Chapter 14

Looking at the Observer Challenges to the Study of Conceptions and Conceptual Change

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In a typical study of students' conceptions and conceptual change, researchers analyze what a student does or says in a classroom or in an interview and recognizes ideas that match or do not match their own understanding of the topic. Attributing the perspective they recognize in the student, those studies support the idea that a conception is the way by means of which an individual intrinsically conceives (of) a given phenomenon. They then hypothesize the existence of some mental structures that can be theoretically and objectively re-constructed based on what is observed in a student's performance. Thus, researchers studying conceptions commonly assume that the observer and the observed are separate entities. However, even in the most theoretical and hardest of all sciences, physics, the independence of the measured object and the measuring subject is not taken for granted: Light, for example, will present itself as waves or as particles depending on how we examine it. The artificial sense of separation from the object(s) of study found in many accounts on students' conceptions makes irrelevant the relationship that exists between the observer and the observed: an interdependence and co-emergence of the observer and the observed. This tight relation exists because each participant not only reacts upon what others say but also acts upon the reactions that his/her own actions give rise to. With this situation come epistemological, practical, and ethical implications for those researching in mathematics and science education. Positing or questioning the existence of an objective reality mediates how we accept or reject another human being and the worldviews s/he develops. It provides a rationale that guides our actions. This is especially important when it comes to teaching and learning at a time where the ability to deal with the plurality and diversity of human culture have emerged as significant referents for our social behavior.

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The most central challenge we face today is the question of reality (Maturana 1988). With respect to the relation of the observer and the observed, the author suggests that there are two postures to reality and objectivity. One assumes that what an observer's actions and knowledge does not affect the object of observation. The other posture recognizes that the observer is constitutive of the observed phenomenon, particularly in his or her ability to distinguish different aspect of a situation. Thus, this framework helps us understand how psychological and socio-cultural perspectives distinctly define the observer. That difference in nature can be captured the following way. Whereas the former attributes conceptions to the students, the latter situates conceptions in the observer who identifies them. The significant epistemological divergence entailed by these two postures has practical implications. Rejecting the observer-observed contingency necessarily leads to the confrontation between exclusive interpretations, for their validity is founded on the posited objective reality. If we pretend to know how things really are, then other interpretations are objectively wrong. This affects not only the work of researchers, but also promotes a certain attitude toward others, the students. In that perspective, we forget that students, too, are observers, thereby examining performances solely in the light of a given (objective) concept and judging them on the base of their compatibility with that single idea. In contrast, the ethical responsibility we have for the others is to fully recognize, and encourage, the legitimacy of various possible understandings brought forth. Understanding how an explanation contributes to different conversations opens the discussion of how desirable these are. Dissimilarities then become invitations "to a responsible reflection of coexistence, and not an irresponsible negation of the other" (p. 32).

In this chapter, we articulate a perspective on the observer and the implications that result from taking a psychological or a sociocultural approach to education research. Drawing on an excerpt from a mathematics lesson in which three second-grade students learn geometry, we argue in favor of a sociocultural approach to conceptions in a two-folded argumentation. First, we enter the epistemological domain to articulate the differences in how sociocultural and psychological approaches define the relation of the observer (student or researcher) and the observed. Second, we illustrate implications by showing how conceptions are not the mere figments from the students' minds but that students' performances can be better understood as discursive co-productions. We conclude by elucidating how the observer-observed interdependence foregrounds ethics as an important dimension of research in mathematics and science education.

The Observer and the Observed

In this first section, we articulate how sociocultural and psychological approaches differently define the relations of the observer (student, researcher) and the observed. We introduce the relationship of the observer and the observed and then examine what it specifically tells us about each approach. For each, we discuss

(a) the observer-observed relationship, and then (b) what entails the reading of students' performances. The subsequent case analysis follows a similar organization.

In the mid 1960, Humberto Maturana became conscious that as a biologist he had no means to make any claim about objects, entities or relations as if they existed independently of what the researcher was doing. That led him to realize that the most central question in any scientific debate about the existence and nature of a given phenomenon implies the nature of the observer. To explain a phenomenon demands delineating the position of the observer in relation to it. When we explain a phenomenon, such as a student's utterances during a conceptual change interview, we propose a reformulation of the particular situation that we are attending to and simultaneously define the extent in which that reformulation is taken as valid. Fundamentally, we can conceptualize how the object of observation is considered in two different ways: as independent or as contingent of the observer. Indeed, the fundamental operation of an observer is one of making distinctions and creating descriptions. These descriptions partially take up the infinite complexity of a situation and organize themselves to provide a re-formulation, an account of what is taking place. As researchers we tend to focus on certain aspects of a phenomenon to answer particular questions. We select data and examine them with a specific theoretical lens. We know that a significant aspect in any researcher's work lies in its personal involvement with its research object.

The Observer from a Psychological Perspective

Many researchers working on students' conceptions position themselves as if reality (a conceptions) exists independently of the observer and the act of observation. This trend is particularly present among researchers who assume psychological or cognitive perspectives. Take this example:

> [W]hen we, as radical constructivists, focus on analyzing children's schemes, we work as first-order observers. Although a first-order observer makes a concerted attempt to assume the position of the child and think as the child does, the observer's ways and means of operating are left implicit, and the observer does not intentionally analyze the mental structures of the child relative to his or her own mental structures. However, the first-order observer does interpret the interactions of the child and by this means tests the interpretations for their viability. … When we focus on analyzing the mathematical learning of a child … in both actual interaction and retrospectively, we focus specifically on explaining the child's learning relative to our own purposes, intentions, and contributions to mathematical interaction. (Steffe and Thompson 2000, p. 202)

When researchers position themselves as if conceptions existed objectively, they develop a perspective in which these conceptions are independent of the operations by means of which they are identified. In this trend, researchers examine students' understandings by analyzing what they do in the classroom or what they say during an interview and theoretically deconstruct and reconstruct students' thinking. It thus makes sense to discuss why students think that way

and how they could be prompted to do otherwise. Students hold conceptions and undergo conceptual changes that the researcher-observer pretends to simply report. Such an approach makes irrelevant the ways and means of operation of the observer, and ignores the relationship of her or his own understanding relative to the children's. The preceding quote is clear about this: When analyzing children's schemes, researchers leave implicit their own operations and do not consider the children mental structures relative to their own.

This corresponds to what can be called the path of transcendental objectivity. Blind to his or her participation in the observation, the observer here "implicitly or explicitly assumes that existence takes place independently of what he or she does" (Maturana 1988, p. 28). The observer accepts his/her cognitive abilities without questioning how they work and influence what is observed. Accordingly, entities like mental structures or interactions can exist independently of what the observer does. In this perspective, even though one might acknowledge that the observer's perception or reason is limited and sometimes fails, what is striven for is an objective account for the observed event. For that reason, researcher-observers naturally find in the common agreement of each other's interpretations a support for the belief that they rightfully account for an event. (See chapter 13 for the justification of observations and their attributions to a particular aspect of identity.) In this, two important facts are put aside: (a) that any observation is secondary to the observer's experience of the world, and (b) that agreement among observers cannot determine the validity of a claim that none of them can make individually.

These are fundamental epistemological implications and they are partially recognized by some researchers in the psychological tradition. Some research complements the search for cognitive structures with an attempt to take into account their own research endeavor by "explaining the child's learning relative to our own purposes, intentions, and contributions to mathematical interaction" (Steffe and Thompson 2000, p. 202). However, there is a fundamental contradiction that comes with this. If the account of students' learning depends on the researcher's purposes and intentions, then the conceptual changes to be observed in the students depend on those motives as well. Thereby, how schemes undergo cognitive re-structuring is based on theoretical entities defined by the researcher and not something intrinsically characteristic of the students. Researchers cannot divorce themselves from their objects of observation when analyzing children's schemes. The consequence is this: Not only (a) can students' conceptions and conceptual changes not simply be reported and (b) observations cannot merely indicate what the students are thinking and why, but also (c) it also makes little sense to deduce from these conceptualizations any form of prescription to lead students to perform differently.

Intertwined in the separation of the observer and the observed is the posited existence of an objective reality. Looking for universal features of development in the child, a typical study in the psychological perspective presents a researcher's analysis of students' performances and theoretically attributes his/her interpretation as being that of the students. The researcher then discusses why students "hold" or "acquire" those conceptions and suggests how they could be "changed" or "replaced."

Belonging to the students, conceptions are then seen as the way in which an individual intrinsically conceives a given phenomenon. Those conceptions are thought as the rendering of mental or cognitive structure made implicitly or explicitly available to others by students' talk or actions. A conception is something that the individual possesses, a "cluster of internal representations and associations evoked by [a] concept—the concept's counterpart in the internal, subjective 'universe of human knowing'" (Sfard 1991, p. 3). In this view, common to much constructivist research, conceptions are imprinted in the mind (some will even say: in the brain) and later are simply acted out when called upon. Thereby, what is (objectively) presented to the students is cognitively re-presented by them and, in their performances, re-presented again for the researcher to examine. Through some sort of reverse engineering, the researcher searches for schemes or mental structures that s/he validates in the observation of an objective reality. An example of this can be found in the first part of the quoted text: Researchers turn to an objective reality that bears the possibility to "tests the interpretations for their viability" through perception or reason. We recognize again the path of transcendental objectivity. Researchers here ultimately validate their explanation by referring to entities like mental structures and interactions that constitute the real: a transcendental referent to which the observer reduces the observed. Such approaches therefore require a single reality (a conception) that explains what was observed by the observer.

This is problematic because cognitive scientists now widely reject the existence of cognitive structures in which representations of the world can be embedded. An additional difficulty with this perspective concerns the constitutive part of the socio-material environment for what is observed in students' actions. Nowadays, researchers generally recognize the situated nature of what students bring forth. It is agreed that we need to consider that what students say or do is closely related to the specific context of the performance. Problems and phenomena are not addressed in the same way when encountered in mathematics or science classroom versus everyday life. Because they have dissimilar goals, means and rules, and because they are in different relations with different people, students do not always do things the same way. The perspective we develop here therefore invites us to consider this by examining coordination of behaviors to understand how "each individual is continually adjusting its position in the network of interactions" (Maturana and Varela 1998, p. 192) that forms the collectives and situations. Being themselves observers, students coordinate with their societal-material world and with others, contributing differently into diverse activities, with and for distinctive "communities of observers."

Most researchers who study students' conceptions are aware of this problem and have tried to answer it by acknowledging the constitutive role of the context in the realization of what they observe. However, this poses an epistemological contradiction. If the context is recognized as shaping individual cognitive structure(s), then it is impossible to assume that what an individual does is based solely on the conception(s) in his/her mind. When what students say or do cannot be isolated from the context in which it exists and is observed, then it cannot be assigned to a

conception that an individual is said to have; it is not a characteristic (internally) belonging to individual students, but also is marked through and through by the context, a fact captured in the notion of ipse-identity that van Eijck presents in chapter 13. A legitimate alternative then is a perspective that focuses on the ways in which students' cognitive and contextual structures play out in the realization of activity. However, such a perspective challenges the notion that individuals construct and reconstruct fixed schema in the mind.

The Observer from a Sociocultural Perspective

Researchers in a sociocultural perspective do not normally talk about conceptions and conceptual change, because their work does not focus on the individuals but on the situations these find themselves in, and on the meaning they create with and for each other. In this section, we briefly outline (a) how the constitutive role of the observer and what is observed is taken into account in sociocultural perspectives and (b) give some insight concerning how students' performances are made with and for the other(s).

"Everything said is said by an observer to another observer that could be him – or herself" (Maturana 1988, p. 27) and the observer and the observed arise together, emerging from one another in the act of observing. A sociocultural approach to science and mathematics education research defines the observer in a very similar way. To begin with, this approach clearly asks researchers to consider how the object of observation is constituted. Instead of striving to objectively assess what a student knows or can do, or to identify transcendental features to the human psyche (on the basis of talk or actions), the observer studies the way cultural traditions and social practices appear to be at play. The observer not only recognizes his/her purposes and intentions, but also delineates a unit of analysis that incorporates "goals, needs, affect, and cognition while locating the individual in the cultural life that precedes all of us" (Lerman 2000, p. 211).

This corresponds to a path of constituted objectivity. In that path, the observer accepts that s/he is constitutive of the phenomenon s/he observes, recognizing that the observer's observation depends on his/her cognitive abilities. We may use as example our inability to distinguish between perceptions and illusions to reject the independence of the observer and the observed. Existence "is constituted with what the observer does, and the observer brings forth the objects that he or she distinguishes with his or her operations of distinction as distinctions of distinctions" (Maturana 1988, p. 30).

In sociocultural approaches, the mutually constitutive role of the observer and the observed is recognized both in the researcher's and in the student's activity. On the one hand, researchers turn their attention to the elements from which what was called a conception can be identified and they try to understand how this happens. In an interview, there is a collective activity from which any data spring forth as a result of the interaction between two types of participants (Roth et al. 2008).

From a researcher-observer perspective, this should mediate our understanding of what was achieved. In other words, conceptions from this perspective are not something that belongs to the children, but to the situation that produces the talk from which conceptions are abstracted by means of multiple reductions.

On the other hand, a sociocultural approach stresses the constitution of consciousness through discourse, which includes all forms of communication such as speech, gestures, written text, and so on. This helps us see how the student's activity is also conceptualized as the work of an observer contingent on its object of observation. In this view, students do not present conceptions stored in some cognitive structure, but participate in mathematical or scientific discourses by which they learn to distinguish different aspects of a situation. In other words, they become scientific or mathematical observers by creating mathematical or scientific objects of observations or by attending to what they observe in those particular ways. Communication includes more than the words a person speaks and encompasses all perceptuomotor activities exhibited to the researcher. Distinctions and distinctions of distinctions are operations in language in which the observer and the observed co-emerge. In the process of making distinctions, the observer is affected by what he or she observes, but simultaneously responds by selecting what is relevant and sensorially accessible to him or her, and therefore affect what is observed. Being an observer implies both agency and passivity because we are both observers and observed:

> I am not a neutral factor. Together with others, we researchers both constitute the situation and are constituted by it. … I have no transcendental position, but neither is my theorizing, as a mathematics education researcher or as a teacher, on a separate level from my work on mathematic. Sociocultural theory does not need the separation of levels of analysis required by Steffe and Thompson's model. (Lerman 2000, p. 224)

These reflections stress the need to avoid attributing conceptions to individuals. Examining how we make sense of things and situations, a sociocultural approach situates knowledge in the social. Researchers from that perspective thus characterized knowing as participation in an activity, and especially turn their attention to examine how meaning is discursively constructed in communicating with others. Sociocultural researchers do not negate the potential existence of some mental plane in which conceptual development might take place for the individual. But recognizing the inescapable dependence of the observer's position and what is observed, sociocultural researchers deliberately orient their undertaking to the conditions in which that mental plane is formed.

This perspective is consistent with the type of observations we make as educational researchers: Whereas it is not possible for us to see inside a student's mind, we can observe what is made available to us by that student's verbal or physical actions. Here, the explanatory domain, in which the observer observes the student, is based on what discourse and actions make available, not on the student herself. The essence of communication is the coordination between an individual and his/her social and material environment. What counts here is not only the content and the form of people's talk and actions, but also, and more importantly, what they contribute with respect to the coordination of actions they

bring about. In that sense, a researcher-observer is interested in understanding what a student's contribution in/to an activity reveals about the conditions in which s/he coordinates him/herself with the societal-material setting. A contribution can take different forms: speech, gesture, action, or any combinations of these. Attributed to the individual, a contribution makes sense in the relation it establishes to an ongoing activity, together responding to a particular situation and affecting its unfolding. These contributions are not the result of an individual conception, but are created with others and for them as much as for oneself. We recognize in this a path of constituted objectivity in which everything is said by one observer/observed to another observer/observed.

A Case in Point

The contrasts between sociocultural theories and psychological perspectives have been well debated over the years, particularly in mathematics education. Our own work led us to articulate the problematic in terms of how the observer is considered. Here we illustrate this position by (a) showing how the observer and the observed co-emerge from the student and the researcher's perspective and (b) illustrating how we can examine their talk and actions as discursive contributions. The following excerpt, in which three students talk about a cone, serves to exemplify this. The episode was videotaped during a lesson in which the students examined whether various solids could stack, slide, or roll.

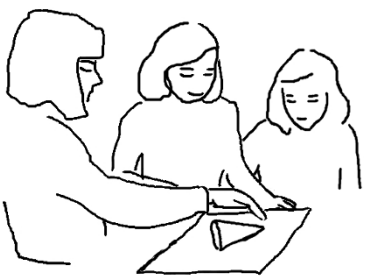

Figure 14.1. Sonia, Jade and Maeve experiencing with the cone.

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01 Je: You can go ahead and record your predictions, okay.
02 Ma: My prediction [is].
03 So: [Slide]
04 Ma: do you remember that if you put it side ways and then it
       will roll like that? ((Maeve place her pen on its side,
       pushes it and finally rotates it on the table, see Fig.
       9.2))
05 Ja: It will slide.
06 Ma: So it rolls actually.
07 Ja: But if you put it on its side it will roll, but if you
       put it up straight it kind of slides.
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08 So: Roll means-
09 Ma: But, but if-
10 So: Ah Maeve, roll means when it goes back, back. ((Sonia
       rotates her hands backward one around the other))
11 Ja: Or keeps on going like in circle. ((Jade rotates her
       hands one around the other like Sonia is doing, but moving
       forward))
12 So: Yea like this. ((Sonia transforms her backward rotation
       in a forward one similar to Jade's))
13 Ma: So which one do we write?
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How the Observer and the Observed Co-emerge

To clarify how the observer, the operation of observing, and the observed simultaneously arise, we examine Sonia, Jade, and Maeve's perspective on whether a cone can roll or not. Asked to make a prediction before they first try whether a cone will stack, slide, or roll, Jade first suggests that the cone will slide, and then nuances her perspective: Placed up straight or on its side, it will either slide or roll. Contrastively, Sonia then insists that a cone could not roll because its movement is not linear, which Jade quickly supports. The three girls discuss some more and Maeve finally concludes, "Oh yeah, because it goes in circles, it's not going down."

As observers, the students make distinctions in what affect them. From those distinctions, they develop an explanation for what they frame as the phenomenon to be examined. This comes from focusing attention on only some of the infinite number of aspects of an event to define what counts as a phenomenon. For instance, the girls here delineate that deciding whether a cone rolls or not has to do with its orientation, the movement and the trajectory of the cone, not its color, the temperature of the room, or the angle of the inclined plane on which it would be positioned. In this, they select some aspect of the situation to attend to, and also define what it means to roll. A selection of what the observer looks at is not only necessary for any explanation to be developed, but is constitutive of what it means to observe (Lat. *observāre*, to attend to, from *ob-*, before, against + *servāre*, to watch, keep). Observing the motion of a cone down an inclined plane thus cannot be realized without adopting an observer position, making distinctions that delineate what count as the phenomenon. For example, in Jade's utterances in turns 05, 07, and 11, the orientation of the cone (placed on its side or upright) and its trajectory (circular or linear) consecutively appear in the explanation of the thought experiment she conducts to make a prediction.

The same happens when students experiment with material objects. Soon after they made their predictions, the three students observed the motion of a cone as it was going down an inclined plane (Figure 14.1). After the cone is released and ungainly moves down the plane, Jade and Sonia observe the phenomenon and briefly pause before they conclude, "Yea … but it rolls. Yea it's okay." The observer's position they adopt now leads them to see the cone as rolling. However,

a few minutes later, they reproduce the experiment. Whereas Sonia affirms beforehand that the cone would roll, when she releases it to look at what happens, she turns to Jade, and the two girls decide, "No, not really, just put slide."

In these two observations, it seems that the trajectory of the cone, taken as an important part of the phenomenon, is no longer included in their observation. Focusing on the revolution of the cone around its axis or considering the path down the plane defines the phenomenon in two different ways. What is observed in each case is different, and that observation arises together with the observer's position with respect to the phenomenon. Because not everything can be attended to and accounted for, the observer and the observed are contingent on one another. Even if here, for us, the articulation of two dimensions of the movement of the cone is not highly problematic, there are still other aspects we can (not so easily) take in consideration. For example, if a cone were to be released on a large and long enough plane, would its overall trajectory be linear or not? Are the wooden block and board adequate approximation of a cone and a plane? These questions are directly related to the means of operation of the observer, which include both his/her disposition and the setting in which the observation is realized.

This example also illustrates how common agreement in different observers' interpretations does not guarantee objective validity to a claim. The girls can differently position themselves as observers, and thus dis/agree about what they perceive and how to report their perceptions. Moreover, they can transform and overcome their agreements or disagreement by changing their observing posture. This is why looking at the observer-observed relation demands considering aspects such as goals, needs, and affect. The movement of the cone on a plane is not absolutely foreign to us. We experience something similar with objects like screws or pens, when their points of contact with a plane (e.g., a table) make them similar to cones. However, because these are part of very different activities, we do not observe them in the way students might do in a science or mathematics classroom. A student observes similar phenomena in different contexts. In each case, we ought not be astonished if the observations have little in common even if a psychologist claims that the situations are structurally identical. We thus see why the mutually constitutive role of the observer and the observed is in itself secondary to the observer's experience of the world in the very moment of making an observation.

It is clear that Maeve, Sonia, and Jade situate themselves as observers making certain kinds of observations. Doing so, they define an observable domain by specifying what counts as a legitimate observation. Similarly, what allow us researcher-observers to analyze bears family resemblance with what the three girls experience. Introducing a piece of data (like a transcript) we delineate an approach in which only some aspects come to the fore, and we make observations from which we emerge with an observed object. What is captured on video is a small part of the students' lives that we frame and isolate. Within those limits, we can portray the students' achievement in school or interpersonal relationships as a lens for our analysis, or describe students' gestures in mathematics communication. By all these means, we create an object of observation by situating ourselves as

observers making certain types of descriptions. Inasmuch, the text we present here is indeed a description that reifies our researchers' experience with the students and the material, it is a commentary co-produced by our observers' activity and what the world is offering us.

The foregoing highlights the fact that the observer cannot be removed from the phenomenon under observation, and, thus, that our observations are something we create in the practical activity of observing. Observers can look for instances in which they recognize that students draw on primitive knowings (everything that they bring to bear on the task at hand), make images of mathematical phenomena, notice properties, or formalize observations. Seeing them as moving from one dimension of mathematical engagement to another, we can evoke growth in mathematical understanding when, for instance, students create new mathematics questions, or new concepts. In our case, we can use this framework to assert that the three girls draw on an intuitive understanding of what a cone is and what rolling means because they do not define them at first. We recognize as images making the moment in which they distinguish rolling trajectories or possible positions for the cone. Similarly, combining these images appears to us as articulating properties relevant in the context. In the same way, we can recognize a form of generalization, as the students do not only discuss a particular cone, but also cones generally. The association of all these elements within the conversation could also be described as forecasting the articulation of formal theories, being like theorems in the talk. For example, the three girls appear to develop an understanding of the task of making a prediction under the law of excluded middle: (a) Since the cone must either slide or roll but not both and (b) if to roll means having a linear movement, then (c) the cone does not roll (from [b]), and therefore (d) it slides (from [c] and [a]).

Such a reading is but one possible approach to these students' activity. It is one in which we do not leave implicit our means of operation, our own observer cognitive abilities, our intentions, and so on. Considering our researcher-observer engagement, it is a perspective in which regardless of what the data might "objectively" present, the researcher looks into how people and material things affect his/her perception and in/form the interpretations of what is happening. It is an approach in which researchers are observers observing themselves and others (students). This is one of the reasons why, in contrast to psychological approaches, sociocultural perspectives would attribute conceptions not to students but to the observer–observed transactions.

Students' Actions Are Made with and for the Other(s)

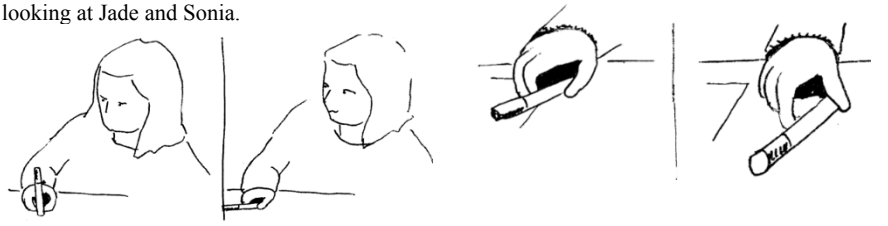
Considering the co-emergence of observer and observed calls attention to the problems that come with the attribution of conceptions to the students. To exemplify this, we examine Maeve's utterance in turn 04 and pay close attention to how a researcher develops his/her own understanding from the student's engagement with the societal-material world. Saying "if you put it side-ways and then it will

roll like that" (turn 04), Maeve gestures with her felt-tip pen (Figure 14.2). She first places it on its side (G1), then gives it an impulsion and follows its rolling motion on the table (G2) and finally grasps it to describe a circle (G3):

04 Ma: [do you remember that if you put it side-ways]G1 [and then it will rolls]G2 [like that?]G3

[G1] Maeve places her pen upright and then on its side. She repeat the gesture three times while looking at Jade and Sonia.

[G2] Maeve pushes the pen and follows its motion with her hand but lets it roll.



[G3] Maeve rotates the pen so it describes a circle.

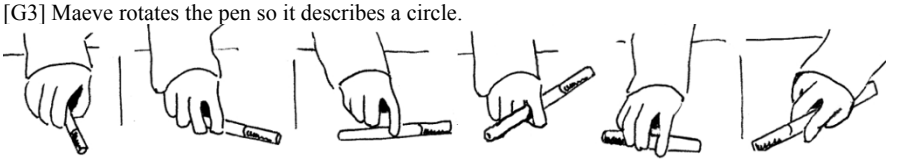


Figure 14.2. Maeve's gestures in turn 04.

If we want to identify a conception by discussing what Maeve means with her utterance, we need to associate speech and gestures and assume they represent a specific understanding of the situation. But here, we face a problem. As she pronounces "it will roll," Maeve pushes her pen which moves linearly. Maeve then seizes the pen and rotates it to trace a circle, emphasizing "like that." The change in her gesture and talk contrasts two rolling motions. But does Maeve expect the pen to roll in a circular way, and then observes that its motion is not the anticipated one, or does she realize from the movement itself that what she has previously observed with a cone differs? In terms of how students' conceptions are traditionally analyzed, these two interpretations are profoundly different. On the one hand, Maeve would have a correct conception of how a cone rolls, and simply adjusts her performance according to that understanding. In the second case, she would have an incomplete conception and, through a cognitive conflict generated by observing a phenomenon, went through a conceptual change by expanding her understanding (to take into account the direction of the rolling object).

As observers, we can only make inferences based on our transactions with the data and make conclusions based on what appears to our eyes. We are here in a situation in which we examine a student's talk and gestures (not a cognitive structure). We see Maeve producing an observation, but we have no means to ascertain what is effectively happening for her. Even if we try to "assume the position of the child and think as the child does" (Steffe and Thompson 2000,

p. 202), there is no way for us to ensure the validity, or even the likeliness of one interpretation over the other. The impossibility to overcome such a simple dilemma (concerning a single utterance of a student in a conversation) captures the limits of an approach in terms of students' conceptions. If we want to explain what a student does or says based on some mental structure, we are forced to impose our own understanding as being that of the student. And if we posit the objective existence of such a structure as belonging to the student, we have to ignore the fact that it is by no means accessible to us.

A sociocultural approach to the work on conceptions foresees the impossibility to objectively decide what a person knows or thinks. The difficulty exemplified in Maeve's utterance also similarly applies to Jade and Sonia's talk: How would we explain the change in what they state about the cone (roll or does not roll) if such affirmations were the sole reflection of their conceptions? As researcher-observers, we also have to admit that what students say or do only partially reveals what they are capable of, and that what is enacted just as much reveals a socio-cultural possibility. Indeed, there is no limit to the number of ways of expressing a concept, and it is the infinite set of possible applications of a given idea that constitutes the concept in the most general sense (Roth and Thom 2009). To go beyond these limitations and contradictions, sociocultural perspectives suggest turning our attention to the observable coordination between individuals and their context, and examine student's performances as contributions made in a discursive domain. We exemplify this by returning to our episode to see how Maeve, Sonia, and Jade brought into being their activity with and for each other by situating themselves as observers.

The communicative functions of language stress that it is the listener's response to an utterance that completes it and, thereby, reveals the actual meaning of what was first contributed (Bakhtin 1986). Maeve's contribution ("Do you remember that if you put it sideways and then it will roll like that" [turn 04]) turned out to become functionally a statement about the cone only following to Sonia's and Jade's responses. Had Sonia and Jade asked about the particular event Maeve was referring to, the conversation might have taken a different course and not focused on the properties of the cone. In other words, students' contributions are not simply individual productions, but what they are worth is made with the other(s). Moreover, students also contribute to an activity not only because it makes sense to them, but also because they assume their contributions will be intelligible for others. For instance, in turn 06, Maeve repeats her conclusion. This affirmation signifies that she has heard Jade and Julia's contributions and that she interprets them as different from hers. It is to this difference that she draws attention.

Students do not simply make neutral and independent responses, because each participant is oriented to responsive understanding from the others. They contribute to the conversation for their interlocutors' and their own benefit and thus do not merely represent their personal conceptions. In turns 08 and 10, Sonia offers a definition of what it means to roll. This consideration marks the departure of the conversation from merely deciding whether the cone slides or rolls, to examine and clarify what these two motions denote. The emergence of that concern,

however, cannot be solely attributed to Sonia; we do not know what precisely she means by rolling. Sonia's utterance is in the first place a response to what was contributed before, including Maeve's speech and gesture in turn 04. Indeed, Sonia's contribution is made in contrast with what Maeve has brought forth. It is thanks to Maeve's suggestion, in its manner and its moment, that Sonia can oppose an alternative view. Therefore, what would appear—from a perspective centered on the individual—as the expression of a conception is in fact developed from turn to turn, at the very heart of the conversation. Each utterance takes an active position in a chain of utterances, made for oneself and with and for the other(s), each one connects to what precedes and what follows. It is in that succession that not only do students reveal their observer positions, but also that questions and observations acquire their productive, functional meaning.

This collective dimension unfolding from students' contributions is not free from external influences. Together they take place in and from a discursive domain closely related to the ongoing activity. Maeve, Sonia, and Jade produce observations about the cone and by doing so, they define an observable domain by specifying what counts as a legitimate observation. It is not surprising to us to find evidence of mathematical thinking in the girls' activity because they are part of a societal situation in which certain forms of talk are valued over others. In search for compelling arguments, mathematical forms of observations provide the students (and us) with both structure and agential possibilities. Classroom mathematics demands to talk about certain things and in certain ways. Because they correspond to typical communication situations, concern particular themes and attribute specific meanings to communicative resources (such as words and gestures) in relation to the circumstances in which they are used, these forms of talk guide the students (and us) in observing. Indeed, what happens between Maeve, Jade, and Sonia is not accidental: at the same moment, Jordan's group is facing a similar dilemma and (after discussion) turns to the teacher (Je), who asks Jordan to repeat the question for the whole classroom:

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Jo: Do we gotta put it like this or like this? ((placing his
    pen upright and then on its side))
Je: Okay, that's a good question. You are gonna be working
    with your group and you are gonna put the object any way
    you want down the ramp.
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Both at the individual and at the collective level, a discursive domain emerges because students contribute with and for others to the conversation, and because those contributions take place in the same sociomaterial context, with similar resources, the participants do so with similar goals and similar rules. It is as part of that emerging geometrical discursive domain at the classroom level that Maeve then concludes clearly addressing her partners: "Look! It will slide and roll!" This we have to take as the, to her most relevant way of examining what happens with the cone in that situation. In another context, she might have maintained her co-ordination with the sociomaterial world by characterizing the cone as a rolling object, stressing for example, what is most remarkable about it. In this, she would have enacted a different understanding of the question, making a different contribution

in a different activity. A researcher who would not take into consideration and include in the analysis this decisive aspect coming from the context could easily and misleadingly make inferences about Maeve's "conception" of the cone. Examining how participants in an activity create meaning indeed reveals that students bring into being a discursive domain for and with each other, a domain that might, or might not, promote their observations as mathematical or scientific. Against the narrowing of an evaluation of student's conceptual development to what is observed in a specific situation, we show here that a sociocultural approach focus of the conditions in which certain aspects of a cone are discussed when the students produce classroom events.

Research and the Ethical Ground

We see in the previous sections that psychological and the sociocultural approaches differ in the path of objectivity they take. This distinction naturally unfolds in an ethical reflection on the legitimacy of the other and of what he or she brings forth in making observations (Maturana 1988). Objectivity is often associated with the absence of value and responsibility for what is said. By simply stating how things are and what students think or know, we do not appear to take a position, unlike when we say that something is right or wrong. The change of discourse over the years in the psychological approach on conceptions captures this very well. Researchers nowadays tend to refrain from talking about misconceptions or naïve conceptions and rather use adjectives like non-scientific, everyday, or incomplete. Such an attitude is typical for the path toward transcendental objectivity. Through reason, observers claim access to an objective reality and the validity of the argumentation that are independent of the researcher. However, presupposing an ultimate source of validation also leads one to define a single reality in which only one interpretation is acceptable. In this view, claims about knowledge are demands for obedience. Because the observers do not take responsibility for their explanations, others are then implicitly or explicitly forced to accept what is said to be true and are not legitimate in their own understanding. We clearly show, however, that observers have the possibility to develop different explanations. For example, a researcher examining a video excerpt will account for different things by examining isolated utterances of a student, or considering how each utterance is a response to what was said before. Observers are thus responsible for the explanations they give, which is why researchers in a sociocultural perspective call to the examination of the implicit elements and the limitations of the theories they, and others, adopt. Blaming learning difficulties on cognitive immaturity or underdevelopment—as psychological approaches often do—blinds the examination of the social, economic, and cultural dimensions of knowledge, learning, teaching, and what it means to succeed or fail. This has ethical implications because in and through language, explanations or discourses, individuals position themselves and others. Saying that students hold conceptions, their perspectives are not recognized

as legitimate explanations because the researcher-observers keep the focus on their understanding. Thus, they (rightfully) note that it would not be acceptable to them to say or do things that way and see students' performances as non-scientific in contrast to what they personally delineate as scientific, and incomplete in comparison to their personal understanding.

Although not all explanations are equivalent, they are all equally legitimate (Maturana 1988). To take responsibility for their explanations, observers are not to decide which explanation is right, but to understand how desirable each one might be with respect to the goals the observers set themselves. We can take on that responsibility if, instead of attributing conceptions to the students, we question how as researcher-observers we recognize forms of mathematical or scientific thinking. Making such observations does not lead to conjectures about what is going on in the student's mind, does not posit the existence of some static mental structure and does not require the acceptance of a single, transcendental reality by means of which our observations can be validated. It opens room to legitimate students' performances and discuss how they do, or do not, bring forth a mathematical discursive domain by positioning themselves as mathematical observers. This applies not only to the researchers, but also to the students as observers. From a sociocultural point of view, objectivity is replaced by something dynamic, discursively constituted in and by experiences: praxis. The concept of praxis entails the adoption of an attitude ethical toward the other because it recognizes the value and the validity of what students do or say, but also makes possible to discuss why it is contextually desirable or not. Such an attitude opens up a "responsible reflection of coexistence" (p. 32) because it avoids reducing students' understandings to another observer's interpretation and thus accepts students as legitimate others by valuing their contributions for what they are. Discussing how and why different understandings are equally legitimate, but not necessarily equally desirable, allows us to situate knowing and thinking not in a student' cognitive structures, but in the action itself, which includes both the individual and his/her context.

Traditional perspectives focusing on cognitive or psychological aspects of learning are unable to value the uniqueness of each student because they treat difference as a derivative of sameness. Talking about students' conceptions is trying to identify something that would be essentially the same about them. It is to create an object of observation that reduces what is brought forth in conversation to singular, well-defined ideas that represent universal features of children's development. The positions such researchers adopt make differences indifferent to difference instead of valuing the heterogeneity of personal experiences. At best addressing students' discrepancies, these perspectives look for standard procedures to approach students' understandings and fix them. Against an instrumental orientation of science or mathematics education, a sociocultural approach places the students' uniqueness at the center of the ethical relation to the other. Aligned with the acceptance of the other and his or her perspective characteristic to constituted objectivity, researchers adopting sociocultural frameworks count that individuals are always more than what they offer in a single moment, or in a

collage of isolated utterances. This "surplus of humanness" comes with any encounter with others, and asks us to "take the performed act not as a fact contemplated from outside or thought of theoretically, but to take it from within … in all its concrete historicity and individuality" (Bakhtin 1993, p. 28). Rather than seeing students' contributions exposing context-free conceptions belonging to the students, these contributions are, for example, to be examined as once-occurring, situated attempts to maintain coherence with the environment. Including what is observed, but also including the others with and for whom observations are made, students' contributions are not widows on the mind, but a moment in a process of becoming.

To undertake our ethical responsibility for the other as non-indifference to differences, a fully developed sociocultural perspective is opposed to the assessment of what students, as individuals, knows or can do as incomplete, naive or inappropriate conceptions. To support students' learning, a sociocultural perspective examines how they contribute to a situation the way they do, and what it is that they create in doing so. Accordingly, researchers will define themselves as a certain type of observer whose intentions are not, in the end, to get the students to a correct or a complete conception (or any predetermined understanding of a situation). Non-indifference to differences exists when we support students to enter in a certain kind of discursive domain, or in other words, by helping them position themselves as observers in a mathematic or scientific way. Inasmuch, difference is theorized in and for itself: It is because they are different that students ought to enter in a shared discursive domain, and they can do so precisely because they are different and, thus, have something unique to contribute. Taking in account the surplus of humanness inherent to the encounter with another, a sociocultural approach sees difference as prerequisite for and constitutive of dialogical engagement and participation with others (i.e., with other's differences). In addition, examining what students say or do informs us about how they position themselves as observers. Consistent with an ethical orientation to the other, what is assess from this are conditions with which students coordinate themselves, not their ability to do so. If Maeve, Sonia, and Jade discuss the cone and its properties in a mathematical way, it is not merely because they have the appropriate cognitive structures imprinted in their mind. It is most importantly because of the societal-material conditions they are in and that they change with their actions.

Such a perspective also allows us to take an ethical stand as to what is going on in a classroom without positioning students and their performances negatively. On the contrary, we value students' differences, give them attention and draw on them to revisit our own understanding of what doing science or mathematics is about. Because mathematics is something we societally (institutionally, culturally, and historically) define, it is justified, for researcher-observers, to discuss whether the situations in which students find themselves lead them to create what corresponds to our vision of a scientific or a mathematical activity. Moreover, we, as mathematics or science educators, have a special responsibility to produce and reproduce, to define and redefine, what is a mathematical or scientific activity as a societal phenomenon. We thus assume our ethical accountability by examining not only the conditions, but also the explanations in and by means of which students are

positioned and position others and what is brought forth in making observations. In contrast, such an ethical ground cannot be found to support making judgment on what students know or do not know.

Conclusion

The path of constituted objectivity is in essence welcoming a variety of world-views, and thus recognizes the path of transcendental objectivity as a legitimate one, because even though one pretends to make observations in transcendental objectivity, the human praxis in which these observations are made is still a path of constituted objectivity. Sociocultural approaches are able to welcome conceptions and conceptual changes perspectives as one possible way to examine students talk and actions, but do not see them as compatible or complementary with their own effort. They are possible alternative views that reveal different assumptions, undertakings, and focal points. But, according to the goals we set ourselves as researchers or educators, conceptions and conceptual change frameworks are not the most desirable way to examine students' talk and actions. The reasons for this lie in the problematic attribution of conceptions to the students in a way that neglects the contingency of the observer and the observed, and in the ethical implication that comes with this contingency. We recognize here a comprehensive ethical approach in which the observer takes on responsibility to discuss how and why different understanding, although equally legitimate, are not equally desirable. This is especially important today because our ability to deal with plurality and diversity guides social behavior. Western culture has long been characterized by separation and universalism, dividing the world from the person. Such division and dislocation leads to the systematic negation of the existence of the other by applying the same cultural logic to all people, as if everybody and all contexts were essentially the same. Although this principle has led to some positive outcomes, it is generally for the benefit of those who are already culturally well positioned, and to the detriment of the disadvantaged, like indigenous or working class peoples, women, immigrants, and so on. Similarly, an approach that reduces language use to the individual is rooted in an ontology that underlies "all inequities, including those along the lines of gender, culture, socioeconomic status, class, and age" (Roth 2007, p. 742). By challenging the assumptions made in research on conceptions and conceptual changes in mathematics and science education, we offer here a practical answer to the urging of those who ask us to address this situation.

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