspects such as *half or hole*. Children also mentioned the tactile feeling of the object such as *hard or soft*. These descriptive responses were later analysed as evidence for Ehrlich et al.'s (2006) representation strategies.

Types of gesture

Responses of children who used gesture were coded to McNeill's (1992) gesture types. Often children would use combinations of gesture e.g., hand movement then pointing. The most common type of gesture for describing the object was iconic gesture. These gestures were often congruent with the verbal responses during co-speech gestures, for example, a child may air draw an arch shape while saying the word *curve*. There were however nine children who has mismatched co-speech gesture. For example, child says *arch* but gestures an oval.

Evidence of Ehrlich et al.'s representation strategies and van Hiele levels

Initial coding to Ehrlich et al.'s strategies was based mainly on children's verbal descriptions as analysis of words to the strategies was less complex than the analysis of gestures. Examples include: Perceptual whole–'*It **feels like a** bridge' '**it feels like a** curve'*; Perceptual features–'*It has **a curve in it**, it is a small wooden block and **if it didn't have the curve**, it would be a rectangle'*; Alignment–'*It feels like there's a smooth bit **on the bottom** with no corners but corners **at the top'***; and Movement–'*I could feel the block **was like that then like that'***.

Ehrlich et al.'s strategies aligned well with the van Hiele levels. When children verbally describe the whole object, as one entity (perceptual whole) using either an 'everyday' word such as *a bridge* or a mathematical term such as *a curve* this can be coded to van Hiele Visualisation Level 1. The other three strategies were all aligned to van Hiele Description Level 2 (inclusive of both single and multiple features mentioned). From 172 children, 165 could be placed on van Hiele's levels, 7 children could not be levelled as their verbal response was vague or unrelated to the task. At this analysis point 122 children were in Level 1 Visualisation, 6 were in Level 2A Description, and 37 were in Level 2B Description.

On a second round of coding, gesture and speech were considered collectively as one multimodal response. While analysing gesture cannot impact the levelling of the verbal only children, considerable change occurred when coding the gesturers. Of the 122 children at van Hiele Level 1, 40% of children could be shifted to Level 2A Description showing emerging geometric thinking that indicated one geometric feature. After this second analysis considering gesture alongside speech, 73 children were in Level 1 Visualisation, 54 were in Level 2A Description and 38 were in Level 2B Description, that is 75% of co-speech gesturers moved levels.

These shifts in level classification decisions were made based on the perceptual features observable in children's gestures, in particular their air drawing that was more geometric in nature compared with their verbal response. For example, many children who named the shape *a bridge* in their verbal response, used a pointing/tracing gesture accompanied by movement that highlighted a specific feature of the object such as the curve, right angle corners, or straight sides. If only attending to the verbal response 'a bridge', a child may have been classified at Level 1, as a bridge is a whole object. Yet once their gesture was considered, air drawing 'the curve' as a feature of the bridge, Level 2A classification is possible. Conversely, children whose gesture used static hands/arms to 'make a bridge' from the table, remained classified at Level 1. Children who indicated perceptual features using gesture, usually used an iconic representation or a temporal action to repeatedly highlight the feature.

Figure 3 displays a 'heat map' of overlapping representation strategies and gestures showing the prominence of iconic gestures to indicate features, not the whole. This connection indicates that gestures were a useful way for children to highlight one or multiple features of the object placing them beyond Level 1 of van Hiele. The majority of children who could identify features and were therefore placed at Description levels, used iconic or temporal gestures related to features, movement or alignment. The data in the heat map totals to more than 165 as children may have used more than one gesture.

Figure 3

Overlapping map of gesture type and geometric features

	Perceptual whole	Perceptual features	Alignment	Movement
Deictic	1	13	9	2
Iconic	14	78	25	14
Temporal	0	16	4	2
Metaphoric	1	4	1	2

Discussion

The task for this study was purposefully designed to activate embodied modes at the input (tactile object exploration) and to elicit embodied modes at the output (communication of complex features of unseen object). Relying on tactile information, the movement of hands, and the relationship between an embodied way of exploring objects and the use of gesture connects our methods with our resulting data. When looking holistically at the findings, the majority (60%) of children preferred to use gesture or co-speech gesture to communicate. When analysing both verbal and gesture representations together, there was a distinct difference between the van Hiele levels obtained by verbal-only children compared with gesturers. This finding illustrates a connection between gesture types and the van Hiele levels where iconic air drawing aligned well with van Hiele Level 2's focus on features. Of the children placed at van Hiele Level 2 Description A or B, less than 10% of these children were verbal-only. This finding shows that when aligning children to van Hiele, there is evidence that children who incorporate gesture into their response are far more likely to show emerging recognition of geometric features at higher van Hiele levels. This finding also supports the use of the adapted van Hiele model (that includes gesture) in determining van Hiele level classifications. The inclusion of gesture may positively impact the way teachers gather geometric thinking data–attending to multiple representations provides a 'fuller' picture of children's development.

The important role of gesture

Attending to multiple representations children used to communicate geometric thinking provided further information and revealed higher levels of understanding expressed in co-speech gesture responses than in verbal responses for many children. This finding aligns with previous research (e.g., Roth & Thom, 2009). Our results revealed that some children produced gestures (Perceptual Features) whose meaning differed, and was 'more' mathematical, than their accompanying verbal response (Perceptual Whole). This mirrors findings from Ehrlich et al. (2006) about spatial transformation that children who referred to movement in their gestures, but not in their speech, were more likely to perform well on tasks. Gesture also benefitted children who did not have the mathematical language to describe known features. Gesture *was* language, non-verbal communication (Elia, 2018) for these children. Similarly, children who used gesture in place of speech are creating a clear point-of-intervention for teachers to explicitly make the connection to the missing terminology. Gesture in place of speech could be seen as an indication of readiness for a transitional stage in cognitive development to a higher level of understanding.

The importance of the type of gesture

Our findings also aligned to Elia et al.'s (2014) regarding the type of gesture, where iconic gestures were "more pertinent to the child's geometrical thinking" (p. 756) than other gesture types. From the heat map (Figure 3) the dominance of iconic gestures to describe a three-dimensional object is evident. This is an interesting finding that may suggest children found it easier to identify the edges of the object via the tactile nature of the task, features that may have been missed if visually examining the object. This conclusion requires further investigation.

Limitations and implications

Keeping in mind the limitations of a study based on a single task with a specific age group of children, our findings begin to address the research questions regarding gesture and their place in van Hiele's classification levels. By attending to children's verbal and gestural representations, researchers (and potentially teachers) can gain insights into how children might be visualising and thinking about geometric properties. Gestures have the capacity to provided evidence of children's thinking about (1) Features that seem most obvious to them, (2) orientation of the object and their ability/inability to mentally rotate the object, (3) structure and alignment of 'how features fit together'. We propose that the early van Hiele levels used in further research should include the types of gesture that children may use to process and communicate their geometric thinking (See Table 3). Further research should encompass a range of tasks with 3D objects, and upper primary grades to further 'road test' the adapted model. The inclusion of older primary children could extend the adaptation to Level 3 Informal Deduction where relationships between properties are comprehended.

Table 3

van Hiele early levels with example gestures for three-dimensional geometry

van Hiele Level	Co-speech gesture representation aligned to Ehrlich et al. (2006) representation strategies and McNeill (1992) gesture types
Level 1 Visualisation (awareness and description of whole)	Representation: **Perceptual Whole**, gesturing with hands. Gesture may also indicate **movement** *'it's like that' [makes an arch with hands];* or **alignment** *'feels like there is one block here [air draws dot on left]and one block here' [air draws dot on right]* Gesture types: **Iconic** *e.g., 'square' [makes square with fingers and thumbs];* **Deictic: '***it's like this' [makes a bridge with hands];* **Metaphoric***: 'I can jump across it' [jumps with fingers]*
Level 2A Description (single feature)	Representation: **Perceptual feature:** Gesture may also indicate **movement** *'I could feel a bridge, there was a curve going over' [air draws curve];* or **alignment** *'it's like an upside-down, like a curve' [air draws large U-shaped curve]* Gesture types: **Deictic**: *'it feels like a bridge upside-down' [air tracing whole outline of one face] 'like that, but it's more like this' [continues to air draw side view of object];* **Iconic**: *It feels like a bridge [air draws three straight sides in one movement];* **Temporal**: *'It's like a ramp, one of these shapes probably' [repeatedly air draws U-shaped curve];* **Metaphoric**: *[air draws curve] 'it's an arch, it's going to be a bridge that people can walk over'*
Level 2B Description (multiple features)	Representation: **Perceptual feature**: '*I can show you [makes vertical sides with hands] there was two lines and there was one [makes horizontal top side] and there was a circle' [uses both hands to make circle].* Gesture may also indicate **movement**: *'I could feel two blocks like that [uses hands to make sides] then like that [makes curve with hands] curve like that'* or **alignment**: *'Like a shape and it has a hole on the bottom; it has 2 rectangles at the sides' [makes right angles with arms]* Gesture types: **Deictic**: *'[Makes rectangle with hands] it's the same thing as this [air draws arch in rectangle] but has a hole in the middle'* **Iconic**: '*It's like a cube [makes cube with hands] like a 3D shape it's got six sides' [air draws vertical and horizontal sides]* **Temporal**: '*It feels like a semi-circle [repeatedly makes circle] … smooth on the bottom, no corners but corners at the top' [moves fingers to top to make corners]*

Conclusion

Although still widely used in education and research, the van Heile model of geometric thinking, like many other areas of mathematics education, is being challenged by increased awareness of the fundamental importance of embodied modes of representation and multi-modal views of learning. Our findings show that children's gesture provides additional data, therefore teachers should consider gesture in addition to speech to notice geometric thinking. Rather than discarding the model, we call for expanding the evidence used to classify student understanding against the model to reflect advances in learning theory such as embodied cognition. The study reported in this paper takes a small step towards achieving that possibility.

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References

Bikner-Ahsbahs, A., Knipping, C., & Presmeg, N. (2015). Approaches to qualitative research in mathematics education. *Advances in Mathematics Education, 10*, 978-94. https://doi.org/10.1007/978-94-017-9181-6

Burger, W. F., & Shaughnessy, J. M. (1986). Characterizing the van Hiele levels of development in geometry. *Journal for Research in Mathematics Education*, *17*(1), 31-48.

Clements, D. H. (2003). Teaching and learning geometry. In J. Kilpatrick, W. G. Martin, & D. Schifter (Eds.) *A research companion to principles and standards for school mathematics.* (pp. 151–178). NCTM

Ehrlich, S. B., Levine, S. C., & Goldin-Meadow, S. (2006). The importance of gesture in children's spatial reasoning. *Developmental Psychology, 42*(6), 1259. https://doi.org/10.1037/0012-1649.42.6.1259

Elia, I. (2018). Observing the use of gestures in young children's geometric thinking. In *Contemporary research and perspectives on early childhood mathematics education* (pp. 159-182). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-73432-3_9

Elia, I., Gagatsis, A., & van den Heuvel-Panhuizen, M. (2014). The role of gestures in making connections between space and shape aspects and their verbal representations in the early years: Findings from a case study. *Mathematics Education Research Journal, 26*(4), 735-761. https://doi.org/10.1007/s13394-013-0104-5

Elia, I., van den Heuvel-Panhuizen, M., & Gagatsis, A. (2017). Geometry learning in the early years: Developing understanding of shapes and space with a focus on visualization. *In Forging connections in early mathematics teaching and learning* (pp. 73-95). Springer. https://doi.org/10.1007/978-981-10-7153-9_5

Goldin-Meadow, S. (2025). The mind hidden in our hands. *Topics in Cognitive Science, 17*(3), 443-468. https://doi.org/10.1111/tops.12756

Kim, M., Roth, W. M., & Thom, J. (2011). Children's gestures and the embodied knowledge of geometry. International *Journal of Science and Mathematics Education, 9*(1), 207-238. https://doi.org/10.1007/S10763-010-9240-5

Nathan, M. J., & Alibali, M. W. (2021). An embodied theory of transfer of mathematical learning. In C. Hohensee, & J. Lobato (Eds.), *Transfer of learning: Progressive perspectives for mathematics education and related fields* (pp. 27–58). Springer. https://doi.org/10.1007/978-3-030-65632-4_2

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. University of Chicago press.

Pegg, J. (1997). Broadening the descriptors of van Hiele's levels 2 and 3. In F. Biddulph & K. Carr (Eds.), *The proceedings of the 20th Mathematics Education Research Group of Australasia Conference* (pp. 391–396). New Zealand, Rotorua.

Pegg, J. (2020). The van Hiele Theory, In *Encyclopedia of Mathematics Education* (pp. 896-900). Springer International. https://doi.org/0.1007/978-3-030-15789-0_183

Roth, W. M. (2014). On the pregnance of bodily movement and geometrical objects: A post- constructivist account of the origin of mathematical knowledge. *Journal of Pedagogy, 5*(1), 65. https://doi.org/10.2478/jped-2014-0004

Roth, W. M., & Thom, J. S. (2009). The emergence of 3D geometry from children's (teacher-guided) classification tasks. *The Journal of the Learning Sciences, 18*(1), 45-99. https://doi.org/10.1080/10508400802581692

Sinclair, N., & Bruce, C.D. (2015). New opportunities in geometry education at the primary school. *ZDM, 47*(3), 19–329. https://doi.org/10.1007/s11858-015-0693-4

Thom, J. S. (2018). (Re)(con)figuring space: Three children's geometric reasonings. In I. Elia, J. Mulligan, A. Anderson, A. Baccaglini-Frank and C. Benz (Eds.), *Contemporary research and perspectives on early childhood mathematics education*. https://doi.org/10.1007/978-3-319-73432-3_8

van Hiele, P. M. (1999). Developing geometric thinking through activities that begin with play. *Teaching Children Mathematics, 5*(6), 310-316.

Wu, D., & Ma, H. (2006). The distributions of van Heile levels of geometric thing among 1st through 6th graders. In Novotná, J., Moraová, H., Krátká, M. & Stehlíková, N. (Eds.). *Proceedings 30th Conference of the International Group for the Psychology of Mathematics Education,* Vol. 5, pp. 409-416. Prague: PME.