Math Ed Res J (2014) 26:735–761
DOI 10.1007/s13394-013-0104-5

ORIGINAL ARTICLE

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

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Received: 11 August 2012 / Revised: 16 July 2013 / Accepted: 9 December 2013 /
Published online: 7 February 2014

Abstract In recent educational research, it is well acknowledged that gestures are an important source of developing abstract thinking in early childhood and can serve as an additional window to the mind of the developing child. The present paper reports on a case study which explores the function of gestures in a geometrical activity at kindergarten level. In the study, the spontaneous gestures of the child are investigated, as well as the influence of the teacher's gestures on the child's gestures. In the first part of the activity, the child under study transforms a spatial array of blocks she has constructed by herself into a verbal description, so that another person, i.e., the teacher, who cannot see what the child has built, makes the same construction. Next, the teacher builds a new construction and describes it so that the child can build it. Hereafter, it is again the turn of the child to build another construction and describe it to the teacher. The child was found to spontaneously use iconic and deictic gestures throughout the whole activity. These gestures, and primarily the iconic ones, helped her make apparent different space and shape aspects of the constructions. Along with her speech, gestures acted as semiotic means of objectification to successfully accomplish the task. The teacher's gestures were found to influence the child's gestures when describing aspects of shapes and spatial relationships between shapes. This influence results in either mimicking or extending the teacher's gestures. These findings are discussed and implications for further research are drawn.

Preliminary findings of this study were presented at the 7th Conference of the European Society for Research in Mathematics Education in Rzeszów, Poland.

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Keywords Mathematics · Kindergartner · Spatial concepts · Shape concepts · Gestures · Verbal descriptions · Microgenetic analysis

Introduction

Mathematical cognition means much more than working with abstract mathematical ideas. It involves the use of speech, symbols, drawings, gestures, and actions with cultural artifacts such as signs and objects. This multimodal approach of examining mathematical thinking has been adopted by a number of researchers in the past few years (e.g., Arzarello et al. 2009; Radford et al. 2009) and is in agreement with the theory of embodied cognition which considers bodily experiences as the basis of mathematical understanding and thinking (Nunez et al. 1999). According to this latter theoretical position, the body serves as a source and a reference point for building up mathematical concepts (Kim et al. 2010). This means that bodily actions, including gestures, are considered to be involved in the process of cognitive change (Goldin-Meadow 2000).

In addition, bodily actions and especially gestures have been acknowledged as crucial components of the communication system, providing a tool to convey information (Goldin-Meadow 2000; McNeill 1992). Goldin-Meadow (2000, p. 231) explains this perspective as follows: “Gesture has privileged access to information that children know but do not say. As such, it can serve as an additional window to the mind of the developing child, one that researchers are only beginning to acknowledge.”

In mathematics education, only a small number of studies closely investigated the ways in which children use gestures to express their thinking (Kim et al. 2010). Therefore, through our study we want to get insight into the phenomenon of gesture and specifically into the role of gestures interacting with verbal representations. The focus is on the use and communication of spatial concepts and concepts of shape in the early years of mathematics education.

Theoretical framework

The present study took place within the theoretical frameworks of Duval's (2006) semiotic approach and the multimodal approach (Arzarello et al. 2009; Radford et al. 2009) to learning mathematics. Furthermore, the study built on research on gestures (McNeill 1992).

A semiotic approach to learning mathematics

According to Duval (2006), no kind of mathematical processing can be performed without using a semiotic system of representation—also called registers of representation—such as natural language, symbols, diagrams, and so on. Furthermore, he emphasized that the representations on their own are not the crucial thing, but their transformations, including treatments and conversions. In the case of a treatment, the transformations happen within the same register, whereas a conversion implies that a representation produced within a system is converted into another system, so that the final representation reveals further meanings with respect to the represented object.

Duval (2006) highlighted the importance of the semiotic transformation of conversion because the transition between different registers of representation of the same mathematical object requires the conceptualization of the represented object. This process of meaning making, or of objectification, as Radford et al. (2007) would have called it, can be mediated by gestures.

A multimodal approach to learning mathematics—the role of gestures

To take into account the role of gestures in the learning process of mathematical concepts, we complemented Duval's (1995, 2006) semiotic theory with the multimodal approach. The multimodal approach suggests that when working with mathematical ideas, it is important to consider "the range of cognitive, physical, and perceptual resources" (Radford et al. 2009, p. 91) that people use and how they are related to each other. These resources incorporate both oral and written symbolic modes of representation as well as drawings, gestures, actions on physical and electronic artifacts, and different kinds of bodily motion. For example, gestures examined in isolation have a limited cognitive scope. Therefore, the cognitive potential of gestures has to be analyzed and understood only in the context of their interaction with other modalities (Radford 2009) and primarily with language. McNeill noted that "[s]peech and gesture are elements of a single integrated process of utterance formation in which there is a synthesis of opposite modes of thought—global-synthetic and instantaneous imagery with linear segmented temporally extended verbalization" (McNeill 1992, p. 35). This means that speech consists of segments that are produced linearly through time, whereas gesture is immediate, represents an image which depends on the whole and cannot be decomposed into parts with isolated meanings. This view suggests not only that gestures should be examined in association with other modes of representation in our attempts to understand mathematical thinking but also that the contribution of gesture to mathematical understanding, which almost always requires both analytic thinking and imagery, is distinct from the role of other modalities.

To make clear which gestures we were primarily concerned with in the present study, we will briefly describe McNeill's (2005) distinction in four major types of gestures which he adopted from Kendon (1988):

(a) Gesticulation: Movement that represents a meaning related to the accompanying speech
(b) Emblems: Signs based on conventions
(c) Pantomime: Gesture or a series of gestures used to tell a story without speech
(d) Signs: Lexical words in a sign language which has its own linguistic structures.

In the present study, our focus was on gesticulations, which we will refer to as gestures. Gestures of this particular kind generally include the spontaneous movements of the arms and hands that are produced in effortful cognitive activity, such as reasoning or problem solving (Alibali 2005; McNeill 1992). Parrill and Sweetser (2004, p. 197) define the meaning of a gesture as "the relationship between how the hands move in producing a gesture, and whatever mental representation underlies it, as inferred both from the gesture and the accompanying speech". McNeill (1992) proposed four categories of gestures with respect to their meaning: (1) *deictic* gestures, pointing movements to existing or virtual objects and actions in space; (2) *iconic* gestures which are closely related to the semantic content of speech, that is, they visually represent the content of concrete entities and actions, (3) *metaphoric* gestures, which represent an image of an abstract object or idea; (4) *temporal highlighting* gestures, simple repeated gestures used for emphasis.

As noted above, an essential aspect of the analysis of gestures is the relationship between the content of gestures and speech. On the one hand, gestures may convey the same information as speech (Arzarello and Edwards 2005), thus reinforcing the speech meaning (Göksun et al. 2010). On the other hand, gestures and speech may contain different information. Gestures may provide information that is conflicting to the content of speech, or they may supplement speech by providing additional information. Such a speech–gesture mismatch is seen as an indication for a transitional stage in cognitive development or in mastering a task (Alibali et al. 2000; Goldin-Meadow 2003).

Space and shape concepts

Geometry is an indispensable part of contemporary early childhood curricula and educational programs (Sarama and Clements 2009). This mathematical domain includes “the study of spatial relationships of all kinds; relationships that can be found in the three-dimensional space we live in and on any two-dimensional surface in this three-dimensional space. These relationships can be discovered all around us” (Egsgard 1970, p. 478). This spatial interpretation of geometry is the natural way in which children encounter geometry. They discover the world around them while they walk, play, and look around. They are, in fact, exploring their environment all the time; by doing so, they learn to find their way, to determine their own location within the environment, to describe to others their own position, or the position of an object, such as their teddy bear. Such activities help children become familiar with spatial relationships from their earliest days and contribute to the development of their spatial awareness, visualization, and reasoning abilities.

Spatial ability is a complex construct; it includes solving visual problems or carrying out tasks that require individuals to estimate, predict, or judge the relationships among figures or objects in different spatial contexts (Elliot and Smith 1983). A comprehensive view for spatial sense was taken by Yakimanskaya (1980, p. 127) by stating: “A child's spatial sense or orientation includes concepts of the magnitude and shape, spatial distinctions, the perception of space and an understanding of various spatial concepts.”

Children can perceive the shape and size of objects and can represent the placement of objects in a three-dimensional space as early as their first year of life (Haith and Benson 1998; Kellman and Banks 1998). By their second year, children develop the ability to code positions of objects in the external environment (Sarama and Clements 2009). The ability to search for multiple objects and to use spatial relationships between objects develops over the toddler and preschool years (Newcombe and Sluzenski 2004). By 5 years of age, children can represent the location of an object in relation to various landmarks, such as an object in the middle of the distance between two other objects (Newcombe 1989).

From the early years of children's life, there is a close connection between spatial ideas and language. Until their second year of age, children have significant spatial abilities and develop relevant vocabulary. Often children use words expressing spatial relations, even more frequently and earlier than names of objects (Gopnik and Meltzoff

1986). Moreover, children use spatial terms to express both location and movement. These are both pertinent to the meaning of spatial words in that such words serve to associate a landmark object with another object that either is moving or has been moved into a given place (e.g., “she is putting the shoes under the bed”; “the shoes are under the bed”) (McGregor et al. 2009). For example, 2-year olds frequently use the word “up” to mean “pick me up”. Acquiring appropriate spatial relational words provides support to the development of flexible spatial understanding (Wang and Spelke 2002). For example, when spatial language accompanies the challenges of children's interaction with spatial material while playing, e.g., doing jigsaw puzzles, spatial learning is enhanced (Levine et al. 2012).

Spatial terms are developed in a consistent sequence in children (Bowerman 1996). Initially, children learn the spatial terms “in,” “on,” “under,” “up,” and “down.” Then, words of proximity, such as “beside” and “between,” are acquired. Next, children learn terms that reveal frames of reference, such as “in front of” and “behind.” The words “left” and “right” are acquired much later and may not be fully understood and sufficiently used until about 6 to 8 years of age (Sarama and Clements 2009).

Although shape concepts are included in spatial sense, they can be separated from the spatial concepts mentioned above, as they refer mainly to geometrical shapes, their properties and relations. At an initial stage of development of shape concepts, children conceive a shape as a whole and identify shapes according to their appearance, by using visual prototypes (Hannibal 1999). Children are not in a position to identify many common shapes or distinguish among figures in the same class or, for example, include the concept of square into the concept of rectangle (Gagatsis and Patronis 1990).

The study of solid shapes is an indispensible component of geometry in kindergarten (Egsgard 1970). In kindergarten, the children become familiar with solids of different shapes, such as cubes, cones, cylinders, spheres, rectangular boxes, prisms, and pyramids, through their play. The children gain experience by sorting solid shapes, ordering solids by size, recognizing things used in everyday life that have these shapes, and constructing with geometric three-dimensional material, such as wooden blocks (Egsgard 1970). Constructing is a major aspect of the learning of geometry in the kindergarten, as it helps children discover how objects can be built (e.g., by combining certain blocks) and learn the properties of shapes (Van den Heuvel-Panhuizen and Buys 2008). Furthermore, while constructing, children learn, practically, the names of shapes, although this is not essential in the particular stage (Egsgard 1970).

Earlier research on gestures in learning space and shape concepts

The phenomenon of gestures in the teaching and learning of mathematics has been the focus of an increasing amount of research in recent years (Radford 2009). Gestures can serve as a representational tool of various mathematical ideas through which children can get a deeper level of consciousness of their meaning. The embodied character of gestures may facilitate the process of reaching abstract concepts through the visual and concrete form of gestures. Moreover, as a consequence of this process, students can communicate mathematical concepts more easily (Gallese and Lakoff 2005; Nemirovsky and Ferrara 2009).

A topic that received considerable attention by research on gesture production is spatial thinking (Alibali 2005). Many studies pointed out that gestures and spatial thinking are linked to one another. People tended to produce more gestures when they talked about spatial topics than when talking about nonspatial ones (Krauss 1998). Gestures are well suited to conveying spatial information (Kita and Özyürek 2003; McNeill 1992), such as location and movement. Along with speech, gestures are a good vehicle for exemplifying spatial relationships (Wagner et al. 2004). A number of research studies have documented that speakers tended to produce gestures when talking about spatial information in various contexts, such as when explaining a spatial layout of a town or a neighborhood (e.g., Emmorey et al. 2000), giving directions (e.g., Allen 2003), and describing motion in space (e.g., Kita and Özyürek 2003).

In a literature review about the role of gestures in spatial cognition, Alibali (2005) pointed out that gestures play a significant role not only in communicating but also in the cognitive processing of spatial information. The visuospatial nature of gesture makes it suitable for capturing spatial information. Gestures represent spatial properties and action-based characteristics of concepts (Krauss et al. 2000). They help speakers activate mental images and maintain these spatial representations in working memory (Alibali 2005). At the same time, using gestures to express spatial properties can help activate related mental representations of the concepts in verbal form (Krauss et al. 2000). In addition, producing gestures facilitates speakers to explore possible ways of organizing and packaging spatial information in speech. Research findings showed that speakers gestured more frequently when they encountered difficulty in organizing spatial information for speaking (Alibali et al. 2000; Kita and Davies 2009).

With respect to shapes, the relationship with gestures is less clear. We only found a few studies discussing the use of gestures when describing shapes. For example, a study by Graham and Argyle (1975) selected irregular two-dimensional shapes as the domain of material to be communicated in order to investigate the accuracy of the information conveyed when gestural communication was allowed. A major finding was that the inclusion of gestures to speech enhanced the accuracy with which shapes were communicated. A number of studies in the domain of artificial intelligence and computer science examined the morphological diversity of people's shape-related iconic gestures and the way they depict aspects of shape objects, in an attempt to capture the meaning of iconic gestures in formal terms and enable their computational treatment through a suitable computational model for gesture and speech interpretation and representation of shape (e.g., Sowa and Wachsmuth 2005). It is noteworthy that these studies did not focus on the role of gestures in the understanding of geometrical shapes or its development. Only recently, researchers in mathematics education have started to investigate this issue (e.g., Maschietto and Bartolini Bussi 2009; Kim et al. 2010). For example, in a teaching experiment carried out in a study by Maschietto and Bartolini Bussi (2009) with students of 10–11 years of age, it was shown that gestures and their interrelations with graphical and linguistic signs enabled students to internalize the mathematical model of a visual pyramid.

The aforementioned studies suggest that to find out how to enhance geometrical understanding, it is important to explore how people communicate and think about space and shapes, paying particular attention to verbal and nonverbal expressions. Considering that between the ages of 3 and 5 there is a gesture explosion in children irrespectively of their language (McNeill 2005), while written symbols do not yet have a primary role in mathematical cognition, the need to improve our knowledge of gestural uses and functions and their interrelations with verbal utterances in the learning of space and shape concepts in young children within this age range is even greater.

However, only a small body of research discussed the role of gestures in the development of space and shape concepts in young children. Specifically, regarding spatial understanding and gesture production, within the age range from 3 to 5, we found only one study, which explored the strategies 5-year-old children used to solve tasks on spatial transformation (Ehrlich et al. 2006). The results of the study showed that children frequently produced gestures whose meaning was not necessarily detected in the accompanying speech. Children who referred to spatial information in their gestures, but not in their speech, were more likely to perform well. These findings can be regarded as an indication that gestures have the potential to improve early spatial skills. Hand movements may support children to mentally simulate transformations in space (Newcombe and Frick 2010).

With respect to shape understanding and gesture production, we did not find any study examining children between 3 and 5 years of age. Nevertheless, an interesting study was carried out by Kim et al. (2010) with second-grade students. In this study, the researchers observed the gestures of students while dealing with complex ideas of geometry and demonstrated how gestures played an integral role in the children's geometry learning. In some cases, children used gestures without talking when they explored and expressed their own ideas. For example, one student was processing the relationship between the roundness of a three-dimensional shape and the concept of rolling with her gestures without any speech. This study has also shown how important gesture was in enhancing communication about mathematical ideas in students. In an episode described in this study, a student's gestures co-emerged with another student's gestures and speech which conveyed geometrical meanings (about three-dimensional shapes' movements when set on an incline plane). The gestures of the first student, who did not speak during the episode, did not mimic but presented creatively her own understanding of geometrical properties and movements of shapes. This suggests on the one hand that gestures could not be distinguished from the learners' own knowing, and on the other hand that this gestural interaction was an indispensible component of an inherently collective and creative communication and coordination of mathematical ideas.

As already indicated by this example from the study of Kim et al. (2010), children did not only produce gestures, but were able also to pay attention to the gestures they watched and draw information from them (see also Ping and Goldin-Meadow 2008). There is evidence that besides producing one's own gestures, watching someone else's gestures can enhance children's learning (e.g., Garber et al. 1998). This seems to apply also for spatial cognition, since observing gestures of others was found to have a positive impact on the addressees' understanding of spatial information included in speech (Alibali 2005). Furthermore, preschoolers who received instruction on symmetry had better learning outcomes when the lesson included speech and gestures than when it included only speech (Valenzeno et al. 2003). A study by McGregor et al. (2009) showed that viewing a gesture for the spatial concept "under" enhanced to a greater extent young children's understanding of the particular spatial term relatively to other conditions, such as viewing a photograph of objects in the under spatial relation. Gestured input in the particular study emphasized both the location and the movement related to the meaning of "under."

Besides watching gesture production of other people, it has been acknowledged that both adults (Chartrand and Bargh 1999) and very young infants (Meltzoff and Moore 1977) can imitate nonverbal behaviors modeled by an experimenter. Furthermore, children who used problem-solving strategies conveyed in their teacher's gestures into their own gestures were more able to master the task (Cook and Goldin-Meadow 2006). This finding suggests that teachers' gesture production during instruction could support learning also by encouraging children to produce gestures of their own.

Research questions

As shown above, the relationship between language and mathematical thinking and particularly geometrical thinking (Sarama and Clements 2009) in the early years has been extensively studied in previous research. Roth (2001), however, stressed the need to specify the nature of mathematical knowledge learners express in their words, but also in their gestures and to find out more about the associations between these two resources when students learn abstract concepts, such as mathematical concepts, at school. Despite the great amount of experimental studies undertaken about the role of gestures in the understanding of concepts within different mathematical topics, such as early algebra (e.g., Radford 2011) and equivalence (Singer and Goldin-Meadow 2005), at different age levels, investigating children's gestures and their dynamics with language in studying changes in early geometrical thinking has received limited attention. This is particularly true for children in pre-elementary grades (see above). In this study, we are interested in improving our understanding of the role of gestures and the variation that gestures and speech undergo in manipulating and communicating spatial concepts and concepts of shape at a kindergarten level. Another important aspect of educational research (Roth 2001) which our study aims to explore further concerns the role gestures might take in a teacher–child interaction in geometry learning. Our focus is on how the kindergarten teacher's gestures are used as resources by the child in making sense of various spatial and shape aspects. In this respect, we have the following research questions:

1. What types of gestures are produced and what are the mathematics-related space and shape aspects they are associated with when converting a spatial construction of geometrical shapes into a verbal description?
2. How are gestures used in relation to speech for the different mathematics-related space and shape aspects that emerge when converting a spatial construction of geometrical shapes into a verbal description?
3. Can gestures used by the teacher function as a model for children's use of gestures when converting a spatial construction of geometrical shapes into a verbal description?

Method

Nature of the study

To address the research questions, a deep insight into the phenomenon of gestures in early geometry learning is needed. As Radford (2009, p. 124) noted: “[t]o better weigh the role of gestures and bodily actions in mathematics cognition, more detailed investigations are required.” Therefore, we chose to carry out a qualitative single-case study, in which we examined one child while interacting with her kindergarten teacher in the context of a geometrical activity.

Specifically, a 5-year-old kindergartner from a private kindergarten in Nicosia, Cyprus, was observed. The child is a girl and speaks Greek as her first language. She had received organized instruction in mathematics. With respect to spatial concepts, this instruction included the concepts in–out, on–under, behind–in front, and between. As to shape concepts, the child received teaching on two-dimensional shapes, i.e., triangle, rectangle, quadrilateral, square, and circle. The concepts left–right and three-dimensional shapes had not been taught in the child's class by the time the collection of the data took place.

Activity and procedure used

For the purpose of this study, we designed a task which involves the understanding and operating on relationships between various positions in space (Sarama and Clements 2009). This task starts with free constructing with three-dimensional shapes and continues with a verbal description of the construction. Thus, the task includes semiotic transformations (Duval 2006), that is, conversions between spatial representations and verbal descriptions. By linking spatial knowledge to verbal, analytic knowledge, children are enabled to move beyond visual thinking which is restricted to surface–visual ideas. Specifically, spatial descriptions comprise an alternation between the use of referents and expressions which provide spatial orientation to these referents (Gullberg 1999). Therefore, connecting spatial representations to language can help children develop the ability to reason and communicate about space and thus gain deeper understanding of spatial concepts and relationships (Sarama and Clements 2009).

The activity had the form of a game which required two players, one of whom was the child's kindergarten teacher. During the activity, the child and the teacher sat opposite each other with a screen divider to hide each other's work. The activity included three parts. In part 1 and part 3, the child created a construction with wooden blocks and then described the structure, step-by-step. The teacher built the construction using blocks from the child's verbal directions. In part 2 of the activity, the child and the teacher switched roles. In this part, during her description, the teacher produced gestures. This enabled us to identify the influence of the teacher's gestural and speech production on the child's behavior.

As shown in Figs. 1 and 2, the blocks that were used in the activity were three-dimensional geometric shapes in different sizes, including cubes, right rectangular prisms (parallelepipeds), and triangular prisms (often called by the children “roofs”), cylinders, and specific concave shapes (often called by the children “bridges”). Both the teacher and the child had the same shapes at their disposal. The child's constructing with these blocks was free. This means that the child could use any of the blocks she had at her disposal in any way she wanted for making the construction.

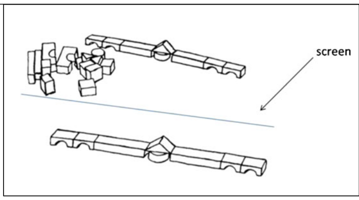
Both in part 1 and part 3, after the child made the construction, she was told that she should explain her construction to the teacher, without taking the objects in her hands. She should talk about it, so that the teacher, who could not see it, could build the same construction. Because there was a screen between the two players, they could not see each other's work. Therefore, the mirror-inversion was not included in the task; the two players did not have to perform complicated left–right mirroring operations. In the description of the construction, the child was expected to use different space and shape aspects, including shapes, size, and spatial words about the blocks' location and orientation.

Data collection and analysis

To examine the child's gestures and language, her reactions and utterances during her participation in the activity were video-recorded. Guided by our research questions and theoretical framework, we conducted a microgenetic analysis (Siegler 1995) of the child's descriptions of her constructions during the activity. This means that we carried out an intensive analysis of the observed behavior of the child (Lavelli et al. 2005), who had incomplete knowledge of space and shape concepts involved in the geometrical activity. It is our contention that this microgenetic approach can shed some light on the processes the child goes through while thinking of, and communicating space and shape concepts, in the complex problem-solving situation included in the activity: describing the spatial arrangement of constructions made of various three-dimensional shapes so that a conversation partner who cannot see it can create the same construction. In carrying out the microgenetic analysis, we focused on the child's use and coordination of two semiotic resources, namely spoken words and gestures. To identify the types of the child's gestures during the activity, McNeill's (1992) proposed scheme for classifying gestures was applied. Changes in the interplay between the two semiotic resources (words and gestures) were also detected, by comparing the child's speech and gestures within and between part 1 and part 3 of the activity. To study the influence of the teacher's gestures on the child's gestures, the similarities between the teacher's and the child's gestures and speech in association with the changes in the child's gestural and verbal production from part 1 to part 3 were examined.

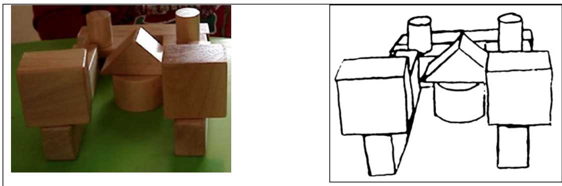
Results

Below, we first present the child's constructions in part 1 (see Fig. 1) and part 3 (see Fig. 2) of the activity. The two figures include also the descriptions of her



Child:	Take a circle.
	Now take a roof.
	Put it on top. [Moves her hands downwards pretending to hold the block and place it on another block]
	Now take two long shapes. [Opens her hands, one hand to the left and the other to the right side of her body]
Teacher:	Where shall I put them?
Child:	Next to it. [Points with both her hands next to the cylinder]
	Then put two small ones [Takes a small bridge and shows it to the teacher]
Teacher:	We said that you shouldn’t show me the blocks you use. Where shall I put them?
Child:	Next to them. [Points with both her hands next to the two parallelepipeds].
	Two more.

Fig. 1 Construction made by the child (on *top* of the drawing) and then by the teacher, in part 1 of the activity, followed by the child's description of her construction



Child: Take two long shapes. [Stretches out one hand vertically to her body and forms a straight line in the air by moving her hand with the palm open near her chest]. Two.

Teacher: How shall I put them?

Child: Like this. [Moves her hands away from one another with one palm opposite the other] Not like this. [Puts the palms of her hands together] Take two squares.

Teacher: Where shall I put them?

Child: On [Moves her hand downwards pretending tohold the block and place it on another block] the ….. [Stretches out her hands vertically to her body and forms a straight line in the air by moving her hands with the pointing fingersstretched near her chest] but not like this [takes a parallelepiped with dimensions of similar length and turns it widthwise], like this [turns the parallelepiped lengthwise]. Then take two [Shows two and then three fingers] small … [Moves her pointing finger to form a semicircle], two small [Moves her pointing finger to form a semicircle], two small bridges. Then put them attached [Joins the fingers of her hands] to the long shapes [Stretches out one hand vertically to her body and forms a straight line in the air by moving her hand with the palm open near her chest], in front of them, not here [Points with both her hands behind the parallelepipeds], but here [points with both her hands in front of the parallelepipeds, close to her]. Then take another long shape. Put it in front of the bridges [Opens her hands to form a flat surface and joins her fingers in front of the bridges, close to her]. Take two circles [Makes a round line vertically in the air with her pointing finger], but small ones [Moves her hands close to her face and forms fists]. Put them on the bridges [Moves both her hands downwards pretending to hold the blocks and placethem on other blocks].

Fig. 2 Construction made by the child, in part 3 of the activity, followed by the child's description of her construction

constructions and her gestural production based on the video-recorded material. This material was analyzed in order to address the research questions of our case study.

At this point, it should be noted that the child did not complete the description of her construction in part 3. She omitted telling the teacher about the cylinder and the triangular prism on the cylinder that were between the two parallelepipeds in her construction.

Fig. 3 Iconic gesture for the shape of cylinder (second construction, lines 46–48)

Fig. 4 Child shows the block having the shape of a "bridge" saying: "take two small like this" in part 1 of the activity (first construction, lines 9–10)

Categorization of gestures

The child was found to produce gestures for various aspects of mathematical content included in her spatial description. These gestures were grouped into three categories based on the dimension (iconic, deictic, metaphoric) that was most prominent according to McNeill's (1992) classification.

When the child gestured about the shape of the various blocks she referred to in her description, these gestures were of iconic character. An example concerns the cylinder shape (lines 46–48), for which the child moved her finger to make a round line vertically in the air (see Fig. 3). It is noteworthy that when the child had difficulty in naming the shape of a particular block, such as a block that looked like a bridge (lines 9–10), she took the object in her hands to show it to the teacher (see Fig. 4). In one case in the description of her second construction, when referring to other properties of the blocks, such as size, the child used a metaphoric gesture. When she was explaining to the teacher to "take two circles (meaning cylinders), but small ones" (lines 46–48), for the word "small", she moved her hands close to her face and formed fists (see Fig. 5).

To explain the location of some blocks in her constructions, the child used deictic gestures, by which she pointed to the position of these blocks. Deictic gestures were usually accompanied by spatial word expressions such as "put it here," "next to," "on," and "in front of." For example, the child produced a deictic gesture (lines 13–14) by pointing with both her hands next to the two parallelepipeds of her first construction to indicate where to put two blocks having the shape of a bridge, at each side of the construction (see Fig. 6).

Fig. 5 Child's metaphoric gesture for the word "small" (second construction, lines 46–48)

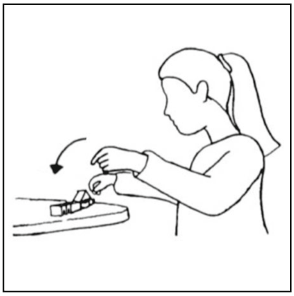


Fig. 6 Child's deictic gesture for the position of two “bridges” next to the two parallelepipeds in each side of the array (first construction, lines 13–14)

To illustrate the orientation of the blocks (e.g., whether they are horizontal or vertical on the plane) in her construction, the child used iconic gestures in her description. For example, to explain the placement and the horizontal orientation of a parallelepiped in the second construction, the child used the verbal expression “Put it in front of the bridges” (lines 44–45) opening her hands to form a flat surface and joining her fingers in front of the bridges, close to her (see Fig. 7). Once, when she talked about how a parallelepiped should be placed in space with respect to its orientation (e.g., lengthwise or widthwise) (lines 29–32), she took the object and turned it with her hands to show the proper orientation of it to the teacher by saying “not like this” (widthwise), “like this” (lengthwise) (see Fig. 8).

In her descriptions, the child introduced not only the location of blocks but occasionally also movements of placing blocks in her constructions. These spatial expressions were represented by iconic gestures. In particular, while the child was explaining to the teacher where to place a block, she was pretending to hold the block, move it downwards and place it in the position she was trying to explain. An example is the verbal expression of the child “…take a roof and put it on top” (lines 2–4), which was accompanied by the gesture shown in Fig. 9.

The examples of the child's verbal and gestural production analyzed above are summarized in Table 1, with respect to the type of gesture and relevant mathematical content.

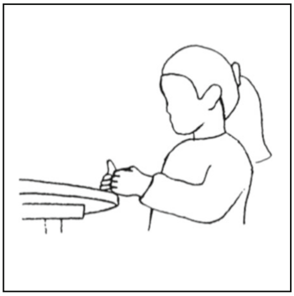


Fig. 7 Child's iconic gesture for the orientation of the parallelepiped in front of the blocks named “bridges” (second construction, lines 44–45)

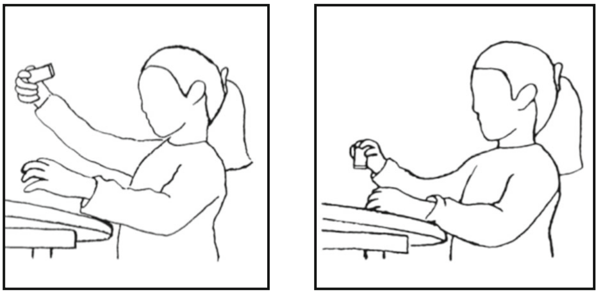


Fig. 8 Child's actions of taking a block and showing its proper orientation to the teacher by saying "not like this" (*left part*), "like this" (*right part*) (second construction, lines 29–32)

Gestures and speech

In exploring the connections between language and gestures, we observed that in most cases the child was using gestures and language simultaneously. However, in one case, the child produced a gesture before expressing the corresponding word. While trying to figure out the name of a block that had the shape of a bridge in the third part of the activity, the child first produced an iconic gesture depicting the form of the block (semicircle) and then she named it as "bridge" (lines 33–36).

With respect to the content of gesture and speech, we analyzed gestures for the various space and shape aspects of the child's descriptions, in terms of two categories: speech–gesture match and speech–gesture mismatch. The majority of the child's gestures contained the same information as her speech. The child's gestures within the category of speech–gesture mismatch were distinguished into two subcategories: gestures which provide information that supplement speech and gestures which replace speech.

A congruence between the information conveyed by speech and gestures occurred when the child referred either to the spatial relations of shapes in her descriptions, or to the shapes of the construction. This was the case when the child gave a precise explanation about the spatial relations of shapes or used a specific name (not necessarily correct) about the shapes in her descriptions. For example, while the child was explaining to the teacher where to place the blocks which had the form of a bridge with reference to the blocks named "long shapes" (parallelepipeds) in the second construction, she used the expression "put them (the 'bridges') attached to the long shapes" and joined the fingers of her hands as illustrated in Fig. 10 (lines 37–38). Furthermore, as noted

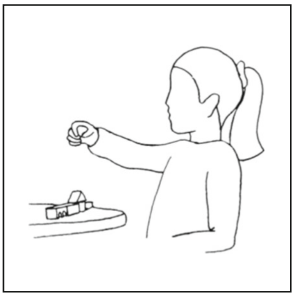


Fig. 9 Child's iconic gesture to represent the movement of placing the block on another block (first construction, lines 2–4)

Table 1 Examples of child's gestures and speech in each gesture category with respect to mathematical content

Speech	Gesture	Type of gesture	Concept	Space/shape aspect	Construction, lines, figure
Circle	Makes a round line vertically in the air with her pointing finger	Iconic	Cylinder	Shape	-Second construction -Lines 46–48 -Fig. 3
Small circles	Moves her hands close to her face and forms fists	Metaphoric	Small cylinders	Size	-Second construction -Lines 46–48 -Fig. 5
(Put the two bridges…) Next to them (…the two parallelepipeds)	Points with both her hands next to the two parallelepipeds	Deictic	Next to	Location	-First construction -Lines 13–14 -Fig. 6
Put it (the parallelepiped) in front of the bridges	Opens her hands to form a flat surface and joins her fingers in front of the bridges, close to her in horizontal direction	Iconic	- In front of - Horizontal orientation of parallelepipeds	Location and orientation of parallelepipeds	-Second construction -Lines 44–45 -Fig. 7
Take a roof and place it on top	Moves her hands pretending to hold the block and place it on another block	Iconic	On	Movement of placing a shape: Translation	-First construction -Lines 2–4 -Fig. 9

Fig. 10 Child's gesture concurring with speech about putting together two blocks with two other blocks (second construction, lines 37–38)

above, the child made a round line vertically in the air with her pointing finger to represent the shape of a cylinder, which she called “circle” (lines 46–48). This latter incident is an example of congruence between the information conveyed by speech and gestures about the aspect of shape.

Considering the aspect of shape, in one case, when the child was referring to the parallelepiped in the description of her second construction, she produced a gesture depicting the shape without the corresponding word (lines 26–30). In particular, she stretched out both hands vertically to her body and formed a straight line in the air by moving her hands with the pointing fingers stretched towards her body to complete the verbal expression “(put two parallelepipeds with dimensions of similar length) on the ….”. The particular gesture (see Fig. 11) was used to complete the sentence by replacing the name of the parallelepiped (“long shape”).

The supplementary role of gesture to speech was identified mainly when the child described the location and/or the orientation of the blocks in an imprecise way, when, for example, the child used general and unclear verbal expressions about these spatial aspects. Specifically, to describe the position of a block, the child often used general verbal expressions such as, “put it here”, “like this”, and simultaneously produced a gesture to illustrate what she meant. For example, the child while trying to explain to the teacher how to place the two “long shapes” (parallelepipeds) in the second construction (lines 21–23), she was showing with her hands their position, highlighting that they should be placed “like this” (apart) and “not like this” (not together) (see Fig. 12). The particular gesture indicates not only the relative position of the two parallelepipeds but also their orientation, that they should be vertically positioned.

Fig. 11 Child's gesture replacing the term parallelepiped (“*long shape*”) in part 3 of the activity (second construction, lines 26–30)

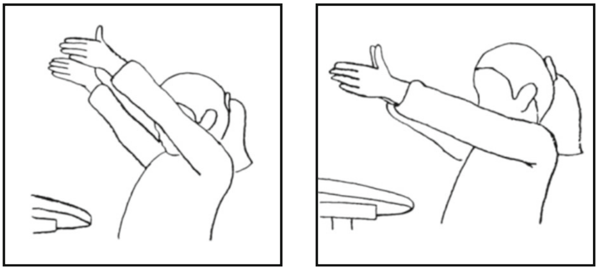


Fig. 12 Child's gesture supplementing the verbal expressions "like this" (*left*) and "not like this" (*right*) about the positions of two parallelepipeds (second construction, lines 21–23)

These spatial aspects of the construction were not given by the child's words, but only through her gestures.

The supplementary function of gestures to speech occurred also when the child gave explanations that included only partial spatial information about the construction. For example, to explain the placement and the horizontal orientation of a parallelepiped in her second construction, the child used the verbal expression "Put it in front of the bridges" (lines 44–45) opening her hands to form a flat surface and joining her fingers in front of the bridges, close to her (see Fig. 7). This gesture depicts the horizontal direction of the parallelepiped and therefore complements the content of the child's words which describe only the location of the block in the construction.

An aspect of the linkage between language and gestures that was examined was how this connection changed during the activity. This analysis provided interesting information about the child's utterances related to the aspects of shapes and their orientation. In the description of the first construction (lines 5–6), the child opened her hands, one hand to the left and the other to the right side of her body (iconic gesture) to represent the "long shape," meaning the parallelepiped (see Fig. 13a). In describing the second construction, when the child used the particular term, she produced a different iconic gesture (lines 16–18). She stretched out one hand vertically to her body and formed a straight line in the air by moving her hand with the palm open near her chest (see Fig. 13b). Moreover, as already noted, when she replaced the term parallelepiped, she performed a similar vertical movement by using both her pointing fingers and not the palms of her hands (see Fig. 11) (lines 26–30). However, the last time she referred to this shape, she did not use any gesture (line 43). This change in gestures for the same geometric shape is explained by the different orientations of the parallelepipeds she referred to in the first and the second construction. In the first construction, the blocks were in a horizontal position, while in the second construction the

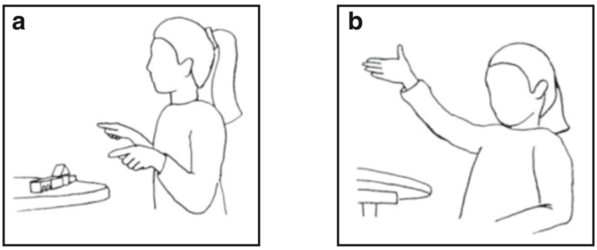


Fig. 13 **a** Child's gesture for the parallelepiped in part 1 of the activity (lines 5–6). **b** Child's gesture for the parallelepiped in part 3 of the activity (lines 16–18)

Table 2 Examples of child's gestures and speech for each category of gesture–speech relationship with respect to mathematical content

Speech	Gesture	Gesture–speech relationship	Concept	Space/shape aspect	Construction, lines, figure
Put them (the bridges) attached to the long shapes	Joins the fingers of her hands	Match	Proximity	Spatial–topological relation	-Second construction -Lines 37–38 -Fig. 10
Circle	Makes a round line vertically in the air with her pointing finger	Match	Cylinder	Shape	-Second construction -Lines 46–48 -Fig. 3
On the ….	Stretches out both hands vertically to her body and forms a straight line in the air by moving her hands with pointing fingers stretched near her chest	Mismatch (gesture replaces speech)	Parallelepiped	Shape and its orientation	-Second construction -Lines 26–30 -Fig. 11
Like this, not like this	Puts the palms of her hands opposite each other at a distance and attached respectively	Mismatch (gesture supplements speech)	Proximity and separation	Spatial–topological relation	-Second construction -Lines 21–23 -Fig. 12
Put it (the parallelepiped) in front of the bridges	Opens her hands to form a flat surface and joins her fingers in front of the bridges, close to her, in horizontal direction	Mismatch (gesture supplements speech)	-In front of -Horizontal orientation of parallelepiped	Location and orientation of parallelepiped	-Second construction -Lines 44–45 -Fig. 7
Long shape	Opens her hands, one hand to the left and the other to the right side of her body	Mismatch (gesture supplements speech)	-Parallelepiped -Horizontal orientation	Shape and its orientation	-First construction -Lines 5–6 -Fig. 13a
Long shape	Stretches out one hand vertically to her body and forms a straight line in the air by moving her hand with the palm open near her chest	Mismatch (gesture supplements speech)	-Parallelepiped -Vertical orientation	Shape and its orientation	-Second construction -Lines 16–18 -Fig. 13b

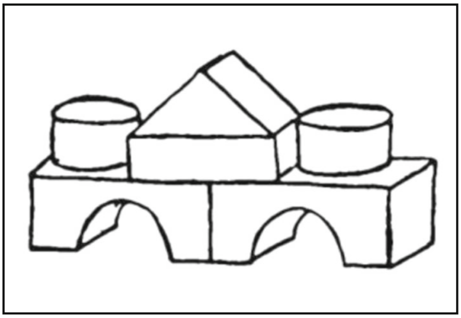


Fig. 14 The teacher's construction in part 2 of the activity

two parallelepipeds were in a vertical position, and the parallelepiped she referred to the last time was in a horizontal position. These results indicate that the child gave verbally just the name of the block, and her accompanying gesture supplemented the mathematical content of this verbal expression, by illustrating the spatial orientation of the block. Thus, further support is provided for the supplementary function of gestures to speech in the child's description.

The examples of the child's verbal and gestural production analyzed above are summarized in Table 2, with respect to the type of gesture–speech relationship and relevant mathematical content.

Influence of teacher on child's gestures

The teacher's gestures during the spatial description of her construction (see Fig. 14) was found to influence the gestural production of the child, with respect to shape and spatial location, in two different ways.

First, the child mimicked the teacher's expression and gesture referring to the shape of a particular block used in her construction, in a similar situation. In part 1 of the activity, the child (lines 9–10), in an attempt to explain to the teacher to take two small blocks that had the shape of a bridge, she picked up the block and showed it to the teacher without being able to name it (see Fig. 4).

In part 2 of the activity, when the teacher described her construction to the child, she told the child to take a block of the same shape by using the term "bridge," and at the

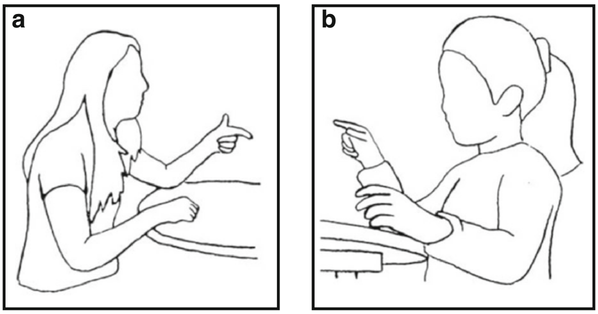


Fig. 15 **a** Teacher's gesture for the block having the shape of a "bridge" in part 2 of the activity. **b** Child's gesture for the block having the shape of a bridge just before using the word "bridge" in part 3 of the activity (lines 33–36)

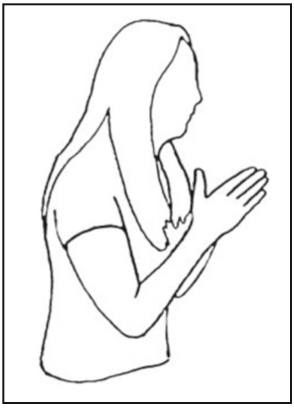


Fig. 16 Teacher's gesture for explaining that two blocks should be attached to one another

same time she moved her pointing finger to form a semicircle depicting the geometric form of the particular block (see Fig. 15a). In part 3 of the activity, when telling the teacher to take the block with the shape of a bridge (lines 33–36), the child thought for a while producing the gesture that the teacher had used, that is, moving her pointing finger to form a semicircle, and then the child recalled the word “bridge,” which was the corresponding verbal utterance the teacher had used earlier (see Fig. 15b).

Besides mimicking the teacher's gesture and speech, in one case, when the child's description referred to the spatial relations between two blocks, the child even “extended” the teacher's gesture. Specifically, in part 2 of the activity, while the teacher was explaining that two blocks are attached to each other, she put the palms of her hands together (see Fig. 16). In part 3 of the activity, when the child had to describe the relative position of two blocks and in particular that they should be apart from one another (lines 21–23), she used the same gesture and the “opposite” gesture that she observed earlier from the teacher. In fact, the child first moved her hands away from one another highlighting that they should be placed “like this” (apart from each other) (see Fig. 12a), and then she put the palms of her hands together clarifying that they should not be put in this way (not attached) (see Fig. 12b).

Discussion

Our study investigated a topic that has so far received limited attention, gestures and their dynamics with language in children's early geometrical thinking, and more specifically in the learning of spatial and shape concepts by producing gestures and by observing gestures while interacting with the teacher. The major goal of the study was to unravel the role of gestures in using and communicating spatial and shape-related ideas by a kindergarten child that was engaged in an activity requiring the transformation of spatial constructions into verbal descriptions. The present case study enabled us to address our research questions, but at the same time it raised a number of issues for further investigation, which will be discussed below.

The child under study was found to use gestures throughout the whole part of the activity in which she acted as a describer. This finding provides further evidence for the strong interrelations between geometrical thinking and gestures shown in previous studies (Graham and Argyle 1975; Kita and Özyürek 2003; Krauss 1998). Describing the spatial arrangement of a construction made of blocks of various geometric shapes so that a conversation partner who cannot see it creates the same construction is not an easy enterprise for a kindergarten child of 5 years of age. The child had to describe at the same time various geometrical aspects, such as shape, size, location, and orientation of blocks. Thus, the high frequency of gestures in this activity may be a result of the difficulty the young child encountered in organizing geometrical information for speaking (e.g., Alibali et al. 2000; Kita and Davies 2009). Producing gestures might have subconsciously functioned as an essential tool to reduce the cognitive effort of the child in this complex spatial problem solving. As previous research has shown, the production of gestures lightens the cognitive load of the speaker (Wagner et al. 2004) and provides support to internal spatial visualization (Chu and Kita 2011).

However, in a few cases in which the space and shape aspects that the child needed to describe were very complex or not familiar to her, gestures appeared to be insufficient in facilitating her description, and as a result she took specific objects in her hands to show to the teacher while describing her construction. This happened only when she did not know or could not recall the name of the shape of a block, and when she wanted to show to the teacher how to place specific objects in her construction in terms of their orientation in space (lengthwise or widthwise). These actions were encouraged by the fact that the child had access to the blocks of her construction when acting as a describer.

Gestures' types and their functions in geometrical thinking and communication

Our results indicate that different aspects of geometrical content were more likely to stimulate the use of specific types of gestures by the child. When the child described the shape (e.g., cylinder), the orientation of a block (e.g., horizontal direction), and topological relations of proximity or separation (e.g., shapes that were attached or not), she tended to produce iconic gestures which depicted the geometrical aspects involved. Interestingly, in explaining the placement of some blocks, the child produced iconic gestures to represent mental images of a dynamic character. Specifically, these iconic gestures depicted the movement of placing the objects in their current location. When the child explained the location of the blocks in her construction (e.g., in front), she was more inclined to use deictic gestures, indicating the position in which the blocks were placed. In sum, iconic gestures served multiple functions in the child's geometrical thinking and were used more often relatively to deictic gestures which were rather monofunctional. At a higher level of categorization of geometrical meanings, we may conclude that iconic gestures represented forms of shapes, spatial transformations, that is, movements of shapes in space, and the effects of these transformations referring to spatial relations or shape orientations. Deictic gestures represented the effects of spatial transformations of shapes referring to specific locations of shapes. The above findings indicate that, in most cases, the different types of gestures the child produced, while making the coordination between language and spatial constructions, had a distinct functional role with respect to the geometric concepts that were addressed. In particular, the results from this case study suggest that iconic gestures were better suited and more pertinent to the child's geometrical thinking than deictic gestures.

It is noteworthy that spatial transformations (e.g., translations and rotations) were rarely expressed in the child's descriptions, while their effects (e.g., spatial relations, shape orientation) were often included in her descriptions. Spatial transformations were represented either through her iconic gestures or actions on objects. For example, with respect to rotation, the child once took a block and turned it in space to show its proper orientation. With respect to block translation, the child used an iconic gesture, that is, she moved her hand downwards to show the movement of putting one block on another block. These findings indicate that spatial transformations of three-dimensional shapes were not completely unseen by the child. Thus, interpreting the geometrical meanings depicted in the various forms of iconic gestures produced by the child served as a valuable communicative tool, as it informed us not only of the shape and space aspects the child was already aware of and explicitly described but also of aspects of geometrical thinking (e.g., spatial transformations) for which the child could still develop further awareness.

In light of the above, we can conclude that gestural analysis which identifies gesture types and the mathematical meanings they refer to may have the potential to improve teaching from a gestural perspective. It can help teachers become aware of children's geometrical knowledge and learning needs, and also of the types of gestures that are more relevant to specific geometrical ideas, and, therefore, are more preferable to be introduced and encouraged in the teaching and learning process of geometry.

Gestures, oral speech, and geometrical understanding

The various space- and shape-related aspects such as size, location, and orientation, in a verbal description, have to be “harmonized” so that this description is coherent and understandable. Our microgenetic analysis showed that in the description of the child under study, these aspects were inherently merged to a great extent throughout the activity. This was accomplished by the child's activation and coordination of two semiotic systems: oral speech and gestures. In fact, a close multidimensional relationship between gestures and language was revealed. This relationship appeared in the child's behavior in two distinct ways. Firstly and most frequently, there was a speech–gesture match (Arzarello and Edwards 2005) with gestures reinforcing the meaning of speech. Specifically, while giving a precise description of the spatial relations of shapes or a specific name (not necessarily correct) for the shapes, the child simultaneously appeared to produce gestures that represented the geometrical information given by her verbal expressions.

Our analysis suggested, however, that the role of gestures in the objectification of knowledge was crucial also when a gesture–speech mismatch occurred in the child's description (e.g., when the child did not have the words to convey her thinking). This is the second type of relationship between the child's gestures and oral language that was identified in our study, in terms of which different information was conveyed by speech and gestures (Arzarello and Edwards 2005). The child's gestures were found to complement, enrich, and specify her verbal descriptions, particularly when her verbal utterances were unclear, general, or incomplete. Some space and shape aspects of the construction were manifested mainly by the child's gestures instead of her words. For example, the orientation of a shape on the plane was a spatial aspect that was never expressed verbally by the child during the activity, but started to become objectified thanks to the iconic gestures she produced. Even when the child explained verbally the location of a block (e.g., in front of another block), she used at the same time a gesture to illustrate the orientation of that block, that is, whether it is horizontally or vertically positioned. These “objectifying iconic gestures” (Sabena et al. 2005, p.135) seemed to be essential and valuable in representing geometrical concepts that were rather complex for the child, such as the orientation of a shape. It can be claimed that the child's gestures, along with her speech, acted as semiotic means of objectification to successfully accomplish the given description task.

Production and observation of gestures: the role of the teacher's gestures

The activity in the present study was designed to include a child–teacher–child interaction while building a construction and describing it, so that we could examine how gesture production, as well as gesture observation, contribute to the process of geometrical understanding. This activity was found to be successful in our study, as it enabled us to identify the changes in the child's gesture and speech acts across the phases and therefore in the ways she was making sense of geometrical concepts both from producing and from watching gestures. Other studies have shown that combining gesture observation and gesture production can contribute to stable mathematics learning over time in third- and fourth-grade students (Cook et al. 2008, 2010). In our study, we extended this body of research in that, we did not focus on the gains in achievement as a result of gestural production and observation in mathematics learning, but with the application of the microgenetic analysis, we described and explained the processes in understanding mathematical (space and shape) concepts and their changes in the context of geometrical problem solving.

Specifically, our findings show how the kindergartner under study took the teacher's gestures as a model in describing her construction after observing the teacher's corresponding description. The child was found to mimic the teacher's gesture, which depicted the shape of a block. It is noteworthy that in part 1 of the activity (before observing the teacher's description), the child took the shape of a bridge and showed it to the teacher without naming it, while in part 3 of the activity (after observing the teacher's description), actually produced an iconic gesture (forming a semicircle in the air) and named the particular object “bridge” when referring to it. In part 2, the teacher, with the use of the previously described gesture, indicated to the child a distinctive component of the particular object, the semicircle, producing also the corresponding word. Thus, the change in the child's description and gestural production for the same shape suggests that watching the teacher's gesture and speech acts contributed to this progress. An attribute of the shape which until then probably remained unseen by the child was made apparent (or objectified) (Radford 2009).

Furthermore, the child extended the teacher's gesture which depicted the spatial relation of proximity between two blocks, by adding a contrast to it in a similar situation, whereas prior to the teacher's description the child did not make any reference to the proximity between blocks. Specifically, the child used a gesture that represented the relative position (separation) of two blocks in her construction, and then a gesture to show how this spatial relation is opposed to the image of two attached blocks (counter-example), which had been previously represented by the teacher's gesture. This change in the child's verbal and gestural acts provides evidence for the contribution of the teacher's gestural and speech production on the child's objectification of the concept of proximity. Furthermore, the contrast added by the child indicates that she understood and used creatively the meaning of the particular gesture she observed and then produced in her own description. Previous research has shown that if children grasp the meanings conveyed by the gestures they repeat, producing those gestures could support their learning (Cook and Goldin-Meadow 2006). Thus, this provides further support to the positive influence of the teacher's gestures and verbal expressions on the child's learning of spatial concepts.

In sum, our study suggests that the child was inclined to mimic or extend the teacher's gestures which represented mathematical meanings that were not parts of the child's initial description and the child was probably not aware of. Watching and mimicking or extending the teacher's gesture and speech acts helped the child enter into a process of objectification for these concepts. Although we are not sure whether the child consciously mimicked or extended the teacher's gesture, the above findings indicate that the child's (lack of or incomplete) prior geometrical knowledge may have a role in the extent to which the teacher's gestures influence the child's gestures during their interaction in geometrical activity. Children's prior knowledge and fluency with a specific mathematical subject are factors that future research may explore to better understand the conditions under which gesture mimicry and extension occur in mathematics teaching and learning and their contribution in the development of understanding.

Final remarks

This study may provide some useful methodological hints for future research on the phenomenon of gesture and the development of spatial concepts and concepts of shape. The application of the microgenetic analysis on the data collected in the present study helped us describe and explain the processes one child goes through in the understanding of different space and shape aspects while solving a geometrical problem, with a focus on her gesture and speech acts, as well as how the teacher's actions exerted their effects on these processes. This can be a first step not only towards elaborating formal models which reflect cognitive development in the geometrical domain and are built on the analysis of children's gestural representations and verbal communication but also towards formulating predictions about the characteristics of teaching which can be beneficial for learning in early geometry from a gestural and verbal perspective. Of course, future studies with more children, longer observations, and a variety of geometrical problem-solving tasks need to be conducted before deriving any didactical or classroom implementations regarding the dynamics of the relationship between gestures and discourse in the teaching and learning processes in early geometry.

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