Title   Development of (scientific) concepts in children’s learning geometry: A Vygotskian, body-centered approach to literacy
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Abstract

The “construction of meaning” tends to be the main pedagogical goal for the teaching of science. Yet, the metaphor of construction, which is also used to theorize the development of word-meaning, articulates only some among the different possible forms of knowing. The purpose of this study is to show a more comprehensive approach to concepts development than exists in Vygotsky’s framework of word-meaning and its logo (word) centric approach. That is, this study takes Vygotsky’s theory of word-meaning and develops it to include bodily forms of knowing and learning to constitute a more holistic approach to scientific literacy and its acquisition. We draw on a model that we had proposed as a new way of understanding the nature of concepts and show how our extended Vygotskian approach allows us to explain children’s concepts development. We present a concrete case study that exhibits the trajectory of conceptual understanding and exemplify the central role of the body in making connections between different forms of experiences, thereby leading to the (initial) formation of the concept. We conclude that the extended framework of word-meaning allows rendering pedagogical principles that encompasses students’ everyday experience of the world as the condition for concepts development.

Introduction

The “construction of meaning” tends to be the main pedagogical goal for the teaching of science and mathematics. Yet, the metaphor of construction, which is also used to theorize the concepts development, describes learning from a perspective of that which is not known to students at the beginning and therefore gives little attention to the real conditions in which conceptions are made possible in the first place. That is, because students do not know a concept, they cannot at the same time aim at (intend) learning it; if they knew the concept, necessary for being able to make it the object of an intention, then they would no longer need to learn. Thus, if learning is an intentional process, it has to be framed in such a way that it is entirely suited in and contextualized by students’ everyday experiences and language. For students, everyday experiences and concepts—which some science educators call misconceptions, alternative ideas, or naïve ideas, and thereby highlight their differences from the scientists’ ways of talking—therefore constitute the very conditions that students depend on when they listen to the other talking and learn about the world. For students, the conceptual growth involved in learning concepts pertains to the transformation of these mundane experiences and everyday (spontaneous) concepts as the materials to be transformed. These materials are given in the everydayness rather than the act of the conscious mind that somehow has to construct an object that it does not know. The purpose of this paper is to exemplify a comprehensive approach to concepts development (formation) that does not begin from the dichotomy between spontaneous concepts and scientific concepts. We take a holistic approach to the meaning development in which everyday experiences constitute the irreducible conditions for conceptions.
Theoretical Framework

Communication is central to the development of meaning in learning science and mathematics. In classrooms, listening to the other talking and interpreting representations allow students to participate in the classroom communication and come to know concepts new to them. For Vygotsky (1986), the development of word-meaning in communication (i.e., verbal thinking) constitutes a central phenomenon that explains the child’s development of scientific concepts and the role of instruction. The significance of communication as linked to the concepts development is that it allows us to attend to all the extra-linguistic capacities that are part of any practice. There is an agreement among language philosophers with a phenomenological bend that linguistic structures and everything else that makes life are woven into an irreducible tissue such as knowing a language is equivalent to knowing one’s way around the world. That is, conceptions mean competency in social actions that presuppose communication and communication necessarily is grounded in knowing the world. Anything linguistic in language use therefore bottoms out in forms of experiences that are pre- and extra-linguistic. In this study, we take a theoretical framework that reviews concepts development through a perspective of a social world that “starts from the actor’s subjective point of view” (Schutz, 1996, p. 9). We suggest that learning science and mathematics is like learning a language that is part of a larger unit encompassing the fullness of life—all the resources that constitute the experience of the living present are also related to concepts development. Learning to speak a new language is considered a good metaphor for the understanding of science and mathematics concepts.

The Body in Concepts development

Conceptions in this study are related to the (temporal) development of meaning (associated with conceptual understanding) rather than meaning that is assumed to reside
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(atemporally) in specific forms of representation (e.g., words, mathematical representations, and other forms of scientific representations). Our approach to the development of meaning follows Vygotsky’s dialectic theory and its extension to a body-centered comprehensive framework.

First, we take a Vygotskian theory of thought and language that is part of a larger unit encompassing the fullness of life (Vygotsky, 1986). For Vygotsky, word-meaning (concepts) arises from the process that integrates thought and speech (gesture) dialectically—“continual movement back and forth from thought to word and from word to thought” (p. 218). Second, we follow other studies that have extended Vygotsky’s word-meaning dialectic toward the point that thought is dynamically related to the whole unit of communication rather than to words alone. For example, in communication, words take forms of sounds (e.g., prosody) and constitute one part of the whole network that marks sense (i.e., living meaning) together with other (embodied and bodily) forms of experiences mobilized simultaneously (e.g., gestures [McNeill, 2002]).

The extension following the Vygotsky-McNeill approach involves two significant contributions that lead to a more comprehensive approach to concepts development than exists in Vygotsky’s framework (i.e. word-meaning). First, conceptions—the concrete ways in which concepts are realized in and by individuals—are distributed across many different forms of experiences, language, gesture, body, etc (the whole, including emotions) (e.g., Roth & Thom, 2009a). That is, rather than consisting of words only, we understand conceptions to be grounded in the experience of dwelling in a world so that our entire body becomes a source of expression (Merleau-Ponty, 1962). This more holistic theory of conceptions considers different, irreducible modes of communication as a whole. Second, in this framework of communication, conceptions then may express themselves concretely as part of an embodied life that is irreducibly interconnected with language; therefore, everyday
(embodied and bodily) experiences constitute the condition for concepts development (e.g., Roth & Thom, 2009b). This focuses our attention on the processes by means of which everyday non-scientific conceptions come to be transformed into scientific conceptions. Rather than being eliminated and eradicated, the everyday conceptions are the ground, material, and even tools in a transformative process that leads to scientific conceptions.

In the way stated, the theory of meaning includes the dynamic role of the body, which allows, for example, emotion to become an inner part of thinking in the way Vygotsky asked for. The following four points summarize the dynamic of meaning development in communication from an extended Vygotskian, body-centered perspective. First, the body constitutes the mediating hub in experiencing the world (objects). Second, the body constitutes the mediating hub in communication; the body is the expression rather than merely a tool for expressing what is in the mind. Third, the real-time articulation of thinking with and for the other is distributed within the unit produced by the bodily action in itself and with respect to them (e.g., speech, gestures, eye gaze, body orientation and movement, etc). Fourth, eye gaze, gestures, body orientation and movement, which are involved in experiencing the world (objects), are also involved in communication. The four principles explain the integral role of the body in the translation of the whole unit of meaning in which the body mediates the unity of different forms of experience: “The unity and identity of the tactile phenomenon do not come about through any synthesis of recognition in the concept, they are founded upon the unity and identity of the body as a synergic totality” (Merleau-Ponty, 1962, p. 369). The role of the body guides the analysis of meaning development without having to mystify it or begin from the dichotomy between spontaneous and scientific concepts.
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A Holistic Analysis of Concept Development

The proposed comprehensive model considers the development (translation) of concepts (meaning) at three levels: the cultural-historical level (e.g., geometry as a field of study), the ontogenetic level (e.g., the child development), and situation (i.e., concrete events in a mathematics lesson). The trajectory of the child’s concepts development involves the three levels dialectically related in the following pair-wise manners. First, concepts development involves an individual’s participation in the reproduction of meaning that has been established and develops at the cultural-historical level. For example, children in the mathematics classroom listen to a teacher explaining geometrical shapes of three-dimensional objects using different sound-words (e.g., cube, sphere, cylinder, prisms, and pyramids). For children, those sound-words may be terms that are not used in their everyday talk and therefore foreign sounds that they are confronted with in the mathematics class. However, words used in geometry have a long history traced back to the ancient Greek in which people at that time used terms that emerged and grew out of their everyday life and experience and have been transformed over a long history, of which the trajectories are left in etymology. Here, the cultural-historical development is tied to the ontogenesis of individuals who became the names associated with particular concept developments (e.g., Euclid, Pythagoras, and Thales with the development of geometrical concepts). Therefore, the analysis of concepts at the cultural-historical level implies that conceptions and (mathematical) literacy require the mobilization of a network in which sound-words make links to other forms of experience (including everyday experience).

Second, concept development involves the development of meaning at the ontogenetic level as an individual actively engages in dealing with the salient aspects of the world (objects). The here-and-now of the situation constitutes the setting in which embodied and bodily forms of experience are mobilized and make links in appropriate ways. Children
learn geometrical concepts by participating in concrete situations in which they have to point out specific objects or speak this or that, which we thoroughly show in the next section. That is, the ontogenesis of scientific concepts is tied to the microgenesis of children’s talk. Therefore, the consideration of the meaning development at the three levels and their intertwined relations integrate embodied and bodily forms of knowing into the unit of meaning and analyzing the child’s concepts development from a holistic perspective.

Case Study

Concepts development happens over time. The child in a geometry classroom participates in talking about three-dimensional objects and temporally develops their understanding of concepts. The act of speaking or listening to others’ talk unfolds through time. But we do not only experience our bodies in absolute spatial, measurable time; rather, we also experience “events in inner time (durée) . . . as manifestations of our spontaneity” (Schutz, 1996, p. 29). That is, time is generated as the conceptual possibilities that classroom objects make available are realized into different forms of experience. Certain ways of being-in-the-world emerge as the body temporally engages in objects and therefore spatially realizes different forms of experiencing the world. From a holistic perspective, those (temporally-emergent) different forms of experience are all potential forms of knowing the world that have significant roles in the child’s concepts development. They involve the potential to affect the real-time translation of the whole meaning unit and therefore are simultaneously unique and partial representations of a higher communicative unit. For example, speech and gestures are two irreducible components both of which dynamically incorporate the context of communication in an integral way and therefore affect the development of the contents of communication; either of them constitutes a potential outlet from which a new way of knowing the world (as a result of the translation of the previous)
emerges and begins to grow. Therefore, the child’s concept development pertains to the
dynamic coordination of different forms of experience in which one form is in the metonymic
relation to the whole.

The body is central to this spatiotemporal coordination because the body mobilizes
different forms and more so makes links between them. The unity that the body makes
available allows the constitution of a meaning unit from which a higher-order cognitive
function arises. In this section, we conduct a case analysis and exemplify the role of body in
the spatiotemporal translation of a meaning unit. We show how a child bodily engages in
knowing the world, and thereby develops an understanding of three-dimensional geometry
concepts. In the following geometry lesson, second-grade children participate in identifying a
mystery object placed on the OHP panel, which is surrounded by standing papers and
therefore invisible. The teacher provides a two-dimensional shadow projected on a screen
(i.e., circle) and different three-dimensional objects on a shelf below a whiteboard. Therefore,
students are given opportunities to talk about the geometrical shapes of three-dimensional
objects and their relation to a two-dimensional. We exemplify a comprehensive approach to
concepts development by substantiating the three-level analysis of meaning development.

**Episode 1**

01 Teacher Clara

02 Clara um

03 [([Clara puts her hand down and stands up)])

04 [(1.8)]

05 [(Clara walks to the front)]

04 [I don’t think it can be a circle]

05 [(Clara grabs a yellow sphere on the shelf and turns toward the teacher and other students. She holds the sphere with her fingertips propping around the round surface/edge*)] (Figure 1a)
06 Teacher1 [(???) circle?] [circles are flat] 

(((Teacher points at Clara)) [((Teacher holds the palms of her hands facing one another and moves them closer *))]) (Figure 1b)

07 ((Clara gazes at the yellow sphere that she holds*)) (Figure 1c)

08 Student1 sphere

09 [(1.6)] 

((((Clara put her palms to the surface of the sphere and holds the sphere using her whole hands instead of fingertips)))

10 Student2 sphere

11 Clara sphere ↓ ((Clara rubs her right palm on the right area of the sphere*)) (Figure 1d)

12 Teacher1 sphere ↑* yes, that’s right and why don’t (you?) think it could be the sphere (Figure 1e)
Figure 1

**Description**

Clara raises her hand and the teacher calls her name (line 01). Clara says “um” and walks to the front side of the classroom (line 02). She picks up a yellow sphere, one of the objects placed on the shelf underneath the whiteboard (line 04). She grabs it by using her fingertips and turns to face the teacher and other students (line 04). She holds the yellow sphere as high as her chest and gazes at it. Simultaneously she articulates that she does not think “it can be a circle” (line 04). A pause comes about (line 05). The teacher points her right hand at Clara and articulates that circles are flat (line 06). Simultaneously, the teacher puts the two palms of her hands together, which constitutes a gesture of narrowing (line 06). Clara gazes at the yellow sphere in her hands (line 07). One of the students sitting in the classroom utters “sphere” (line 08). Clara puts the palm of her right hand attached to the surface of the sphere and grabs it by using the whole hand instead of fingertips (line 09). Another student utters “sphere” (line 10). Clara repeats the word “sphere” and rubs the right surface of the sphere using the palm of her right (line 11). The teacher repeats the word (“sphere? yes, that’s right”) and utters “why don’t you think it could be the sphere” (line 12).

**Analysis**

In this episode, we see a child participating in talking about the mystery object projected by an OHP and verbally thinking by talking to a teacher and other students in a
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second-grade geometry class. (The episode exemplifies a beginning (formation) of mathematical thinking realized in communication.) Clara proceeds with picking up a sphere and shows it to others. She holds a round surface/edge of the sphere using her fingertips and articulates that she does not think “it can be a circle” (line 04). After a one-point-four second pause, the teacher points at Clara and articulates that circles are flat. The teacher’s action provides concrete form of knowing “circle.” The utterance “flat” and her gestures of narrowing the space between her facing palms connects the word “circle” to flatness, which contrasts to the spatial shape of the sphere that Clara holds. Clara’s utterance juxtaposes two words, “it” and “circle,” neither of which directly refers to the object that she holds up (i.e., a sphere). Therefore, the teacher’s action makes Clara’s simultaneous coordination of the utterance and the act of picking up the object problematic: It is not clear why she picks up a sphere among others and what she means by “it” or “circle.” Clara gazes at the object at her hands. By actively participating in talking about the mystery object, Clara encounters something that does not simply receives her senses but “which provokes sense without being meaningful itself, but still something by which we are touched, affected, stimulated, surprised (Waldenfels, 2004, p. 238).

Immediately one of her classmates utters “sphere,” and thereby makes a sound-word available in the classroom. The articulation of the sound-word “sphere” opens an opportunity for the emergence of a different form of experiencing the object. Clara puts her palms attached to the surface of the sphere, and thereby changes her way of holding the object from using her fingertips to using the whole hands, which allows her to touch the round surface of the sphere rather than the circular edge of the surface. This new form of experience is linked to Clara’s speech when Clara repeats the sound-word “sphere” following another student’s uttering “sphere” in the next. Clara’s speech translates the experience of the object into the sound-word, “sphere,” which also affects the experience of the object into her rubbing
movement over the surface of the sphere using the palm of her right hand. Clara’s body mediates the translation between the experience of the object and the word and therefore constitutes the hub of translation. Clara’s change of her way of bodily holding (experiencing) the object constitutes a point at which she explicitly changes the contents of her speech but also lets a new meaning unit emerge. It constitutes an outlet through which everyday forms of knowing the world (e.g., round surface of a sphere) is mobilized in such a way to link to the sound-word and other forms of experience (e.g., teacher’s gesture) and therefore expands a network. Conceptions from this holistic perspective exist “only in, through, and as of the experiences” (Roth & Thom, 2008a). Any single experience serves as an entry point, because it is not only integral part of the conception but also stands for it. The relation of any experience to the whole therefore is of metonymic nature.

The episode exemplifies the beginning of mathematical thinking to which the child’s basic experiences in their everyday life are integral. For Clara or anyone in this second grade mathematics classroom, the round surface of a sphere may not be an experience unique to mathematics (geometry) but common to their everyday lives; for examples, when children play with a ball, they have chances to touch the round surface of a ball. Thus, etymology shows that the Greeks words pertaining to “circle” (kúklos) and “sphere” (sfáira) originate from the sound-words referring to “ring” (kúklos) and “ball” (sfáira) individually. That is, for Greek people, speaking the word sfáira immediately mobilized their everyday experiences of using a ball and therefore constituted a metonymic relation to a network of their bodily and embodied experiences related to this toy. Yet, children today have no clue as to the words “circle” or “sphere.” These foreign words are associated with geometry classes but not with the general experience outside of school. In a way, these words are dead metaphors where they have been very much alive for the ancient Greek, for whom they denoted everyday experiences. Today, English-speaking children have to learn to make explicit links between
these foreign sound-words to their everyday experience (e.g., playing with a ball) in the mathematical classroom.

In this way, the episode exemplifies the beginning of concepts development in which Clara learn to differentiate “circle” and “sphere” by actively participating in making a network of everyday experiences. Yet, again, this cannot the result of her intention to differentiate them. For example, Clara simply says “circle” because it makes sense to her—she raised her hand and volunteered to speak. Speaking the word “circle” brings her to a situation in which she encounters different forms of knowing “circle” and the object (i.e., sphere) that she holds in her hands (e.g., “flat,” narrowing gestures, and “sphere”). In this situation, Clara does not know what or whether she needs to differentiate. She just engages in touching the object that she has already held in her hands (i.e., the palm curved along the round surface of the sphere) and speaks the word (“sphere”) that her classmate has spoken. These simple actions align the configuration of interpretive resources that constitute the meaning unit metonymically related to her action of picking up the sphere. Thus, the teacher utters, “why don’t you think it could be the sphere,” which thereby translates Clara’s initial claim (i.e. “don’t think it can be a circle” [line 04]) into another (i.e. “don’t think it could be the sphere [line 12]). The episode exemplifies the central role of the body in the child’s conceptual development: it consists in bridging interpretive resources and the everyday experience of the world metonymically in two ways. First, the body mobilizes different forms of experiencing and increases interpretive resources for knowing the world. Second, the body coordinates different forms of experience and increases conceptual possibilities (e.g., the emergence of higher-order cognitive functions).
Discussion and Implication

The purpose of this study is to exemplify a comprehensive approach to concepts development (formation) that does not presuppose self-identical meaning separated from the everyday conditions that make communicating concepts possible in the first place. We take Vygotsky’s theory of word-meaning and develop it to a holistic approach to the meaning development in which bodily forms of knowing and learning constitute the irreducible conditions for conceptions. This study exemplifies that the child’s body temporally engages in objects located in local spaces and makes links between different forms of experiences. The body is central to learning geometry because of the capacity to realize everyday forms knowing the world in a specific setting and translate them to a spatiotemporally coordinated form. Our study suggests that conceptions involve the development of one’s way of knowing the world, which co-evolves with the development of literacy and therefore provides implications for a more holistic approach to scientific literacy and its acquisition.

Literacy is a core aspect of science and mathematics education. Literacy is generally discussed in terms of language, and our study informs precisely where the very possibility of literacy comes from: the body bridges and translates between interpretive resources and the experience of the world and contributes to the development of higher-cognitive functions. The child in our example participates in a cultural activity (i.e., geometry curriculum enacted in the elementary mathematics classroom) and simply works with objects (including words) given to her. The alignment of action emerges as she encounters the words and other forms of objects rather than through the intentional act toward an outcome that should have been known to her already and therefore does not make sense otherwise. The totality of interpretative resources that the body produces in its mundane engagement in the social world provides the body with its characteristic mundane rationality and reality.
Pedagogically, the body-centered approach to literacy provides a different way of theorizing learning science: students’ conceptual development is part of their mundane efforts to transform the conditions of the bodily performance, and thereby increasing room to maneuver in their lifeworlds. Therefore, this study answers questions about learning science without passing through psychological models that prescribe some mental construction about which we have no access. For example, what are the central aspects of linguistic practice in knowing and learning science? What makes knowing and learning possible in the scientific understanding of phenomena? The implication from this study is that the relationship between students and the phenomenal world they are supposed to learn about is made in such a way that we cannot understand the actions, knowing, learning, and identity of the subject independent of the body. Meaning develops in such a way in which different forms of experience are marked and remarked in and through the bodily forms of experience—a new way of knowing the world appears from the totality as the body copes up with the given material conditions and increases possibilities for knowing the phenomenon at hand.

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References


