The Bodily and Contextual Foundations of Conceptual Coherence and Continuity

Case studies from the teaching and learning of science inquiry

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PART I:
EXTENDED ABSTRACT

Chapter 1 – Introduction

This thesis is concerned with conceptual coherence and continuity in and of knowledgeable participation in everyday activity. To better illustrate the nature of the phenomena that are of interest, and to frame the question that the thesis addresses in most general terms, I begin this introduction with an account of an episode of learning by a young child. I then use this learning episode to formulate the general purpose of the thesis. In the remainder of the chapter, I provide a brief introduction to the relevant research literature on the problem of coherence and continuity in the cognitive and the learning sciences, and I outline some of the basic tenets of an ecological (sociocultural and situative) analytical approach. I then list the specific research questions that the thesis addresses and outline the structure of the thesis and the empirical studies included.

An episode of learning

> *Clara is two and a half years old and greatly enjoys drawing and painting. Since she was very small, her parents encouraged her to color, scribble, and doodle on blank pages, and many of her paintings hang on her house's walls. Often, she asks her parents to draw figures for her, such as animals, landscapes, flowers, and the like—figures that she cannot yet draw on her own. Lately, her parents have begun to show her how to draw geometric shapes. They take her hand as she holds the crayon, and they guide her to draw circles and squares on the paper while they say "See, Clara, we draw circles!" or "Look there, that's a square." One afternoon, Clara is sitting with her dad, ready to draw some random lines on the paper, when she wonders (aloud) what they could paint. Clara then spontaneously begins to draw an elliptical shape. Suddenly, she looks at the shape and, with an expression of great surprise in her face, says, "Look, Daddy, it's a troll!" She then draws two circles that can now clearly be recognized as the troll's eyes, and then the nose and the mouth. Her dad then encourages her to continue drawing the troll's ears (in red color, Figure 1) and hair. Clara has just drawn her first ("troll") face.*

Figure 1: Clara's first drawing of a (troll's) face

I documented the episode described above two years ago while I was drawing with my daughter, Clara. This episode is one of many remarkable but mundane events that have occurred in the course of Clara's cognitive and literacy development, and which I have been lucky enough to witness and document in situ. Whereas the episode does not feature any particularly advanced technology, nor takes place as part of an inquiry-based curriculum—the empirical context of this dissertation—the episode is relevant to this thesis because it raises questions of learning and development: of how prior experiences relate to the development of new literacy skills, and of how the immediate context of bodily engagement is involved in such development. The episode is also important because, along with the empirical materials presented in this study, it forms part of a larger set of experiences and observations that have been influential in my work. Thus, this and other similar episodes that I have documented throughout my daughter's development have been important resources throughout my doctoral studies, and many of the things that I have subsequently paid attention to, talked about, and written about with regard to learning and cognition became salient during discussions about episodes such as this one with my colleagues and supervisors in the project.

In this episode, Clara draws a face for the first time (Figure 1). Importantly, the episode is not an isolated event, disconnected from Clara's developmental history. The drawing in Figure 1 is the first of many different faces that she is capable of drawing today, two and a half years later. As Clara drew her first face, a new horizon of possibilities opened up for her and changed her *forever*—she would never again be the little girl who could not intentionally draw a face. But how did this event of development come about? On what grounds did she come to master a skill that she lacked before? How can we understand this event of *change* as being *continuous* with Clara's prior and subsequent history of developing literacy in pictorial representation and, therefore, of intellectual development?

Most current approaches to learning and cognition explain episodes of change such as the one described above in terms of "prior knowledge," which is most often described as an already existing intellectual, formal, or linguistic competence—such as an "idea"—that has been acquired from everyday experience. Accordingly, knowing something new "begins with the selection of ideas from everyday experience" (Roschelle, 1995, p. 41). From that perspective, Clara was already learning to draw circles, so she knew circles. She already knew how to hold the crayon and draw circle-like shapes with it. She already knew faces and she already knew trolls. All

these she knew not just by herself, but thanks to the social interactions in which she had previously engaged with her parents, where she had been presented with drawing, faces, and trolls. It was these already existing "ideas" that allowed—in a sense, *caused*—her to draw first, and then to recognize her drawing as a troll's face.

Yet, some aspects of Clara's episode seem to be left unexplained by an account that takes "prior knowledge" as the primary ground of the developmental event. First, there is no evidence that Clara is intentionally "selecting" from prior "ideas" what she will end up drawing or how she will come to recognize it later on. Rather than out of previously knowing some thing, everything in the episode suggests that Clara's drawing of a troll's face comes to her as an *absolute surprise*. She begins to move her hand over the blank sheet at the same time as she wonders aloud about what she should draw. She does not anticipate the outcome of her drawing. Indeed, she *could not* anticipate it because she did not yet know that she could draw a troll's face by herself. How could she intend what she did not yet know? Rather, Clara was able to *do* something before knowing (intellectually) that she could do it. More than an intellectual understanding about drawing troll faces, there was prior *bodily* knowledge: the knowledge by means of which Clara's hand moved and left a particular shape on the sheet. There was also her bodily and sensorial capability of being *affected* by the shape that she had just left, the capability of perceiving the drawing as a face and letting herself be surprised by it. All these aspects seem to play an important role in her coming to be someone who *can* draw faces and, therefore, in her development of these literacy skills. But bodily and affective dimensions, such as a learner's body movements or her sudden surprise, are seldom investigated in the context of science and mathematics education (cf. Roth, 2010, 2011). Yet, there are studies showing that early bodily and apparently non-rational skills such as *scribbling* are fundamental to toddlers' development of symbolic communication (e.g., Stamatopoulou, 2011). Such studies also show that Clara's episode is not just incidental and particular to my daughter's history, but is also an instance of a more general aspect of the development of literacy skills.

Another aspect that makes problematic the idea that previously learned "ideas"—e.g., the idea of "the circle," the idea of a "troll's face," or the "image schema" of "drawing a circle"—are the most fundamental ground on which the episode takes place is that the event itself does not seem to be determinable by any given idea (form), but is rather open-ended and indeterminate. It is rather difficult to locate the idea of "troll face" in a single participant or aspect of the setting. Thus, Clara's drawing begins with an indeterminate shape on the blank sheet that, at some point, comes to be named as a troll. It is only *after* the first shape is recognized as such that the drawing actually begins to take the *form* of a face. And yet, what the form comes to be is not determinate either. First there is just an elliptical trace. Then eyes, nose, and mouth are added; finally hair and ears. In this process of form making, of achieving a sense of coherence, the act of drawing and the act of naming the drawing are not one and the same, but both seem to form part of the bringing the event to closure. Thus, Clara articulates her surprise not only to herself but also to her father. In doing so, she provides resources for them both to turn what initially was a random shape on a blank sheet into something that can be recognized as a coherent troll face by others as well.

Episodes such as the one described above highlight aspects that are unaccounted for in current theories of learning that reify rational knowledge structures as the ground of

continuity and coherence in intellectual development. The episode suggests that aspects that are more often associated with irrational or non-intellectual dimensions of life, such as the way we move and come into contact with our immediate material context, as well as the way we are overwhelmed and surprised in experience, may be important for understanding how we come to talk and reason about the world. Even if intellectual aspects are important—obviously Clara needed to have some intellectual competences to think and to talk about faces and trolls—these cannot be thought of as having a determinate form that somehow structures action. If there are ideas—whether social or individual—underlying the event, they do not seem to be at the origin, but rather seem to be part of a larger unfolding process that cannot be reduced to either the initial idea or the final product. Instead, to understand how "prior knowledge" is involved in the development of new intellectual skills, we need to investigate and theorize knowing not as determinate and formal, but as fluid and open-ended, and as connected to actual engagement with others and with materials.

Problem statement and purpose of the thesis

In this thesis, I investigate the emergent, social, and performative aspects of engaging with materials that are salient during episodes of literacy development such as the one described above. Specifically, the problem investigated in this thesis is:

- *How do relations of conceptual coherence and continuity emerge as practical and embodied achievements during joint social activities?*

The purpose of the thesis is to provide empirical and analytical accounts of conceptual coherence and continuity—which I investigate in the context of science education in general and of inquiry-based instruction in particular. The formulation of conceptual coherence and continuity as *practical and embodied achievements* derives from a situative and sociocultural analytical perspective, according to which intellectual cognitive skills, rather than being the result of private individual mental operations, emerge first as material operations between people participating in particular *social practices* (e.g., schooling practices). Throughout three empirical studies, I draw on video recordings and other ethnographic materials collected as part of a larger design-based research project concerned with developing and testing a computer-supported inquiry-based learning curriculum on the topic of "energy of the future." In the studies, I analyze how teachers and students together draw connections of significance among events, the teaching materials, and the core topics of the science curriculum.

To establish the grounds on which the present investigation of conceptual coherence and continuity is built, I begin by introducing a broad division between two main currents of thought that have dominated research on learning and cognition during the past century, cognitivist and ecological (sociocultural and situative) approaches. I then position my work as forming part of the latter kind and elaborate on some basic implications that derive from taking an ecological perspective on the problem of coherence and continuity in experience.

Towards a genetic and ecological account of coherence and continuity

Information-processing approaches

When information-processing approaches emerged during the second half of the last century (Bruner, Goodnow, & Austin; Miller, 1956), thinking and learning were conceptualized as the mental manipulation of symbols. Since then, and throughout the following constructivist interpretations of learning as the learners' active construction of mental models and conceptions (Greeno, Collins, & Resnick, 1996; Mayer, 1996), accounts of how learners achieve a coherent understanding of the world during and across learning situations have most often been articulated in terms of rational connections between mental knowledge structures or *representations* (e.g., symbols, conceptions, ideas, schemas, models). This is particularly the case in research on *learning transfer,* where a learner's ability to recognize a new problem-solving situation as belonging to a particular class of situations experienced before—e.g., recognizing the cycles of evaporation and condensation inside of a heat pump as an instance of a transforming thermodynamic system—is a function of structural alignments or *mappings* between mental representations of the knowledge domain on the one hand, and of the current problem-solving situation on the other (Chi & VanLehn, 2012; Gentner & Markman, 1997; Gick & Holyoak, 1983; Reed, Ernst, & Banerji, 1974; Singley & Anderson, 1989). In science education, the influence of these models has led to a long tradition of *conceptual change* studies, where researchers investigate the nature and content of learners' *prior ideas* or *conceptions*, and how instruction may facilitate learners drawing rational connections between those prior "everyday" or "naïve" ideas and the ideas that scientific experts hold (diSessa, 2006; Vonsniadou, 2008; Treagust & Duit, 2008). Common to these approaches is the view that the competence of recognizing and producing rational order during situated action rests upon the existence of already developed individual mental structures or "prior knowledge," which analysts can identify through diverse methods of observation and then treat as antecedent conditions to explain the observed ordered and ordering behaviors.

Ecological approaches

During the last decades, researchers from a number of approaches, including *situated cognition* (Clancey, 1997; Lave & Wenger, 1991; Suchman, 1987), *socio-cultural-historical psychology* (Cole, 1995; Engeström, 1987; Säljö, 2000; Wertsch, 1991), and *distributed cognition* (Hutchins, 1995), have raised the criticism that the cognitivist accounts described above entail a decontextualized stance towards human activity, where rational thinking is divorced from the bodily, sensual, affective, and direct experience of everyday engagement with others and with materials. In particular, the view that situated action can be accounted for by distinguishing an individual's knowledge representations on the one hand, and the implementation of such representations in behavior on the other, has been problematized. Anchored in philosophical and scientific traditions such as phenomenology (e.g., Husserl,

1946/1981), American pragmatism (e.g., Dewey, 1938; Mead, 1934), cultural-historical psychology (e.g., Vygotsky, 1978), and ecological psychology (Gibson, 1979) among others, these emerging *ecological*[1] approaches reject the analytical divisions between mind and body, and between people and their cultural and material contexts, that characterize traditional cognitivist approaches. Instead, they propose to study the mutually constitutive relations that bind together subjects and their social and material environments during situated action.

Ecological approaches give analytical primacy to *social practices*, which both produce and are produced by individuals' situated and embodied actions (Lave, 1988). Cognitive phenomena such as learning and thinking are seen as *emergent properties* of the larger social process of participating in particular sociocultural practices. Becoming a participant in social practices such as schooling, in turn, is viewed as a process that involves mastering historically developed cultural tools—such as language, mathematical techniques, scientific reasoning, and inscriptional practices—during engagement in concrete activities (Lave & Wenger, 1991; Mercer & Littleton, 2007; Roth & McGinn, 1998; Wertsch & Kazak, 2011). It is through the process of participating in social practices that such cognitive functions as perceiving, thinking, learning, or arguing emerge: first as a social relation in the plane of social interaction, and then as a cognitive function in the individual (Vygotsky, 1978).

Ecological approaches have increasingly been adopted in what some researchers refer to as the "practice turn" in educational research (Arnseth, 2008, p. 289). In science education research, this turn has involved the emergence of empirical studies documenting episodes of conceptual change as achievements of social—rather than psychological—order (e.g., Furberg & Arnseth, 2009; Krange & Ludvigsen, 2008; Lindwall & Lymer, 2008; Roth et al., 1997). Methodologically, an interest in learning as social practice has involved a proliferation of video-based ethnographic studies aimed to capture the situated social practices by means of which students and teachers jointly make sense of learning situations in the moment-by-moment interaction (Derry et al., 2010). Results from these studies suggest that there is more to learning science than knowing or constructing mental knowledge structures: a large part of the students' activities in the science classroom are oriented towards *practical* concerns that, more than the deployment of already learned conceptual knowledge structures, reflect an everyday competence of participating in *institutional practices* of schooling.

Two analytical implications of an ecological approach

In this thesis, I take an ecological approach to studying how relations of conceptual coherence connecting events, artifacts, and topics in and across situations emerge as

[1] Throughout this dissertation, I use the term *ecological*, as Clancey (1997) and Robbins and Aydede (2009) do, to refer to a set of otherwise diverse approaches to learning and cognition that share as their object of study a postulation of the mutually constitutive relations between subjects and their social and material environments. Other researchers have used other terms to refer to the same group of approaches. Greeno, Collins, and Resnick (1996), for example, use the label *situative/pragmatic-socio-historic*, whereas Sawyer and Greeno (2009) and Greeno and Engeström (2014) refer to them as *situative* approaches.

achievements of social practice. Whereas classical cognitivist approaches to these questions have been challenged on both empirical and theoretical grounds during the last decades (e.g., Lave, 1988; Lobato, 2003), an important challenge in current research and theorizing is to account for the competence to perceive or structure dissimilar situations as involving the same general conceptual aspects—that is, the classical question of transfer—while acknowledging the inherently social and context-bound nature of cognition (Clancey, 1997; 2011; Greeno & Engeström, 2014; Sfard, 1998, 2008).

Two interlocked analytical implications that derive from choosing an ecological approach are of particular relevance to the purposes of this thesis. The first implication is that the coherence and continuity of any set of ideas or concepts, as made relevant by the participants during joint activity, cannot be analyzed in terms of a priori formal properties of either the material setting (e.g., texts, graphs, demonstrations) or the individuals' thinking (e.g., a learner's mental representations of texts, graphs, or demonstrations), but must be treated as *the result of material and practical operations* that involve both. This is in line with Vygotsky's (1978) basic premise that any higher cognitive function exists as a relation between people before it becomes an individual function. For Vygotsky, as for pragmatists such as George H. Mead (1934), higher-order cognitive functions—such as those involved in the use of linguistic or conceptual forms during scientific inquiry—are not the precondition for the conscious experience of coherence during action. Rather, "the social act is the precondition of it" (p. 18). Accordingly, in this thesis I follow the premise that any "two events are 'simultaneous' *if* they are included within one and the same *act* of observation" (Dewey, 1929, p. 145, emphasis added). In the context of research in inquiry-based instruction, this implies that the analytical task is to describe those practical "acts of observation" by means of which teachers and students come to treat any two or more aspects (e.g., an event in a laboratory experiment on the one hand, and a scientific law as formulated in a science textbook on the other) as being formally connected.

Research consistent with this premise can be found, for example, in ethnomethodologically informed studies of scientific practice (e.g., Garfinkel, Lynch, & Livingston, 1981; Latour & Woolgar, 1986), which describe "the local historicity" of the scientist's "embodied shop practices" (Garfinkel et al., 1981, p. 132) by means of which newly discovered phenomena, such as the "optical pulsar," are made visible and accountable during scientific work. In science education, research informed by these and other related situative and sociocultural frameworks has begun to document how cognitive skills relevant to science education, such as reading scientific inscriptions (e.g., data tables, graphs) (Roth & McGinn, 1998; Wu & Krajcik, 2006) or interpreting laboratory experiments (Bergqvist & Säljö, 1994; Lindwall & Lymer, 2008), involve the joint practical and discursive work of teachers and students during social interaction, which produces and stabilizes patterned and disciplined ways of perceiving and talking about the material features of the setting.

The second implication is that, by virtue of conceiving conceptual coherence and continuity as *achievements* of social order, the object of study cannot be the final outcome of the social interaction (i.e., the already established connection), but must include the *process of development* that leads to such order. This premise finds an intellectual anchor in cultural-historical psychology, particularly in the work of Lev S.

Vygotsky (1986/2012), who understood that, to analyze the emergence of cognitive functions and intentions in individuals, we need to take a historical and *genetic approach* to the relation between individuals and their social and material contexts. From this perspective, the minimal object of interest cannot be the initial situation, in which an individual does not yet master a particular cognitive competence, nor can it be the final outcome, when the individual already masters it. The minimal phenomenon of interest needs to be the process by means of which new intellectual competences *emerge* in and through collective social interactions. In the context of studying continuity and coherence, therefore, the analytical focus needs to be on how both individuals and settings *change* so as to lead to particular renderings of ordered and connected objects. Such an approach requires a shift away from what Vygotsky calls an analysis into elements, and toward a method of *analysis into units*. Whereas the former treats the different aspects of social practice as analytically separable elements that analysis must bring together to account for events of social order, the latter aims at retaining all the mutually constitutive relations of the basic properties of the whole.

Research questions

In the previous section, I briefly introduced the historical context of research in the cognitive and the learning sciences, and I outlined some basic tenets of an ecological approach to the problem of coherence and continuity. Here, I state the two research questions that this thesis aims to address in the context of computer-supported inquiry-based learning. Importantly, the two questions are interrelated and must be understood as necessarily complementing each other (under the analytical premises of this study, either one would not make sense without the other).

The first research question is analytical:

- *What characterizes a unit of analysis capable of accounting for the emergent and indeterminate character of intellectual understandings of coherence and continuity during joint activities?*

To understand how learners' own actions during bodily engagement can bring about unexpected possibilities and transform them in ways that bring about new competences, we cannot start from individual knowledge, because what is already known cannot be the ground on which the radically new—and therefore unforeseeable and unknown—grows. To capture the emergent and transformational dimensions of learning, it is necessary to expand the unit of analysis. In this dissertation, I do so in two interlocked ways. First, consistent with the ideas sketched above about the primacy of social practice, and in line with other research in science education from ecological approaches, I take the collective as the minimal unit of analysis. Social relations, and not individual cognitive processes, are the site and source of development (Vygotsky, 1978). However, to understand episodes of development as phenomena of *change,* and not as phenomena where what already is known by individuals (i.e., prior knowledge) is only repeated or combined, we need to have a unit of analysis that captures the *unfolding of time* as something *internal* to the phenomenon (Roth & Jornet, 2013). Accordingly, and drawing from Dewey's writings on the notion of *experience* (e.g., Dewey, 1934/2008a), I expand the unit of analysis in this second way: it includes not just a social relation—which may be

captured by linguistic categories such as a "relation of power"—but a *changing* social relation. I refer to this minimal unit of collective change as *transactional.*

The second research question is empirical:

- *How is everyday bodily engagement related to the achievement of conceptual coherence and continuity during and across inquiry activities?*

I use the term *engagement* to mark an interest in whole persons-in-context, rather than in just their ideas, utterances, mental schemas and intentions, or any other category that reduces to the intellectual the fullness of life that is involved in thinking and doing during situated action. The object of study is the *performed act* (Bakhtin, 1993), and not "the psychic process" (p. 38). I use the modifiers *everyday* and *bodily* to mark the emergent, spontaneous, and embodied aspects of everyday involvement with the social and material world. In the same way, my interest is not in the body as an aspect that is isolated or distinct from concrete activity or from the cultural forms, such as language, that such concrete activities bring about. The unity of body, action, and culture is both a premise and an object of investigation in this dissertation. In this regard, I follow closely *situated cognition* approaches and consider the "lived-in world of engagement in everyday activity" as both the source of cultural practice and the proper site for the study of its emergence (Lave, 1988; Lave & Wenger, 1991).

I use the notions of *coherence* and *continuity* to address the sense-making practices by means of which relations of signification are established within and across contexts and situations. Although these terms may be used interchangeably, coherence is a more encompassing term in that it denotes the achievement of order, whether within or across a given problematic or situation. The term *continuity* refers more explicitly to the achievement of coherence across settings and activities, which has been traditionally investigated as the question of *transfer*. In the empirical studies included in this thesis, I investigate conceptual coherence and continuity by analyzing student-student and teacher-student interactions in different computer-supported inquiry-based settings involving different technological tools. These include both hands-on activities in small groups of students and plenary sessions in classroom settings, and they involve the use of hands-on analogs, interactive visualizations, digital video tools for capturing and displaying experimentations, and web-based platforms for sharing information.

Outline of the thesis

The main purpose of this thesis is to contribute to the development of theoretical and empirical accounts of the (mutually constitutive) relation between *everyday bodily engagement* and the emergence of conceptual coherence and continuity during situated activity in general, and during computer-supported inquiry-based activities in particular. To that aim, throughout this dissertation I develop two main thematic threads, each one reflected in each of the two research questions formulated above, namely the question of a unit of analysis capable of capturing the transforming person-in-setting as she changes during situated action, and the question of the role of the body in the constitution of lived-in, meaningful, coherent experience.

The thesis is divided into two parts: the Extended Abstract (Part I) and the Studies (Part II). The Extended Abstract includes five chapters, including this introduction. In

Chapter 2, I address the question of unit of analysis by reviewing the ways in which existing analytical approaches investigate the problem of coherence and continuity in the learning and the cognitive sciences. In the review, I present detailed accounts of two representative empirical studies in a sub-field of particular interest to this thesis, *learning transfer*. This allows me to discuss the premises and units of analysis (i.e., methodologies) by means of which distinct approaches construct their objects of research by referring to concrete materials rather than to more abstract theoretical discussions. It also allows me to frame the discussion on unit of analysis in the context of the transactional perspective that scholars such as Vygotsky and Dewey laid down, and on which this thesis draws. Building on such discussion, in Chapter 3, I elaborate on the transactional perspective, a methodological approach to study coherence and continuity as phenomena of development, and to account for how talk and the performative aspects of interaction are internal aspects of such development. In Chapter 4, I present the research design and methods. In Chapter 5, I summarize the results of the empirical studies that are included as part of this thesis and elaborate on the theoretical, methodological, and empirical contributions that the studies provide with particular reference to the fields of inquiry-based learning and science education.

Part II consists of the three studies on which the thesis is based. In study I, the focus is on discussing and elaborating a unit of analysis capable of addressing *change* as the minimal unit of analysis. The unit is applied to describe an *episode of transfer* in a computer-supported inquiry-based setting where a small group of students is working with a set of digital simulations as part of a longer trajectory of inquiry activities. In the analyses, my co-authors and I describe important cognitive processes involved in transfer, including *recognition, analogical inference,* and *applying conceptual knowledge* to a problem-solving situation, as collective and emergent bodily achievements. Study II investigates how a group of students works with multiple analog and digital learning materials that, from the perspective of the curriculum designers, represent a common underlying phenomenon and bear iconic and conceptual connections. Taking the perspective of the learners instead, the study examines how connections of signification emerge as a function of the students' bodily and social engagement with the learning materials. Study III investigates the achievement of continuity across inquiry activities in the context of video-supported plenary classroom sessions designed to offer opportunities for the students to reflect in conceptual terms on prior hands-on activities. I analyze how bodily performances and material arrangements in the classroom are involved in the teacher's work to facilitate the emergence of conceptual accounts of prior experiences.

- Study I: Jornet, A., Roth, W.-M., & Krange, I. (submitted). A transactional approach to transfer episodes. *Journal of the Learning Sciences.*

- Study II: Jornet, A., & Roth, W.-M. (in press). The joint work of connecting multiple (Re)presentations in science classrooms. *Science Education.*

- Study III: Jornet, A. (submitted). Bodily performances of coherence facilitation: The role of the body during teacher questioning in science classrooms. *Journal of Research in Science Teachin*

Chapter 2 – Prior Research on Coherence and Continuity

In the introductory chapter, I introduced a distinction between two general approaches to learning and cognition: cognitivist and ecological. In discussing these two approaches, I pointed out that much research in the cognitive and the learning sciences begins from the premise that, for individuals to make sense of an event or object of experience in a coherent sense, they require a knowledge representation (i.e., prior knowledge) that precedes and makes it possible to perceive and conceive of the particular event or object in a meaningful way. Through analysis of a concrete episode in which a child was just learning to draw a face for the first time, and citing the wider discussions that both cognitivist and ecological approaches have brought up in the literature, I problematized the premise of prior knowledge as the most fundamental unit on which a coherent understanding of the world emerges during everyday activity.

In this chapter, my aim is to review how questions of conceptual coherence and continuity have been addressed in the literature. In doing so, I focus on the different premises and units of analysis that have emerged to address the limitations of the so-called *classical transfer paradigm*. Focusing on both premises and units of analysis rather than on empirical findings alone is important because, as has been established in contemporary philosophy of science, there is interdependence between the theoretical assumptions that lead to particular observational procedures on the one hand, and the empirical observations themselves on the other (e.g., Guba & Lincoln, 1994; Quine, 1993). Accordingly, "the most empirical 'technical' choices cannot be disentangled from the most 'theoretical' choices in the construction of the [scientific] object" (Bourdieu, 1992, p. 225). I use the notion of *theoretical technologies* (Dewey, 1929; Sørensen, 2009) to refer to the instrumental interdependence between premises and units of analysis in characterizing the particular scientific objects of empirical research. Different theoretical technologies lead to different scientific objects, which in turn may lead to different and sometimes incompatible conclusions about what learning is and how it can be recognized in any given set of empirical data (Säljö, 2009). Prior discussions on the questions of continuity and coherence have shown that solving the theoretical and methodological questions that are of pertinence to this thesis requires an acknowledgement of the framing assumptions on which claims about empirical evidence are made (Greeno, 1997; Sfard, 2008).

In the following, I elaborate on how different theoretical technologies are put to work in specific empirical studies that are explicitly aimed to address the problematic of prior knowledge in the study of coherence and continuity. I first introduce the problematic as it has been raised in research on learning *transfer.* Research on learning transfer is particularly relevant to this thesis because it addresses the questions of both coherence and continuity; it investigates how knowledge relates to knowledge on the one hand, and how the same knowledge structure can be said to be present across different contexts/situations on the other. I then provide a detailed account of two studies that are representative of two alternate frameworks—constructivist and ecological. This detailed account allows me to identify and discuss how specific scientific objects emerge by reference to the concrete analytical work rather than by reference to scholastic discussion alone. I conclude the chapter by providing a critical assessment of the two studies in particular, and of the constructivist and ecological strands in general, with regard to the aim of addressing achievements of conceptual coherence as emergent and context-bound phenomena.

Coherence and the problem of representation

In this section, I first introduce the classical view or paradigm that has dominated research on the questions of coherence and continuity during most of the last century. Then I provide a brief account of the empirical and theoretical challenges that more recent literature has raised with regard to the classical perspective.

The classical view

Learning transfer is one of the oldest problems in the cognitive and the learning sciences, with studies about the topic appearing early during the twentieth century (Judd, 1908; Thorndike & Woodworth, 1901). The question continues to be the object of much debate and research today, as two recent special issues of two influential journals demonstrate (Engle, 2012; Goldstone & Day, 2012). In broad terms, transfer refers to the "ability of individuals to 'treat a new concept, problem, or phenomenon as similar to one(s) they have experienced before'" (Chi & VanLehn, 2012).

From the information-processing perspective that dominated research on transfer during most of the second half of the last century, transfer is the result of a process of structural correspondences between abstract mental representations (e.g., Gick & Holyoak, 1983; Reed, 1993). According to this view, bodily and situated experiences in the world are encoded and stored in abstract symbolic form in mental memory systems (Vera & Simon, 1993). Importantly, these representations, and the situations they represent, are seen as being constituted by two kinds of substances or structures. On the one hand, representations have a *surface structure,* which consisting of the "literal objects, concepts, or entities" that are "explicit" in a situation (Chi & VanLehn, 2012, p. 178). On the other hand, they have a *deep structure,* a "structured syntax" (Day & Goldstone, 2012, p. 154) that connects the surface objects into coherent, systematic wholes. According to this view, the ability to act on a new problem situation in terms of a previously known "type" of problem situation, despite the differences in surface (context-bound) features, depends on the ability to perceive the *deep,* context-free *structure* (e.g., Singley & Anderson, 1989; Gentner & Markman, 1997).

Building on these premises, researchers during the seventies and eighties investigated learning transfer in experimental laboratory studies in which participants first learned to solve a problem or set of problems, then were presented a second problem that was, to the eyes of the experimenters, isomorphic in its conceptual or "deep structure," but different in its "surface features" (e.g., Gick & Holyoak, 1983; Reed, Ernst, & Banerji, 1974). This research tradition, however, has been the object of much critique during the last decades on both empirical and theoretical grounds.

Empirical challenges to the classical view

Challenges to the view sketched above have emerged on several empirical grounds. First, most experimental studies conducted within the transfer paradigm failed to show spontaneous transfer of the problem-solving skills learned during the initial task into the second task, which, in the view of the researchers, was isomorphic in its "deep structure" but different in its "surface features." Most often, participants transferred what they had learned in prior situations most readily when the problems shared surface features, or when they were explicitly prompted by the researchers to draw connections between the two situations (e.g., Gick & Holyoak, 1983; Reed, 1987). The finding that the surface commonalities between cases are the strongest driving force in succeeding during transfer tasks, which Day and Goldstone (2012) summarize as being "by far the most robust finding" (p. 154) in transfer research, has come to be known as the *failure-to-transfer* paradox (Chi & VanLehn, 2012; Detterman, 1993; Lave, 1988). The paradox lies in the contradiction between the premise that transfer depends upon the identification (conscious or subconscious) of common, context-free deep structure, and the observation that it is the context-bound aspects which seem to be most determinant.

Further empirical findings contradicting the cognitivist premises sketched above emerged as a series of ethnographic studies moved research out of the laboratory and into informal everyday settings. These studies investigated the extent to which conceptual (e.g., mathematical) problem-solving skills were similarly displayed across formal and informal contexts (e.g., Lave, Murtaugh, & Rocha, 1984; Lave, 1988; Nunes, Schliemann, & Carraher, 1993; Suchman, 1987). Particularly influential was the seminal work of Lave (1988), who compared arithmetic practices in formal school situations and during everyday situations such as grocery shopping in the supermarket. In her studies, she found important discontinuities between the ways that the same participants performed arithmetic calculations in the formal and the informal situations. Lave described how arithmetic problem-solving practices that may have been seen as isomorphic from an expert's perspective (a) were structured differently by the participants (b) as a function of the actual material and cultural contingencies of the emerging situations.

Theoretical challenges to the classical view

In addition to the empirical findings described above, several theoretical problems have been articulated in the literature during the most recent decades. Upon examination of the literature, three related implications that derive from the representationalist stance of the relation between learners and their context can be identified. First, an approach that holds an unproblematic relation between structure in the environment and an individual's representation thereof requires an a priori, unequivocal definition of what the relevant, inherent properties or structures in the

environment are that can be represented, thus neglecting or at least not accounting for the myriad possible ways in which learners may structure a situation differently than researchers, teachers, or experts in a given domain do (e.g., Lave, 1988; Lobato, 2003). An implication of this assumption in research on education is that, by using this approach, we begin by adopting a particular stance of how the world *ought* to look like for the students. Thus, from this approach we can inquire whether or not learners achieve a favored, canonical understanding of a problem situation that we have previously selected, but we cannot account for other alternative understandings that the learners may have achieved of the situation.

Second, by holding that representations are *symbolic* descriptions of the structures in the environment—i.e., that representations *denote* or *describe* objects, properties, and their relations (e.g., Gentner & Markman, 1997)—information-processing approaches divorce perception from the motives and material contingencies that characterize situated action, while on the other hand they conflate the processes of perceiving that particular structure (e.g., seeing a graph) and the process of conceptualizing it (e.g., reasoning about the graph as having a particular currency in a particular scientific practice) (Clancy, 1997; Wagner, 2010). From this view, knowing is always "inherently *conceptually* knowing *about* some *thing*" (Clancey, 1997, p. 279, original emphasis). This assumption, however, makes it difficult to account for the empirical evidence presented above, which suggests that relating a new problem situation to prior experience entails dealing with the particular contingencies. It also makes it difficult to account for the emergence of new knowledge structures during learning situations. For, if symbolic processing and deep structure govern the organization of thinking at both the perceptual and the conceptual level, how do the knowledge structures necessary for processing emerge in the first place? This question, the so-called *learning paradox* (e.g., Bereiter, 1986), is recognized as one of the major troubles of the classical cognitivist approach (Roth, 2011; Sfard, 2008).

Addressing the challenges to the classical view

The empirical and theoretical evidence described above challenge the idea that transfer is dependent on context-free structures. To address these challenges, several researchers from the information-processing perspective have adapted their models and methods without modifying the basic premises of knowing as the encoding and representing of information in abstract knowledge representations (e.g., Chi & VanLehn, 2012; Gentner, Loewinstein, & Thompson, 2003; Kolodner, 1997; Nokes, 2009). However, by maintaining the assumption of an unproblematic relation between the objective structures in the environment and the symbolic representations that an individual holds of them, these approaches do not solve the more fundamental problem of how it is possible to perceive structure in the first place when we do not yet have the necessary representations to perceive it.

During the last decades, several researchers have advanced not just reorganizations of the classical notion of transfer, but deeper re-conceptualizations of the whole concept. These include sociocultural conceptualizations of transfer as *consequential transitions* across social activities (Beach, 1999); activity-theory-oriented conceptualizations of transfer as *developmental transfer* between activity systems (Tuomi-Gröhn & Engeström, 2003; Konkola et al., 2007); situative approaches emphasizing the perception of *affordances* in the environment (Greeno, Moore, & Smith, 1993; Engle, 2006; Lobato et al., 2012); phenomenological analyses of transfer as the awakening of

bodily *episodic feelings* (Nemirovsky, 2011); and constructivist approaches replacing the notion of abstract representations by that of context-sensitive *concept projection*s (diSessa & Wagner, 2005; Wagner, 2010). Common to all of them is an expansion of their conceptualizations of learning beyond the individual mental abstract representation to better account for the intrinsic relation between subjects and their immediate material and social environments. In the following section, I discuss these alternative frameworks in more detail.

Alternative theoretical technologies

In this section, I provide a detailed account of two particular studies to characterize two of the most influential approaches that have been developed to address the challenges described above—the constructivist and sociocultural/situative (ecological) approaches. The studies are selected for several reasons. First, each study can be seen as representative of one of the two major strands. Of course, considerable variability exists within each approach, a variability that is not possible to cover within the scope of this dissertation. For that reason, throughout the analyses I elaborate on how the features found in the two particular studies coincide with or differ from extant research from similar approaches. Second, the two studies specifically address the problems with the classical paradigm described above and pursue accounting for how learners come to establish relations of similarity across situations through context-bound activities. Third, the two studies are recent and published in one of the most influential journals in the cognitive and the learning sciences, thus constituting up-to-date and relevant contributions to the fields of interest to this thesis. Both studies provide important contributions toward a characterization of the role of context in establishing conceptual connections across objects and situations during educational activities. Finally, the two studies take a methodological approach that can be coined as *event-centered* (Reimann, 2009), as opposed to a variable-based or systemic approach (Arnseth & Ludvigsen, 2006). Accordingly, the studies' interest is in studying learning events as these unfold in real time. Throughout my account, I pay particular attention to the video-based analyses of interaction. As discussed below, the two studies conduct different kinds of analysis. This makes it possible to elaborate a critical assessment of how theoretical technologies typical in constructivist and ecological approaches result in particular kinds of empirical objects, and therefore in particular accounts of how conceptual structures and objects of learning emerge and are connected through activity.

Constructivist approaches I

Constructivism has possibly been the most influential approach in educational research since Jean Piaget's writings became widely influential during the sixties and seventies (e.g., Piaget, 1974, 1977). Piaget's conceptualizations of children's cognitive development as involving the formation of logical interpretive structures provided the ground for the emergence of a long tradition of *conceptual change* studies. Conceptual change studies investigate the conceptions that students generate during activity in their attempts to make sense of the surrounding world (e.g., Carey, 1985; diSessa, 2006; Posner et al., 1982; Treagust & Duit, 2008; Vousniadou, 2008).

Despite retaining a focus on internal mental processes as a mediating mechanism between ontologically distinct learning subjects and objective environments, Piagetian

and neo-Piagetian frameworks differ from information-processing approaches in that they do not assume an unproblematic relation between the world and its representation in the mind. Instead, individuals *construct* the representation. Piaget explained this process of construction as consisting in cognitive processes of *empirical* and *reflective* abstraction (Piaget, 1977). Through the former, individuals develop an understanding of the properties of the things in the world as a result of registering sensorimotor patterns that arise during active interaction with the world. Through the latter, patterns of one's mental activities are registered. These patterns result in schemata, which further develop through the processes of *assimilation* and *accommodation.*

Notwithstanding the wide adoption of the constructivist framework, few explicit attempts have been made to address the problem of transfer from this perspective. An exception is the work of Wagner and diSessa, who have developed the *transfer-in-pieces* framework (diSessa & Wagner, 2005; Wagner, 2006). Building on this framework, Wagner (2010) has recently advanced a detailed account of how people structure different situations as belonging to a same class of conceptual—in this case, mathematical—activity. Wagner's study attempts to challenge the classical premise that "transfer requires the identification of common structure across situations" (p. 451) by showing "how what experts consider a *single* mathematical concept or principle may come to be recognized through a *variety* of assimilatory cognitive resources whose usefulness is influenced by contextual factors" (p. 443). It is in addressing the relation between "contextual affordances" (p. 444) and the development of coherent conceptualizations that Wagner's study is particularly relevant to this thesis.

Constructivist approaches II: Wagner's transfer-in-pieces

Central to Wagner's approach is the notion of *concept projection,* which in several ways differs from the classical notion of mental representation as well as from other characterizations from the conceptual change literature that consider individuals' mental conceptions as consisting of coherent, relatively systematic frameworks (e.g., Vosniadou & Skopeliti, 2013). A concept projection is "a set of knowledge elements with which a knower assimilates and interprets … the situation's *affordances* in a particular, meaningful way" (Wagner, 2010, p. 450). Importantly, those knowledge elements are not abstract but "context-sensitive" (p. 450). Thus, "any single concept may require the use of different knowledge elements by the knower in order to attend to … and sensibly coordinate information relevant to that concept in a particular context" (p. 450).

Drawing on this framework, Wagner presents a detailed case study of a single undergraduate student who solves and reflects upon a number of problems involving a common mathematical principle (the law of large numbers) during a *teaching interview* (Hershkowitz, Schwarz, & Dreyfus, 2001). The case study is complemented with excerpts from interviews with five other students. During the interviews, Wagner presented the students with a variety of problems, activities, and computer simulations related to the mathematical "law of large numbers," which the students had been learning about during their regular classroom time. To analyze the ways in which the students structured and related the different problem situations, Wagner conducts microgenetic analyses of the moment-by-moment actions and utterances. Wagner (2010) describes his analytical approach as *knowledge analysis,* which aims at

"describing students' responses with respect to knowledge used as suggested especially by accompanying language and reasoning strategies" (p. 455). Wagner's method, thus, falls within a larger family of analytical practices that are common in conceptual change studies, where interactional data is used to make inferences regarding the knowledge held by the participants. In these practices, verbalizations and actions are interpreted as the expressions of an underlying conception that, although hidden from direct examination, somehow dominates the participants' speech and gestures.

To better understand how Wagner makes use of this method, I examine some of the concrete analyses that the author presents in his study to account for how a student, Jason, comes to structure and draw conceptual connections across different problems that relate to a common mathematical principle, the "law of large numbers." I present the analyses in three sections that highlight practices that can be found in other constructivist-oriented analyses of social interaction: *reifying talk and gestures as expressions of underlying hidden knowledge, treating the knowledge domain as the context of interaction,* and *reifying courses of ordered action as courses of mental synthesis*. In discussing these aspects, my aim is to address general questions about data analysis rather than Wagner's specific case.

- *Reifying talk and gestures as expressions of underlying hidden knowledge*

The first practice I wish to discuss is that of treating the participants' talk and gestures as expressions of underlying knowledge that needs to be inferred by means of the analyses. To illustrate this practice, I recur to the excerpt below, which takes place as Jason attempts to solve a problem. In the problem, a skier who knows that she can run a particular course in under 2 minutes and 15 seconds should choose between running that course only once, or running it three times to compute the average, in order to qualify for a competition. Jason has to decide which option is best. To facilitate reading, I present the excerpts numbered (they are not numbered in the original), and shorten some of the length elaborations that do not feature in the analyses by using ellipses (…).

1 J: So I think it's better for her to shoot for just doing it once, give all of her gusto once. Because, let's say, even if we had the three times, the other choice, she would do one really bad [gestures to his left], one really good [gestures to his right], and so the other one was a true representation of her 40% [moves hands together to meet in front of him] (…) So I would say run the course once and drink a lot of Gatorade and feel real good.

2 W: What did you mean there when you said, "take the one left and represent that with 40"? I'm not sure what that meant.

3 J: For some-, it's not, it doesn't, I don't see the math in it. But it seems for some reason on, on averages, or, well, I guess it's the average compared to the median, almost. Do you have that balance? So she has an extreme over here [gestures to his left], a real bad day, a real good day [gestures to his right], or vice versa, two of them are gone, we can exclude those, because that almost seems like chance. A good one and a bad one. Then only left with what she typically is [joins hands together]. I don't know if there's math that could-, which is 40. (…)

4 W: So do you have any math associated with that or not?

5 J: It seems like the average is what a-. Well, just loose. Nothing, no numbers, actually bop in my mind and [garbled].

6 W: OK, so, so I'll ask it this way. Have, have you used that concept somewhere else?

7 J: I think so. Or at least on that, the concept of, of averages being weighted here, weighted here. And that, you know, if you get something here you have to balance here if you want to-. I think.

Wagner (W) begins his analysis by drawing the inference that "Jason interpreted this problem through his understanding of how averages work" (p. 457). To ground such a claim, the author refers to Jason's uses of the term "average value" and his "repeated use of hand gestures varying between extremely high or low values and a central … value" (p. 457), which the author interprets as a "visual presentation" of Jason's reasoning. In this, the student's speech and gestures are taken as an expression of an underlying "understanding" of "how averages work." Words and gestures are presenting something—an underlying understanding—that they themselves are not, but which nonetheless can be inferred from them. Importantly, participants do not seem to have to be aware of it for the analyst to identify such an understanding. Thus, that a concept of the "average weights" grounds the student's talk is not something that the student explicitly articulates. Indeed, it is not until the interviewer offers the idea of "a concept" in turns 4 and 6 that the student begins to talk of the concept of "average weights" as a possible way to characterize his ongoing reasoning. Paradoxically, however, what could be seen as a product of the unfolding conversation is presented as the explanatory structure underlying it.

- *Treating the knowledge domain as the context of interaction*

An important goal in Wagner's analyses, and a general goal in any model aiming to overcome the limitations of the classical approach discussed above, is to account for how contextual aspects are related to the emergence of coherence and continuity during activity. Despite the careful attention to interactional detail, however, in different parts of Wagner's analyses context seems to be conceptualized as consisting of the explicit problem formulations or the implicit mathematical knowledge domain rather than the actual interview situations being analyzed. Thus, in the excerpt above, there seems to be work conducted by the researcher (W) in conducting the interview, producing questions that seem responsive to the ways the student answers. In Wagner's analyses, however, these questions (turns 4 and 6) seem to be treated as means to pull out from the student what he already understands or knows rather than being directly involved in the formation of Jason's thinking. Rather than focusing on the material aspects of the ongoing interaction, there is a focus on whether and how the problems are being discussed in mathematical terms. This aspect can be further illustrated in the excerpts below, where Jason is discussing another problem, one in which he is asked whether Christina, who does not play squash as well as her friend Angela does, should go for a 9-point or a 15-point match if she wishes to have more chances to win. The excerpts are interesting because, as Wagner elaborates, Jason comes to associate his reasoning about percentages and averages with a previous task involving "flipping the coin." That is, Jason comes to draw conceptual connections across the different problems.

1 J: … OK. So we assume Christina stinks. She's below average, saying average is 50%. She's below average [gestures to his left]. Uh, the other chick's above average, above 50% [gestures to his right]. The above 50%, it's gonna be easy to keep on going high, and it would be easier for the lower one, the one who plays bad to go low, because she only has to do better on a few times. It's, it's almost like those ones we were talking about. (…)

2 W: [garbled] Talk about how it's like those other ones. // I mean, I [garbled]. //

3 J: // Like, uh, flipping // flipping the coin. Uh, if you wanted exactly something or between something, sometimes you might want to go ten times, sometimes you might want to go ten thousand. Um, it's where I think this is the same sort of thing, to where she's below average, so she wants to go

less, to where the other person is better than average would want to go more. I think that, the average comes into play there, um, for each of them (…)

…

4 J: This, the same thing, in a sense of…she's choosing the options of once or three times. Large, small. A, B. Um, large small; large, small; A and B again. [Flipping between the Skier and the Hospital Problems as he talks]

5 W: They're similar in the choice she has to make. Are they similar in the, in the principles you used to answer them?

6 J: Exactly. They're exact in the sense of, from two ways, maybe, the person to do something who has a bad-. This is less math, but just-. The person who USUALLY does not do it well, is better to do it less times, than more …

Wagner's main claim with regard to the episode is that "Jason made an association between an intuitive argument against a poor performer consistently performing well over a long period of time and his understanding of the law of large numbers" (p. 461). Although the law of large numbers is not mentioned in the excerpt, Wagner finds evidence that "Jason associated his reasoning with his experience of the law of large numbers through the coin-flipping simulations"—a task that the student had solved previously. Although Jason had not structured the previous problems as having to do with the law of large numbers, in the current excerpt he mentions that the problem is "almost like those" about flipping the coin" (turns 1 and 3). This, Wagner convincingly argues, shows that Jason comes to structure differently a number of problems (some of them in terms of "average," others in terms of "the law of large numbers"), yet recognizes them as addressing *the same* underlying mathematical principle.

However, and despite acknowledging the "context-dependent and rather intuitive" ways in which Jason discusses the connection, Wagner seems to pay little attention to the interview situation as part of the developmental process that he is describing. Rather, the author focuses on the problems' statements, which, according to him, in previous occasions had not given the affordances to draw the connection that the student has now achieved. Thus, Wagner suggests, "the peculiar nature of the sample sizes in the problem served as a distraction for Jason" because "nothing in the statement or context of the problem gave the idea of statistical sampling or the law of large numbers high cuing priority, and the question of whether to average or not to average—reflecting the actual problem statement itself—became the point of concern" (p. 458).

- *Reifying courses of ordered action as courses of mental synthesis*

Throughout the analyses, Wagner aims to demonstrate how Jason came to accommodate his understanding of the "law of large numbers" to the different contextual situations that the different problems posed. In doing so, Wagner provides detailed accounts of the interactional materials that he is analyzing. It would indeed seem that those interactional materials are fundamental to the phenomenon being described. Thus, with regard to the excerpts presented above, Wagner argues, "*it is here*, in the accompanying adjustments to Jason's knowledge structures that took place as he associated previously distinct ideas, that I locate his process of accommodating different contextual conditions" (p. 461, emphasis added). *Accommodation*, then, seems to be described as a local, publicly available process that takes place in and as the actions that the participants perform during interaction. However, as the analysis continues, we do not find an articulation of how these

interactional materials are involved in the process. In explaining how Jason had come to develop his new understanding, gestures and utterances acquire a *self-actional* character (Dewey & Bentley, 1949); that is, they are described as having independent cognitive powers. As Wagner notes, "Jason's … language and interpretive ideas were assimilatory knowledge elements with which he composed a concept projection for the law of large numbers that served him well in structuring particular contextual circumstances" (p. 464). Jason's words are thus conceived as "assimilatory knowledge elements" in their own right, without reference to their actual contexts of occurrence, that is, independent of the interview as the social and material context under analysis.

There is in this treatment an inversion in which the cognitive processes of assimilation and accommodation, which are inferred from the conversation, come to be posited as existing *in advance* of the conversation itself. Thus, in describing what arguably is a course of situated action during which new ways of structuring and connecting problems indeed *emerge*, the circumstances of such emergence—the words and actions that are materially produced in the course of activity—are submitted to a formal process that is then given ultimate causality to explain the sequence(s). There is no account of interaction as a process of change; rather, interaction is explained by the mental changes that are assumed to underlie the episode. This practice, which can be found throughout much literature on conceptual change, stems from the (more or less) tacit premise that conceptual thinking underlies all situated action. Yet, empirical research from an ecological perspective has shown that the *conceptions* and *misconceptions* that researchers identify in interviews are as much results of the ongoing material interactions taking place during conversation as they are part of the participants' knowledge and thinking (Schoultz, Wyndhamn, & Säljö, 2001; Roth, Lee, & Hwang, 2008).

Summary

Wagner's constructivist transfer-in-pieces approach represents an important re-conceptualization that overcomes many of the problems of classic paradigm. The framework provides a neat distinction between the processes by means of which a situation comes to be structurally perceived on the one hand, and by means of which it is subsequently associated with a particular class of situations on the other. It offers a transfer mechanism that builds upon the interdependence between knowledge elements and situational contingencies rather than on abstract, context-free representations. Yet, despite acknowledging the context-bound nature of learning in its premises, upon examination of the analytical practices it is possible to observe how some of the limitations associated with the classical paradigm are retained. Whereas the analyses provide convincing evidence that the students were developing different ways of structuring diverse problems, yet conceptually connecting them to the same underlying mathematical principle, they do not provide an account of how these achievements were related to the immediate contextual aspects of the interview situations that were being analyzed.

Sociocultural and situative approaches I

Since ethnographic studies such as those by Lave began to evidence the inherent discontinuities that characterize arithmetic practices across formal and informal settings, a growing number of researchers have been concerned with developing new

conceptualizations of continuity and coherence, building upon the premise that knowing is an accomplishment of situated *social practice*. Unlike constructivist approaches, which set the analytical focus on an individual's mental constructions, sociocultural and situative approaches aim to investigate how structures and structural connections emerge in and as the result of coordinated social activities that take place as people participate in and across different social practices. Notions such as *trajectories of participation* have been developed to account for this aspect of growth as indivisible from the social contexts within which it develops (Lave & Wenger, 1991; Ludvigsen et al., 2011).

A way in which studies within these frameworks get away from the premise of a dualistic division between subjects and objects is by appealing to the notion of *affordances,* as developed in Gibson's ecological psychology (Gibson, 1979). According to Gibson, "the perceiving of an affordance is *not* a process of perceiving a value-free physical object to which meaning is somehow added" (p. 140, emphasis added). Rather, the notion aims to capture the inseparability of our perceptual processes and our sensory-motor coordinations with the environment during situated activity: "the possibilities of the environment and the way of life of the [organism] go together inseparably" (p. 141). Greeno, Smith, and Moore (1993) build on this notion to offer a situative alternative account in which seeing coherence and continuity across different situations does not consist of bringing the same knowledge structure, but occurs as the structure of affordances of an activity is perceived as invariant across changing situations.

Another important premise in ecological approaches is the *culturally mediated* nature of learning and cognition (Vygotsky, 1978). Accordingly, as discussed in detail in Chapter 3, *cultural tool*s, and most importantly language, shape the ways we come to think and relate to the world around us. In this regard, researchers have investigated *discursive practices* such as *recaps* that teachers elaborate to summarize and conceptually connect classroom activities (Edwards & Mercer, 1987; Mercer, 1995), and they have discussed *pedagogical link-making* as a fundamental practice that teachers perform to draw conceptual connections across ideas (Scott, Mortimer, & Ametller, 2011). Engle (2006) discussed the notion of *framing interactions* to describe the ways in which a teacher performed particular discursive moves to frame the different problem-solving activities in which a group of students engaged as conceptually related to each other, and to frame the students' participation in ways that promoted intercontextuality. Combining content analysis and interaction analysis methods, Engle concluded that "transfer is more likely to occur—all other things being equal—to the extent that learning contexts are framed as part of larger ongoing activities in which students are integral participants."

In this section, my aim is to examine how the premises and analytical practices that are common across these studies play out in the concrete analytical work of one particular study. I have chosen Lobato et al.'s study because it nicely combines aspects from both situative and sociocultural approaches. With regard to the former, the study emphases perceptual processes that emerge during social activity. With regard to the latter, the study also pays attention to the role of the cultural artifacts in organizing activity. The study builds upon the *actor-oriented* transfer perspective, which Lobato has developed to approach continuity from the point of view of the learners rather than from pre-given, expert-based definitions of what kind of

knowledge is interesting to investigate (Lobato, 2003, 2012). The goal of Lobato et al.'s (2012) study is to expand that perspective by elaborating on the notion of *noticing* as a plausible "transfer process" (p. 433). In the context of their study (mathematics education), noticing refers to "selecting, interpreting, and working with particular mathematical features or regularities when multiple sources of information compete for students' attention" (p. 438).

Sociocultural and situative approaches II: Lobato et al.'s "noticing framework"

An important premise in Lobato et al.'s study is that there is interdependence between what learners come to notice during a classroom situation and how such noticing relates to the social organization of the classroom activity. To investigate this interdependence, the authors present the *focusing framework.* The framework identifies a set of situational aspects or elements, including (a) *task features,* (b) *centers of focus,* which describe the features that teachers and students pay attention to, (c) *focusing interactions* or "discursive practices" (p. 440) by means of which particular centers of focus emerge, and (d) the *nature of the mathematical activity*, which aims at capturing the "classrooms' culture of doing mathematics" (p. 441). These elements then become different levels of analysis by means of which the authors investigate how "the nature of reasoning on transfer tasks across students from two classes are related to the centers of focus that emerged in each class" (p. 442). In the following, I describe how the framework is applied in concrete analyses, paying special attention to how social interaction data is mobilized to draw inferences about conceptual coherence and continuity phenomena.

- *Identifying discursive practices*

The first step in Lobato et al.'s analyses consists in identifying different reasoning trends among four classrooms of 8^{th}- and 9^{th}-grade students studying the same mathematical topic, namely "slope and linear functions." To that end, the authors analyze individual interviews, the classroom materials produced by the students, and video recordings from the actual classroom interactions. In analyzing these materials, the authors identify two different patterns of reasoning about linear function graphs. In one classroom, the students consistently appeared to treat the points and axes in the graph as representing *quantities,* that is, "conceptions of attributes of objects, events, or situations as being measurable" (p. 452). By contrast, in the other classroom the students consistently treated the same aspects as *physical objects*, which limited the students' ability to correctly find and interpret the slope in context. Unlike classical transfer studies that would disregard these practices as a failure-to-transfer, within the actor-oriented framework these are studied as events of coherence achievement.

As other studies from an ecological perspective do, Lobato et al. set their study to identify *discursive practices* associated with the two identified reasoning trends. To that end, the researchers turn to the analyses of the video recordings of the actual classroom situations. A first important discursive practice identified is *renaming,* which the researchers first derive from prior research by Goodwin (1994) and further identify in their own data. Goodwin describes "coding schemes" (which Lobato et al. rename as "renaming practices") as "one systematic practice used to transform the world into the categories and events that are relevant to the work of the profession" (p. 608). The second discursive practice is that of *quantitative dialogue,* which emerges from the analyses of the first class's interactions—the class that came to

develop reasoning about graphs in terms of quantities. The authors define it as "verbal communication that focuses attention on quantities as measurable attributes of objects" (Lobato et al., 2012, p. 463). A third discursive practice is *object dialogue,* namely "verbal communication that emphasizes physical objects or events without additionally focusing on relationships among measurable attributes of these objects" (p. 466). Most of the remaining analyses in Lobato et al.'s study consists in demonstrating *that*—but, as we shall see, not so much *how*—these discursive practices are related to the emergence of distinctive forms of reasoning about graphs in each of the classrooms.

- *Reifying situated interaction as discursive practice*

Particularly important for the purpose of this chapter is to examine the ways in which interaction data is mobilized to provide accounts of how coherence and continuity are achieved as social, context-bound achievements. To do so, I focus on how the discursive practice of *renaming* is investigated in what the authors call "focusing interactions." As part of their analyses, the authors present the following excerpt from the classroom that came to develop reasoning about graphs in terms of quantities. The episode takes place after the teacher asks the students to graph a known same-speed value of 30 centimeters in 12 seconds. The interaction takes place as there is a graph inscribed in the whiteboard with time in seconds in the *x*-axis and distance in centimeters in the *y-axis*. Before, the teacher has emphasized that it is "points" that must be inscribed in the graph to mark values, and that these "points" are labeled by a number pair, which in the example above would be "(12, 30)." The excerpt is presented as part of the evidence that "same-speed value was renamed as a point" and that this renaming "was accomplished in a manner that supported students' continued quantitative reasoning" (p. 463). In the excerpt, the students are working to address the questions "Can you think of any other points that you can put on the graph?" and "How many points do you think there will be?" (S: student; T: Teacher).

1 S: How many points do you think there will be like to count these?

2 T: Well do you think that's it, or do you think that you can put more up there?

3 S: You can put any single point right here [gestured to the graph].

4 T: Well if you put a point out here [gestured to a region not populated with points], do you think that it will be the same-speed value?

5 S: No.

6 T: Okay do you think there are any others that are same-speed values?

7 S: It could be 20 and 8.

8 T: Then you need to keep going. You've got a few more in there.

Despite the relative detail of the excerpt, which describes talk and gestures, as the sole analysis the authors state the following: "In this exchange, the meaning of *point* was negotiated and associated with 'same-speed' value" (p. 464). From reading the premises that frame the presentation of the excerpt, the reader gets the sense that the excerpt is meant to exhibit the "negotiation of meaning" of the word "point," and that the word comes to be used to name a particular feature of the graph, namely the same-speed values. However, no articulation is given of just *how* the excerpt is evidence of what it is claimed to be evidence of (a negotiation of meaning and an association of terms/features). Rather, the excerpt is presented as self-explaining, assuming that

whatever is there to be seen is immediately available to the reader. And whereas this may be so for knowledgeable readers, precisely which features of the excerpt make it readily accessible, and by means of which competences such features come to be identified, is not addressed.

This way of presenting interactional data to exemplify a discursive practice is not limited to one excerpt. The analysis follows by presenting more instances in which renaming is claimed to occur, such as when a collection of same-speed values (i.e., points) was labeled a *line,* as described in the following account:

> …one of the students, Ana, exclaimed, 'Oh I get it! So basically you can just fill the whole part . . . you can just go like this,' and she drew a line on the graph through a collection of points. The teacher immediately followed up this student's discovery by renaming the collection of same-speed values as a *line:* 'Yes, you can fill the whole entire thing . . . but would you go like this [marked dots randomly on the graph] or would they be on the line?' to which many students responded, 'The line.'" (p. 457).

In analyzing this sequence, the authors note that "renaming functioned as part of a discursive practice in which students contributed ideas and the teacher responded by rephrasing, renaming, and elaborating their ideas as part of the students' progressive mathematical development" (p. 465). Again, although specific actions such as "rephrasing," "renaming," and "elaborating" are mentioned, little to no reference is made to how those aspects come to exist as actual, material aspects of the situations transcribed. Thus, whereas evidence is provided that renaming practices lead to "solidified" ways of accounting for particular features of graphs *as* quantities (classroom 1) or *as* objects (classroom 2) throughout the history of classroom interactions, and that those ways of accounting can be found in the students' subsequent reasoning during the interviews, the question *How does the discursive practice of renaming relate to the situated practices that are transcribed in the excerpts?* remains unanswered.

- *Coherence and continuity as unproblematic aspects of discourse*

An implication of reducing interaction data in terms of larger discursive practices without specification of how the materials provide for the identification of those practices is that the emergence of coherence and continuity is presented as a seamless flow in which linguistic and bodily aspects are unproblematic for the participants. It is as if once the discursive practice has been defined, there is no need to elaborate on how the practice is brought about by the participants as an actual course of action. Most lacking is an elaboration of just *how* and *why* there is a "negotiation of meaning" going on in situ when a new category (e.g., a *point*) is introduced as a way of structuring perceptual fields in the classroom. The question is particularly important if one considers that learning/teaching situations must involve some sort of struggle, a passage along which learners come to populate a perceptual field of action that was not accessible to them before. Other studies from an ecological perspective have addressed the conflicting aspects of adopting new categories introduced as part of the [science] curriculum (e.g., Arnseth & Säljö, 2007; Ludvigsen, 2012), though these have not elaborated on issues of coherence and continuity. In general, however, and as Mehan (1998) notes in a review of the literature, sociocultural studies of classroom interaction often exhibit "snippets of inquiry, higher order thinking, and sense making, but not the incredible amount of back-stage preparation, the in situ disciplining, behavior management, and improvisation that is necessary to carry off any teaching-learning interaction" (p. 264). Rather than the "in situ disciplining" that

must be involved in any teaching situation, and which the very category of "renaming" seems to assume, the analyses offered by Lobato et al. appear to treat the transcripts "as docile fields for writing formal analysis" (Macbeth, 2003, p. 255), where the *renaming* practices appear as uncontested and unproblematic affairs for those involved in constituting the practice itself as an actual event.

Summary

Lobato et al.'s study provides important insights to any theoretical attempt to account for the emergence of coherence and continuity as a function of the social organization of classroom activities. Through a multiple-level analysis, the authors identify specific patterned practices that are associated with specific patterned forms of reasoning. These findings resonate well with other research building on the Vygotskyan premise that individual psychological functions exist first as social functions of communication, then are later internalized by individuals, and therefore the findings contribute to mounting evidence that particular forms of discourse can be related to particular ways of reasoning (e.g., Mercer & Littleton, 2007; Scott, Mortimer, & Aguiar, 2006; for a review, see Mercer, 2008). Notions such as *renaming* and *focusing interactions* grant attention to the connection between discourse and the immediate social and material environment, and thus they constitute an important reconceptualization of the relation between subjects and objects with respect to the classical approach. However, in the discussion above I have also identified limitations associated with particular analytical practices that come to treat the classroom materials of interaction as instances of the identified discursive practices that bring about coherence and continuity without elaborating on how those practices become a matter of interest to the participants in their moment-by-moment talk-in-interaction.

Units of analysis and the problem of emergence

Throughout this chapter, I have discussed different approaches to conceptual coherence and continuity. I began by describing the classical view of transfer as the carrying over of abstract knowledge structures, and then I discussed the empirical and theoretical challenges that this view has motivated. To better understand how these challenges have been taken up in the recent literature, I provided detailed accounts of two studies representing two alternate frameworks—constructivist and ecological. Though starting from different premises, both studies share an interest in describing conceptual coherence and continuity as a function of situational contingencies. Upon examination of their respective analytical practices, both achievements and limitations with regard to that aim were described. In Wagner's study, detailed descriptions of the actual courses of interaction were subsequently explained as being the result of individually constructed *concept projections*. In Lobato et al.'s study, that the achievement of conceptual coherence was inherently a social process was a premise. Yet, by identifying extended stretches of talk-in-interaction as instances of particular *discursive practices,* that study left unexplained the detailed organizational work that was performed by the teachers and students to constitute such discursive practices. In both studies, the courses of situated action that were the object of study were reduced to analytical categories—mental constructions in Wagner's case, discursive practices in Lobato et al's—that, though displaying radically different premises, had one thing in common: the exclusion of the unfolding of time as part of the minimal unit of

analysis. This is captured in schematic form in the (abstract) unit of analysis depicted in Figures 2a and 2b.

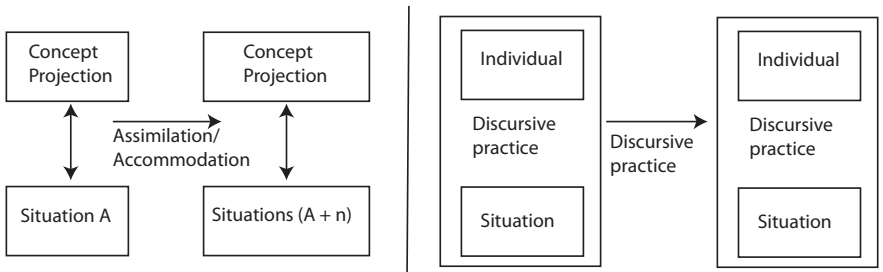

Figure 2a: Wagner's unit of analysis

Figure 2b: Lobato et al.'s unit of analysis

Figure 2: Inter-actional unit of analysis.

In the case of a constructivist framework as exhibited by Wagner, a concept projection is related to a given social and material situation (Figure 2a). Through assimilation and accommodation processes during interaction, the concept projection is expanded or transformed so as to cover a wider set of situations. Interaction, however, remains outside of the unit of analysis. In the case of an ecological framework, as exhibited by Lobato et al.'s study, the minimal unit involves a change in discursive practices, which irreducibly connect subjects and objects (Figure 2b). In the case described above, whereas before the classroom was focusing on "objects," there is now a focus on "quantities." Yet, the actual work that comes to constitute those practices, and therefore, the internal mechanisms by means of which participants come to change participation, are left out of the unit of analysis. Missing in both analytical units is the temporal transition, the process of *development* that takes place between one state of knowledge (or practice) and the following state in which a new way of accounting for objects has been established. Between states, the temporal gap is surmounted by an analytical category that accounts for the transformative situated engagements, which constitute the empirical materials that give access to the analyses.

Precisely these transformative engagements are the main focus in the foundational frameworks that were laid down by scholars such as Dewey and Vygotsky, from whom definitively the ecological models, and, according to several accounts, the constructivist frameworks as well (e.g., Phillips, 1995; Savery & Duffy, 1996), draw to elaborate their respective analytical approaches. Common to these scholars was an effort to develop units of analysis capable of accounting for coherence, continuity, and development as irreducible (i.e., not to be divided by a temporal gap) empirical objects of research in their own terms. In the remainder of this thesis, my aim is to elaborate on how the pragmatist and cultural-historical frameworks developed by Dewey and Vygotsky respectively offer a foundation on which to develop theoretical technologies to account for how talk and other bodily aspects of social interaction come to be aspects *internal* to the constitution of coherence and continuity.

Chapter 3 – Analytical Framework

In the previous chapter, I discuss the important contributions that recent constructivist and ecological approaches have made towards an understanding of the relation between the emergence of conceptual coherence and the contexts of activity within which it emerges. In the same chapter, I also point out that the units of analysis developed as part of these two research programs have left unaddressed the question of how the concrete aspects of moment-by-moment social interaction come to be constitutive moments of the phenomenon under research. This is so because of an analytical reduction of stretches of talk-in-interaction into categories—mental or discursive—that do not retain the emergent, temporal, and transformative aspects of situated action. Thus, even when the irreducible relation between subjects and social contexts is a premise, by describing actual courses of interaction in terms of "discursive practices" without specifying how the concrete interactional materials provide resources for the identification of such practices in the first place, the premise comes to be delivered as a sort of "black box." Here, I use the term *black box* in the specific sense given by anthropologist Gregory Bateson (1972), who characterized it as "a conventional agreement between scientists to stop trying to explain things at a certain point" (p. 49). As an illustration, Bateson used the example of engineers who "instead of drawing all the details [of a complicated machine], … put a box to stand for a whole bunch of parts and label the box with what that bunch of parts is supposed to do" (p. 49–50). Just as in Bateson's example, the goal of the present study is to contribute to an understanding of how the "bunch of parts" that constitute particular discursive practices are involved in the emergence of conceptual coherence and continuity during joint (e.g., classroom) activities.

In this chapter, I articulate an analytical framework that, although sharing most of the premises of current sociocultural and situative approaches, leads to a type of unit of analysis that is different from those depicted in figure 2 in that it includes not only the irreducible relation between subjects and their material and social environments, but also their transactions *as these unfold in time.* As a result, the material features of interaction, rather than being left outside of the analysis, fall within the analytical lenses as inherent but differentiated aspects of the unit as a whole (Figure 3). The framework builds upon the works of soviet psychologist Lev S. Vygotsky and American pragmatist John Dewey. Similarities and complementarities between Dewey and Vygotsky, and, more generally, between Marxist and Pragmatist

philosophies, have been the object of several publications (e.g., Garrison, 1995, 2001; Glassman, 2001; Miettinen, 2001, 2006; Russell, 1993; Stetsenko, 2008) and the source of analytical developments in the learning sciences (e.g., Clancey, 2011; Hall, 1996). In science education, Dewey's ideas have motivated a number of analytical developments. Based on Dewey's ideas, a group of scholars have advanced notions of *aesthetic understanding* as an important aspect of science education (e.g., Pugh, 2011; Wong, 2007; Wong et al., 2001). In several works, Hamza, Wickman, and colleagues have developed a pragmatist and situative approach to analyze classroom interactions that builds upon Deweyan premises, and which aims to understand how contingent aspects of activity are involved in the development of conceptual understandings (e.g., Hamza & Wickman, 2009, 2013; Wickman, 2006; Wickman & Östman, 2002). The framework elaborated in this chapter, although definitely informed by these other developments, reflects and expands original work developed as part of this thesis (Jornet, Roth, and Krange, submitted; Roth and Jornet, 2013, 2014).

I begin by articulating the historical and conceptual grounds on which Vygotsky's cultural-historical theory develops, and then I elaborate on a distinction already introduced in Chapter 1 between two alternate forms of analysis, *analysis by elements* and *analysis by units* (Vygotsky, 2012). An analysis by units, grounded on a dialectical materialist tradition of thought, allows for an elaboration of how the distinct interactional aspects are reflexively related to the larger social events of collective coherence that become their outcome. In two following sections, I elaborate how. First, a unit of analysis that includes the unfolding of time/activity as an *internal* aspect of the phenomenon under study allows for (and demands) characterizing each individual (speech, gesture) act in its reflexive relation to the whole event (activity) that is being investigated. In this regard, I discuss the notion of *semiotic mediation* (Vygotsky, 1978), according to which the words, actions, and artifacts (i.e., signs) that are mobilized during, in, and for social activity become means for affecting and controlling one's own behavior.

Second, as I elaborate in a third section, because the reflexive relation between individuals and their contexts of collective activity is seen as unfolding *in* time, neither the individual subjects nor the talk and actions that they perform can be fully accounted for from the perspective of already known linguistic or intellectual categories. This is so because, in the midst of unfolding activity, neither teachers nor students can know in advance what order their own actions and words will bring forth. Thus, to understand individual and collective activities in their mutual process of *becoming* coherent, we need to adopt the first-time-through perspective of the participants, who are both active agents and passive subjects of their own bodily engagement with others and with materials. Before *a sign* comes to mediate an individual's activity, and therefore her competence to perceive and conceptualize different aspects of engagement into a coherent whole, there must be a transition from the immediate experience of a lived-in situation to its articulation as an ordered field of action. Both Dewey in his notion of *experience,* and Vygotsky in the Russian *perezhivanie*, laid down the foundations for a unit of analysis capable of capturing this transformative process of mutual constitution between subjects and their objects during instrumental, tool-mediated activity.

Analysis by units

Cultural-historical psychology as a dialectical materialist approach

The analytical perspective that frames the work of this thesis is grounded in the cultural-historical approach founded by Vygotsky in the Russia of the 1920's and 1930's. Central to the historical emergence and development of this approach was Vygotsky's concern with overcoming the *crisis* that he found dominating the field of psychology during his time. According to Vygotsky (1997/2004), the different extant disciplines in psychological research—which included behaviorism, reflexology, psychoanalysis, and Gestalt psychology, among others—had failed to provide a consistent and unified account of the most fundamental problem of psychology, namely the relation between consciousness and behavior. Through exhaustive meta-theoretical analysis, Vygotsky came to the conclusion that these diverse disciplines could be reduced to "two different, irreconcilable types of science, two fundamentally different constructions of systems of knowledge … a natural scientific, materialistic one and a spiritualistic one" (p. 299). These two coexisting modes of doing and conceptualizing research resulted in a number of apparently insurmountable dichotomies: whereas the first approach aimed to understand psychological phenomena in terms of causality, the latter organized its object of research in terms of ideal intentions; whereas the former aimed at description, the latter aimed at explanation; whereas the former aimed to deal with mental aspects, the latter was concerned only with the material. From either side, an adequate account of both the material and the ideal aspects of consciousness seemed to be unattainable.

To overcome the dichotomies between theory and practice, and between consciousness and behavior that derived from the empiricist and metaphysical methodologies of "the two psychologies," Vygotsky argued that it was necessary to develop a *dialectical materialist* approach. Accordingly, the analytical concepts of the "new psychology" should not be *abstract* in the classical sense given by formal logic, but should retain the concrete aspects of the object under investigation: "the dialectic unity of methodology and practice, applied to psychology from two sides, is the fate and destiny of one of the psychologies" (p. 309). Vygotsky exemplifies this formal notion of abstraction discussing the notion of *reflex*—an emerging explanatory principle in the psychological discussions of the time (see, e.g., Dewey, 1896): "a reflex is an abstract concept; methodologically it is extremely valuable, but it cannot become the fundamental concept of psychology *as a concrete science of human behavior*" (Vygotsky, 1979, p. 9, emphasis added; see also Vygotsky, 1989). Importantly, the use of the notion *concrete* in cultural-historical theory is not the same as that typically made in the classical empiricist and metaphysical traditions. Thus, concrete here is not the material instantiation of an abstract category. Rather, following Marx (1857/1971), "the concrete is concrete because it is the concentration of many determinations, hence unity of the diverse" (p. 101). Understanding a phenomenon in the concrete, therefore, means understanding it as "an organic system of mutually conditioning phenomena" [by contrast] to a metaphysical conception of it as a mechanical agglomeration of immutable constituent parts that are linked with each other only externally, more or less accidentally" (Ilyenkov, 2008, p. 33).

Analysis by elements and unit analysis

In *Thinking and Speech,* Vygotsky (2012/1986) materializes the dialectical materialist approach that he had only outlined in the works cited above. Central to this work is a distinction between *analysis by elements* and *analysis by units* (or *unit analysis*). As Vygotsky writes, "Two essentially different modes of analysis are possible in the study of psychological structures… The first method analyzes complex psychological wholes into *elements*" (p. 4, original emphasis). To clarify this first method, the psychologist recurs to an analogy with the chemical analysis of water. In the analogy, an analysis into elements would take hydrogen and oxygen as the primary units of analysis. As Vygotsky notes, the advantage of such an analysis is that it leads to formal generalizations: "the chemical formula for water is equally applicable to the water in a great ocean and to the water in a raindrop" (p. 5). However, precisely because neither hydrogen nor oxygen retains the properties of the whole (water), "the student applying this method in looking for the explanation of some property of water—why it extinguishes fire, for example—will find to his surprise that hydrogen burns and oxygen sustains fire" (p. 4).

Neuropsychologist Alexander R. Luria, Vygotsky's colleague and follower, further characterizes this approach as typical of what he terms *classical science:* "Classical scholars look upon events in terms of their constituent parts. Step by step they single out … elements until they can formulate abstract, general laws. These laws are then seen as the governing agents of the phenomena … under study" (Luria, 1979, p. 174). As a result, the dynamics of the properties of the "living whole" (Cole, 2005, p. 40) are reduced to abstract categories. Just as is the case in the example of water, Vygotsky (2012/1986) argued, the approaches that take verbal thinking—i.e., word meaning—and actual speech—i.e., word phonemes—to be independent elements of analysis, cannot provide an adequate account of *verbal thinking*—the object of study in *Thinking and Speech*—as a *concrete* and unitary phenomenon.

By contrast, an *analysis by units* aims at retaining the properties of the whole under study. It involves finding that concrete and dynamic aspect of the phenomenon of interest "that is further unanalyzable and yet retains the properties of the whole" (p. 5). Rather than reducing the phenomenon through formal abstraction, the aim is to retain its richness in the analytical concepts. By contrast to the "classical" approach, *unit analysis* is characteristic of what Luria (1979) calls *romantic science*: "romantic scholars … do not follow the path of reductionism… [they] want neither to split living reality into its elementary components nor to represent the wealth of life's concrete events in abstract models" (p. 174); the goal is "to preserve the wealth of living reality" (p. 174).

In the case of the study of verbal thinking, Vygotsky (2012) finds such a minimal unit in *word meaning.* Word meaning, as a concrete aspect of the world, captures both the material (e.g., phonetic) and the ideal dimensions of consciousness. That is, in word meaning, thinking and speech are united. "A word without meaning is an empty sound" just as "the meaning of every word is a generalization or a concept … a phenomenon of thinking" (p. 225). Importantly, it is not that meaning exists in two separated domains, word and thought. Rather, word and thought are dialectically connected to each other: "Word meaning is a phenomenon of thought only insofar as thought is embodied in speech, and of speech only insofar as speech is connected with thought" (p. 223). *It is in the concrete act of speaking*—rather than in the

abstract analytical category—that thinking and word are united (on this point, see Bakhtin, 1993).

Thinking coherence from a unit analysis perspective: self-movement and diachronical historicity

When conceptual coherence, as social event, is approached from a unit analysis perspective, we need to move away from a synchronic view of the interactional processes that both analysts and participants recognize as leading to coherence. Those processes, as concrete and real, unfold in time and space. It is precisely in their concrete unfolding, in their detailed elaboration, that they provide both researchers and participants with the resources to produce and understand them, in situ, as achievements of coherence rather than of confusion, divergence, or any other possible state of affairs. From this view, therefore, achievements of conceptual coherence—as any other cognitive achievement *as* achievement, as something that was *not* but now *becomes*—are *self-moving* phenomena. That is, they develop not because of external forces but because of their own internal organization. Accordingly, the starting point of analysis cannot be an abstraction—a one-sided aspect of the phenomenon, such as an individual's knowledge or a given discursive practice—but the episode of coherence achievement as a concrete whole. It is with regard to the whole that all other elements can be meaningfully described as part of its internal historicity. Importantly, the notion of *history* here does not mean to describe the chronological succession of synchronic occurrences that are then to be integrated by formal analysis into a sort of a *backward reading*, as would be the case with the units of analysis depicted in Figure 2. It rather involves beginning by identifying the episode as a whole and then tracing its genesis by reading it *forward*. As anthropologist Tim Ingold poses it, the analysis must begin with "a world that already coheres, where things and events occur or *take place,* rather than a world of disconnected particulars that has to be rendered coherent, or joined up after the fact, in the theoretical imagination" (Ingold, 2011, p. 251). Only then can we begin to trace the history of how the different aspects of interaction are integrated to constitute a coherent whole and thus achieve a *causal-genetic* (Vygotsky, 2012) account of how context and cognition are related to each other in the joint establishment of conceptual coherence in and across activities.

The type of unit depicted in Figure 3 includes the temporal dimension that is otherwise abstracted in the unit depicted in Figure 2. It therefore includes the final result of a particular course of concrete activity (e.g., a coherence achievement) along with the concrete process of its integration through interactional materials. Yet, figure 3 does not elaborate on the reflexive connections that unite the different concrete elements (i.e., individual actions) to the whole collective activity. Nor does it elaborate on precisely which elements are to be included as fundamental. To achieve an operative unit of analysis for the study of the endogenous production of episodes of conceptual coherence, I turn to elaborate on two important analytical resources. The first one is the notion of *mediation* as developed by Vygotsky*,* which addresses how individual actions, through the introduction of *signs,* transform the ongoing activities and, by virtue of transforming collective activity, come to transform their own ways of participating in and reasoning about collective activity. The second is the notion of *experience* as a unit of analysis, which both Vygotsky and Dewey

developed to account for how processes of transformation in collective activity became an aspect of individual consciousness.

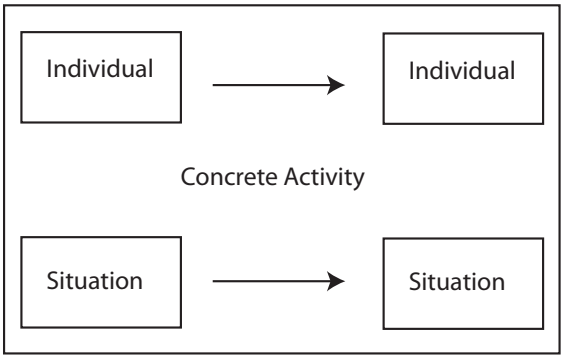

Figure 3: Transactional unit of analysis

Semiotic mediation

A central premise in cultural-historical psychology is that the relation between what a person does and the contextual situation in which she finds herself is not direct but *mediated* by instrumental activity with cultural tools and signs. Vygotsky was convinced that central to the foundation of a new psychology was the formation of a concept of human consciousness that should capture the specifically human features not just in quantitative terms, but also as *qualitatively* distinct from those of other species. Just as recent situated cognition scholars have critiqued the information-processing approaches for explaining both perceptual and conceptual processes in terms of symbolic processing (e.g., Clancey, 1997), Vygotsky critiqued the connectionist approaches of his time, which "emphasized that one and the same type of physiological connections stands behind elementary as well as higher mental functions" (Vygotsky, 2012, p. 117), the only difference being "the number of connections" (p. 117). Following a dialectical materialist stance, Vygotsky found the key in the unity of human cognition and the specific cultural forms that most uniquely define humans' activity: the use of tools and language in instrumental activity. Rather than assuming the classical stimulus-response (S-R) model of a direct relation between context and behavior, Vygotsky proposed that the relation comes to be mediated by the introduction of *signs* during joint activity with others. As he wrote, "between the stimulus to which behavior is directed and the person's reaction, a new intermediate member intervenes and the whole operation assumes the character of a mediated act" (Vygotsky, 2004/1997, p. 360).

To exemplify how subject and object come to be indirectly related by social means of interaction (i.e., signs), Vygotsky describes the development of the pointing gesture as an indicatory sign, which, according to him, "plays an important role in the development of the child's speech and in general is largely the historic basis of all higher forms of behavior" (Vygotsky, 1981, p. 160). In the case of the toddler who does not yet master cultural means of communication, and who attempts to grasp something, there is at first a direct and natural relation between her and her objective context. Her gesture is "simply [an] unsuccessful grasping movement directed toward an object and denoting a future action" (p. 160). The situation is transformed,

however, when the mother recognizes the child's unsuccessful grasping as a pointing gesture and comes to help her. Thus, the child's gesture, rather than eliciting a reaction in the object, comes to elicit a *social* relation: "there arises a reaction not on the part of the object, but on the part of another person" (p. 161). There is no longer a chain of action-reactions between child and environment. A relation with others mediates the relation with the object. A spontaneous action becomes a directing sign for others. This is the first important aspect of mediation: concrete, material aspects of natural interaction acquire relations of signification in and through joint engagement with others; signs are means to influence others.

From this derives a second function: signs as means to influence oneself's actions, as means of individual thinking. Thus, by virtue of having become a means of social interaction, the gesture can be grasped as a sign by the child too. The child can now internalize it as a means to relate to himself. As Vygotsky argued, "it is through others that we develop into ourselves" (p. 161). Vygotsky captured these two aspects of mediation in his general law of cultural development:

> "Any function in the child's cultural development appears twice, or on two planes. First it appears on the social plane, and then on the psychological plane. First it appears between people as an interpsychological category, and then within the child as an intrapsychological category" (p. 163).

Vygotsky's notion of mediation and its associated theory of cognitive development have important implications for the study of conceptual coherence. First, according to this view, the emergence of coherence is not a property or achievement of the individual mind, but a property of a societal relation (e.g., classroom activity) as a whole. Contrary to the classical Saussurian characterization of signs as tokens of an already existing formal system of meaning (i.e., language as *langue* in Saussure's terminology), from a Vygotskyan perspective signs are seen as integrated in a coherent system of signification by virtue of becoming means for the organization of concrete societal activity. Accordingly, coherence emerges *as* (i.e., is itself) a coordination of activity in which particular actions and tools (i.e., signs) acquire particular functions with regard to particular purposes. This point aligns with that made by other pragmatist and dialogically oriented scholars, such as Wittgenstein (1953/1967), Ryle (1949/1963), Dewey (1938), or Bakhtin (1981), who reject a view of language as a stable logical system and argue for views of language as a fluid aspect of *living* practice (Roth, 2014). It is this aspect that appears to have received most attention in recent ecological approaches to coherence and continuity in science and mathematics education, where studies have been concerned with the question of how learning materials such as computer simulations (e.g., Furberg, Kluge, & Ludvigsen, 2013) or traditional line graphs (e.g., Lobato et al., 2012), rather than repositories of information, become *structuring resources* in and through situated classroom activity.

A second aspect that derives from the semiotic framework elaborated above is that, because they can only be elaborated with regard to the activity as a whole, the functions and purposes of an activity—and, therefore, the relations of signification that emerge during activity—cannot be grasped in advance, but only after activity has been already carried out. The latter point has important implications for how we account for the role of individuals in establishing relations of coherence during

activity, because it implies that individual participants cannot be in full control of the actual consequences of what they do and say, and therefore—contrary to individual and social constructivist accounts—cannot aim at *constructing* what they do not yet know (Roth, 2011). This is particularly the case for students, who find themselves in a situation similar to that of the child in Vygotsky's example of the pointing gesture, where "the child is the last to become conscious of his/her gesture" (Vygotsky, 1981, p. 161). Rather than the result of something already known, it is by being part of the situation in which the gesture acquires a particular function that the possibility of mastering intentional tools for controlling others' and one's own behavior emerges. Thus, as it has been noted in the fields of sociology (e.g., Giddens, 1979), social studies of science (Pickering, 1995), cognitive archaeology (e.g., Malafouris, 2013), and anthropology (e.g., Ingold, 2013), individual intentions are an outcome and not a premise of social interaction.

In the literature on science education, however, this latter aspect has received much less attention, as discussed in length in two recent volumes (Roth 2011, 2013). Thus, even when analytical frameworks are elaborated in line with Vygotskyan premises of semiotic mediation, microgenetic analyses tend to treat individual actions, utterances, and tools mobilized during interaction in terms of what participants *already know,* often assuming that an underlying intellectual process of, e.g., *meaning-making* precedes each concrete action. As discussed in Chapter 2, a risk of this is that, despite postulating a dialectical relation between subjects and environments, individual intentions either become independent explanatory causes of activity or are dissolved as indistinguishable aspects of social discursive practices. Discussing alternative ecological approaches to the problem of transfer, Packer (2001) notes precisely the latter challenge when he wonders, "doesn't the sociocultural conception of cognition risk dissolving the person into whatever community of practice, whatever language game, they happen to be a member of?" (p. 501).

Although the cultural-historical framework discussed above does provide important conceptual tools to address this question, several researchers have pointed out that further methodological development needs to be undertaken to account for the individual as a *moment* of the social unit of analysis that the premise of semiotic mediation implies (e.g., Packer, 2001; Stetsenko & Arievitch, 2004). What is the unit of analysis that shall allow us to investigate social achievements of coherence and continuity as phenomena of change without either reifying its individual elements as self-sufficient explanatory causes of activity or dissolving those individual elements as undifferentiated aspects of the whole? Throughout my doctoral studies, I have found the ideas of American pragmatist John Dewey particularly useful to address this question. It is to those ideas that I turn in the next section.

Experience as a unit of self-movement

In this section, I discuss how Dewey's ideas about experience as an irreducible category that extends in space—across individuals and environment—and time—across a changing situation—provide a useful basis for addressing the challenges exposed above, and one that is consistent with the cultural-historical approach described above. First, I frame Dewey's contributions as part of his attempts to overcome the classical view of logic. According to the latter, rational forms consist of a set of ordered and ordering self-standing symbols. Instead, Dewey aimed to bring

logic back to the domain of lived-in joint instrumental activity. Then, I elaborate on his ideas of experience as an analytical category.

From formal to naturalistic logic

A central concern in Dewey's work was to develop a naturalistic view of logic that would overcome the limitations of both empiricist and rationalist approaches. Rather than grounded in a set of self-standing knowledge entities apprehended by reason, or as immediate sense data, Dewey argued that "rational operations *grow out* of organic activities" (Dewey, 1938, p. 19). According to him, there is interdependence between particular courses of "organic activity" and the rational forms that such activities lead to. Importantly, "rational operations grow out of organic activities, *without being identical with that from which they emerge*" (p. 19). Thus, the forms of activity that lead to forms of logic should not be confused with the latter. Accordingly, organic life cannot be accounted for in terms of the formal elements of logic that it leads to. Importantly, in using the words "organic" and "naturalistic," Dewey does not mean to exclude the cultural dimension, but seeks a *cultural naturalism* (p. 20). As he writes, "man is *naturally* a being that lives in association with other in communities possessing language" (p. 19, original emphasis).

To develop a naturalistic logic, Dewey elaborates on the *continuum of inquiry* as the basic principle underlying the establishment and organization of rational activity. Accordingly, inquiry is the situated, instrumental, and operational process of transforming "*an indeterminate situation into one that is so determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified whole"* (p. 104, original emphasis). All logical forms (e.g., the formal symbols in a mathematical formula, the words in a proposition such as "the cat is on the mat") are means-consequence relations that emerge during situated inquiry. As he poses it, "rationality as an abstract conception is precisely the generalized idea of the means-consequence relation as such" (p. 10). On this account, coherence is not given by a particular arrangement of forms and structures in themselves, but emerges as "doing and making" are involved, "which determines means … of effecting a prospective end, a unified situation, as a consequence" (p. 461). It is by reference to a *unified situation* that the different emerging forms—material and procedural—come to be integrated as forming part of a larger coherent whole. Just as in Vygotsky signs emerge as part of an ongoing societal relation, for Dewey "words mean what they mean in connection with conjoint activities that effect a common, or mutually participated in, consequence" (p. 53). The similarities of Dewey's thinking with the idea of activity as a minimal unit of analysis are here noticeable. Yet, to fully grasp the analytical implications that this view on coherence has, it is important to analyze the particular sense in which Dewey uses the notion of *situation,* and how it is related to *experience*.

Irreducibility of situation and experience

Dewey's philosophy involves a rejection of Cartesian dualism and an elaboration of how organism and environment are intrinsically related as a unit of life. Central to such an elaboration is his notion of *situation*:

> "What is designated by the word 'situation' is *not* a single object or event or set of objects and events. For we never experience nor form

> judgments about objects and events in isolation, but only in connection with a contextual whole" (p. 66).

A situation, therefore, is a contextual whole. It is only as part of such a contextual whole that any individual *experience* unfolds. As Dewey and Bentley (1999/1949) clearly remark,

> "the word 'experience' should be dropped entirely from discussion unless held strictly to a single definite use: that, namely, of calling attention to the fact that *Existence* has organism and environment as its aspects, and cannot be identified with either as an independent isolate" (p. 193).

Situation and experience, therefore, form an irreducible unity of organism and environment. In this regard, Dewey's ideas are analogous to those sketched by Vygotsky (1994) about *perezhivanie* [experience], which the Russian psychologist considers as "a unity of environmental and personal features" (p. 343). This unity extends both in time and in space. Experience extends in space in the sense that it is not seen as internal to the individual; it "does not go on simply inside a person" (Dewey, 1938/2008b, p. 39). It has, too, objective consequences in the material environment. Thus, "every genuine experience has an active side which changes in some degree the objective conditions under which further experiences are had" (p. 39). It is this realization that leads Dewey to formulate the principle of continuity, according to which "every experience enacted and undergone modifies the one who acts and undergoes, while this modification affects, whether we wish it or not, the quality of subsequent experiences" (p. 35). Hence, experience is *a moving force* that leads to transformation of both the individual and her environment as it changes the objective conditions in which further experiences are had.

Experience as an analytical category

In most literature about learning and education, the notion of experience, whether it is seen as an abstract mental process or as a social phenomenon, tends to be treated as an unproblematic aspect of the phenomena investigated (Roth & Jornet, 2014). In Dewey, however, experience is not an object of analysis but *an analytical category* that captures a process of living, of situated activity or inquiry. This is made very clear in, for example, *Knowing and the Known* (Dewey & Bentley, 1999/1949), where it is stated that experience is "neither subjective nor objective but … a *method* or system of organization" (p. 115, emphasis added). Experience is not a thing that individuals "have," but is, as the quotation says, a *method,* a *system of organization.* Similarly, Vygotsky (1994) considers *perezhivanie*—the Russian equivalent term for *experience*—as one of "a few such units with which psychological research operates" (p. 342). As a unit of analysis of personal development, however, Vygotsky never developed *perezhivanie* to the extent that he developed the unit of *word meaning* for the study of verbal thinking (Rey, 2009, 2011). In Dewey, on the other hand, we find an elaborated description of the category of experience throughout several of his latter works.

In *Art as Experience* (Dewey, 1934/2008a), Dewey makes a distinction between the general stream of experience and *an experience.* He defines the latter as that experience which "is a whole and carries with it its own individualizing quality and

self-sufficiency" (p. 42). After the fact, *an experience* "has a unity that gives it its name, *that* meal, that storm, that rupture of friendship" (p. 44). *An experience* is, therefore, that experience that can subsequently, after it has already reached a determinate conclusion, be named. In this regard, Dewey sees having an experience as the precondition for semiotic mediation to take place. It is as long as we go through some event that has both temporal extension and a *determinate* terminus that we can jointly refer to it as some*thing* distinct from the flow of experience itself as a whole. As he writes in *Logic,* "a universe of experience is the precondition of a universe of discourse" (Dewey, 1938, p. 38).

This characterization contains a view of experience as a *diachronic* category in which two aspects or moments are differentiated: one that involves a temporal unfolding of the experience as an *ongoing event*, and a second one that retains the event as a whole and that can therefore be grasped by a category or label, such as a word or a gesture. As a unit of analysis, thus, *an experience* implies a moving of itself, as ongoing process, and towards itself as final outcome. It involves self-movement. Within it, Dewey argues, neither organism nor environment can be seen as either static or in constant change, but both as becoming and as actuality. In this regard, there is in *an experience* both an aspect of *doing* and an aspect of *undergoing.* Accordingly, individuals cannot be seen as active agents only, but must be seen also as *receptive* and passive. "The undergoing phase of experience is receptive. It involves surrender" (Dewey, 1934/2008a, p. 59); it involves an element of "suffering in its large sense" (p. 47). Thus, as an aspect of experience as a becoming, the individual cannot be seen as acting only on the basis of what she already knows or what she already is, but must be seen as undergoing a process of *transformation*, as going through an *adventure* that cannot be reduced to the intellectual but must most centrally involve the affective. During an experience, Dewey writes, "the old self is put off and the new self is only forming, and the form it finally takes will depend upon the unforeseeable result of an adventure" (Dewey, 1929, p. 246).

From interaction to transaction

Throughout this chapter, I have presented a number of conceptual and analytical tools that were conceived for the study of the emergence and development of new cultural and intellectual competences. The notion of mediation allows for an analysis of how material cultural tools are involved in the genesis of intellectual competences as we engage with others in joint activities. The notion of experience, as unity of organism and environment, allows for an approach to mediation that does not take the latter only as a transitive process that brings a subject from one state of development to another, but also elaborates on how both subject and environment are transformed during this process.

The framework presented above, which combines ideas about mediation with ideas about the analytical category experience, involves a shift from a unit of analysis that focuses on *inter-action* (Figure 2) to a *transactional* unit (Figure 3). The former, Dewey & Bentley (1999/1949) note, is directed to the study of phenomena that are composed of several independent elements, and includes such cases as when

> "selves are said to inter-act with each other or with environmental objects; when small portions of organisms are said to inter-act with

> environmental objects as in the traditional theories of sensation; when minds and portions of matter in separate realms are brought by the epistemologies into pseudo-interactional forms; or, probably worst of all, when a word's meaning is severed from the word's actual presence in man's behavior, like a sort of word-soul from a word-body" (p. 133).

Transaction, by contrast, refers to the analytical procedure "where systems of description and naming are employed to deal with aspects and phases of action, without final attribution to 'elements' … 'entities,' 'essences,' or 'realities,' and without isolation of presumptively detachable 'relations'" (p. 133). A transactional approach, consistent with a unit analysis, is concerned with describing phenomena in their genesis and development. With regard to the problem of continuity that concerns us here, it pursues an elaboration of how the material elements involved in the actual interactions that lead to episodes of conceptual coherence relate to the larger unfolding whole. Most importantly, a transactional approach demands considering each of those elements, including the individual participants and the materials they participate with, as immersed in a process of *becoming*. This has the following important implications, all of which involve substituting a *backwards reading* in which the final outcome of what are actual courses of action is set as the antecedent cause with a first-time-through *forward reading* of the relation between the course of actions and the whole that comes to be its outcome.

First, the cultural tools and signs involved in classroom activities must be approached not in final form but in their process of formation. Thus, scientific and disciplinary talk, as well as such teaching materials as experiments, texts, graphs, or digital simulations, must *not* be studied as already standing for or *representing* given knowledge or meanings, but must be followed in their transition from first appearing as *presentations* in immediate experience to their being *re*presented through communicational activity. It is through situated communicational activity that what first appears in experience as presence comes to be related to, or viewed as standing for, some other event or thing. In this, the observed discursive practices shall not be read backwards and posited as antecedent conditions of the learning process under development.

Second, the individual contributions that lead to the emergence of new forms of social organization involving signs and tools—such as new ways of *talking science* in the classroom (Lemke, 1990)—cannot be described as the implementation of already formed individual cognitive competences or understandings, but must be accounted for in their process of formation. Individual cognitive functions such as perception, recognition, inference, or understanding shall neither be ignored nor accounted for as standing against the cultural signs and tools that are being perceived, recognized, inferred, or understood. These cognitive competences, too, are to be seen as distributed across space and time, and, therefore, must be described as moments of the larger unfolding social activity of coherence formation. As has been discussed above, there is in experience an aspect of receptivity during which individuals cannot be regarded as being in rational control of what they do and of what their actions lead them into.

Finally, both points raised above imply abandoning an intellectualist reading of situated activity in which linguistic aspects of interaction alone are given primacy in the organization of activity. The *performative* and *bodily* dimensions must be

addressed in their relation to the emergence of intellectual competence. The full-person-in-activity, rather than just her intellect, is the object of study. This is how Vygotsky describes *perezhivanie*: as a unity of both affective and intellectual aspects. For Vygotsky, an approach focusing only on the intellectual dimensions is problematic because "it makes the thought process appear as an autonomous flow of 'thoughts thinking themselves,' segregated from the fullness of life, from the personal needs and interests, the inclinations and impulses, of the thinker" (Vygotsky, 2012, p. 10). For Dewey, too, intellectual thinking alone cannot be the ground out of which intellect grows because, in the philosopher's words, rational "operations grow out of organic activities, *without being identical* with that from which they emerge" (Dewey, 1938, p. 18, emphasis added). That is, according to Dewey, intellectual growth cannot be explained by "prior conceptual construction" (p. 24). Rather, it must be grounded in what he calls the organization of "organic life" (p. 25). Thus, a focus on organic life involves a focus on processes of sense- and form-making as *performative* processes. This implies that sense- and form-making involve both intention and improvisation, both bodies and minds, in irreducible connection. Yet, although often recognizing bodily performances as important aspects of communication, sociocultural studies of classroom interaction tend to focus on spoken language (e.g., Mercer & Littleton, 2007; Mortimer & Scott, 2003). A transactional framework implies complementing these sociocultural-oriented studies with an account of the emergence of conceptual coherence while attending to empirical research that suggests the importance of bodily engagement with materials as a precursor to mastering symbolic forms of representation in science and mathematics education (e.g., Alibali et al., 2014; Hwang & Roth, 2013; Novack et al., 2014; Roth, 2000).

Chapter 4 – Research Setting and Methods

Throughout chapters 2 and 3, I discussed the close relation that exists between particular theoretical technologies and the empirical objects they produce. The aim of this chapter is to describe the methodic practices by means of which I have constructed the empirical objects presented in my empirical studies, and how those practices relate to the analytical framework presented in Chapter 3. First, as part of the research setting, I describe the MIRACLE project, the larger research project as part of which I have conducted my empirical studies. As a PhD candidate enrolled in the project, I have been actively involved in all phases of the process, including design, implementation, data collection, empirical analysis, and dissemination. Here, I provide a brief account of the project's general motives and how they relate to my own research purposes. In subsequent sections, I describe the data collection procedures and the data corpus. In doing so, I pay particular attention to the analyses of video recordings of social interaction, which are the core data source for my studies, providing a discussion of how interaction analysis, and in particular the ethnomethodological framework that informs it, is an adequate technique to analyze social interaction from the perspective that the unit of analysis developed in chapter 3 provides. I conclude the chapter with a consideration of validity, generalization, and ethics issues.

The MIRACLE project

The general aim of the MIRACLE project is to design, develop, and investigate technology-supported pedagogical solutions for connecting science education activities across occasions and settings. The project focuses on the socioscientific topic of *energy for the future*. This topic is part of the natural sciences curriculum in Norwegian upper secondary schools and, at the time of the project's establishment, was the planned topic for a new interactive exhibition in the Norwegian Museum of Science and Technology. Building upon this shared interest, the MIRACLE project arranged an interdisciplinary collaborative process in which a team of museum conservators, exhibition designers, learning and computer scientists, and educators participated to develop a curriculum that would foster the students' conceptual understanding of socioscientific issues by participating in activities across the school and the museum.

Throughout the collaborative design process, the different participants' interests and concerns with regard to the project's implementation were discussed and negotiated in meetings, workshops, and seminars. In several studies documenting this collaborative process, we have identified two central concerns that emerged during the collaborative work, and which became driving motives in shaping the project's technological and pedagogical solutions (Jahreie & Krange, 2011; Jahreie et al., 2011; Jornet & Jahreie, 2013).

The first concern involves considerations of how different forms of explorative engagement in the classroom and the science museum can be related to the development of conceptual understandings of curricular (socioscientific) issues. The concern has historical roots in pedagogical practices spread through science centers and museums during the most recent decades, where there is an increased interest in implementing interactive and engaging exhibitions to make scientific knowledge more accessible and appealing for the general public (e.g., Allen, 2004; Falk & Dierking, 2000; Oppenheim, 1968). The concern has also been central in science education, where educational reforms for over a half-century in the US (Pea & Collins, 2008) and the UK (Hodson, 1996) have included notions of learner-centered and *inquiry learning* as central to curriculum development.

The second concern involves how to make use of and combine diverse digital and analog technologies to facilitate the use of learning experiences in one activity/setting as resources for conceptual understanding during latter activities in the curricular trajectory. This concern also finds parallel in the respective disciplines, where there is a growing interest in implementing computer-supported forms of hands-on engagement and conceptual scaffolding in the classroom (e.g., Koschmann, 1996; Scardamalia & Bereiter, 2004; Linn, Davis, & Bell, 2004) and in the science museum (e.g., Parry, 2010; Falk & Dierking, 2008; Hall & Bannon, 2006).

To address the issues discussed above, MIRACLE has developed a technology-supported inquiry-based approach with an explicit focus on providing technological resources for teachers and students to draw connections across different activities, artifacts, and representations throughout the curriculum. In this regard, three key interrelated strategies in MIRACLE's particular approach can be identified: *providing multiple linked representations, combining open inquiry with teacher-led summary sessions,* and *providing opportunities to revisit and revise learning products* throughout the curricular trajectory. In the following, I discuss how these aspects relate to the research literature on science learning and describe the particular tools that have been developed to support them.

Providing multiple linked representations.

Building on research showing that multiple linked representations offer promise in fostering deep conceptual understanding of scientific issues when implemented as part of inquiry-based learning activities (e.g., Ainsworth, 2008; Lee et al., 2010; Rutten, van Joolingen, & van der Veen, 2012), one of the central approaches in the MIRACLE project has been the design and development of multiple ways of presenting similar or related scientific phenomena across settings and activities. To that aim, *heat pumps* were used as a means to address many of the more general socioscientific issues related to energy. Different representations of heat pumps and of the processes involved in their functioning were made available in the form of

tangible phenomena during hands-on experiments and dynamically linked digital simulations in the classroom and in the museum. An example is given in Figure 4, where we can see how the students interact with (a) a spray-can of compressed air that exhibits evaporation and condensation phenomena, (b) a digitally enhanced exhibit in the museum that displays evaporation and condensation phenomena taking place inside a heat pump, and (c) a more elaborate simulation of evaporation and condensation processes in heat pumps in the classroom setting.

Figure 4: Multiple representations of related scientific phenomena.

Combining inquiry with teacher-led summary sessions

During the most recent decades, the implementation of and research on inquiry-based learning environments has received increasing attention in the field of science education (Hmelo-Silver, Duncan, & Chinn, 2007; Hofstein & Lunetta, 1982, 2004). As several reviews show, a consistent finding across the extensive literature is the observation that inquiry-based instruction is an effective means for teaching science as long as it provides adequate supporting tools and scaffolding (Anderson, 2002; Edelson & Reiser, 2006; Hmelo-Silver et al., 2007; Minner, Levy, & Century, 2010). As part of this scaffolding, research into the role of classroom communication has shown that the role of teachers' sum-up discussions (e.g., Mercer, 2000; Scott et al, 2011) and questioning practices (e.g., Roth, 1996; Scott et al., 2006) is of particular relevance. In line with this research, MIRACLE develops a curricular trajectory where activities in which groups of three to five students engage in guided inquiry and experimentation are combined with teacher-led summary sessions in which the experiences and products of inquiry are revisited and further discussed in plenum.

Providing opportunities for revisiting and editing learning products

In addition to focusing on the teacher's role as a facilitator of the emergence of conceptual coherence and continuity through sum-up and recap practices, research has shown that supporting students' deliberate collaboration on constructing shared knowledge objects facilitates the development of integrated disciplinary understandings during inquiry activities (Damsa et al., 2010; de Jong et al., 2010; Linn & Eylon, 2011). In line with this research, the MIRACLE project has arranged for a curriculum in which students have continued access to an online repository where their own and others' learning products can be accessed, edited, and delivered as part of their course completion. As part of this, the project has designed an online platform for sharing digital products across the trajectory, including pictures, videos, and tweets that the students produced during inquiry activities. These products can be accessed through the trajectory and shared in, for example, plenary summary sessions (Figure 5).

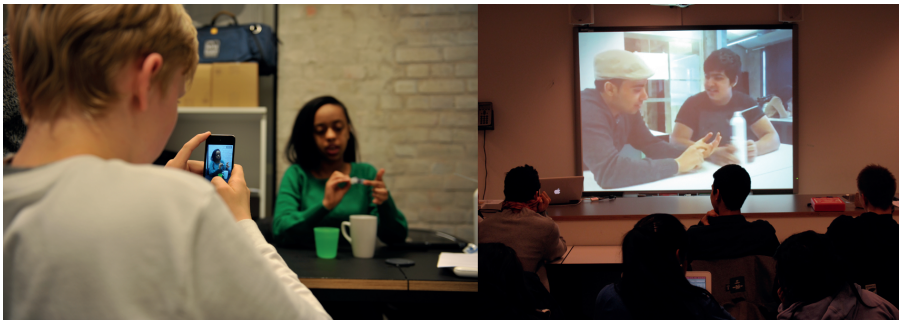

Figure 5: Students record their hands-on experimentation (left), which is subsequently shared in plenary sessions for further discussion (right).

Empirical settings and participants

The MIRACLE project is driven by a design-based—also known as *design experiment*—research approach (Brown, 1992; Collins, 1992). Design-based research is a means to investigate learning phenomena in the complexity of natural (e.g., classroom) settings, while at the same time retaining the aim of evaluating the impact in the learning outcomes of particular design aspects (Collins et al., 2004). This often leads to an *iterative design* process in which new tools and pedagogical solutions are tested and new theoretical models about learning generated (Cobb et al., 2003). As a result, both the theoretical premises and the instructional designs and institutional practices involved in teaching/learning are revised with regard to emerging pedagogical goals (Krange & Ludvigsen, 2009).

In line with its design-based research agenda, the MIRACLE project has conducted three iterations of design, implementation, and data collection (Table 1). As part of the first iteration, a pilot experimental setting featuring two different learning scenarios, a classroom and a museum space, was set up in a studio at the University of Oslo. The aim of the pilot study was to test initial developments and ideas, including early versions of the online platform (SciHub), of the digital simulations, of iPod-based applications for video and picture recording, and of a museum exhibit. Two groups of four students from an upper-secondary school and their teacher of natural sciences participated in the study. The two groups and their teacher went through a four-hour experimental sequence of activities that combined inquiry activities—including a set of physical experiments and a set of digital simulations—with teacher-led interventions in which prior experiences were summed up and discussed with regard to curricular issues. In Study II (Jornet & Roth, in press), we document how one of these groups and their teacher drew conceptual connections across the entire trajectory of activities.

	Iteration 1	**Iteration 2**	**Iteration 3**
Period	Oct 2010 – Nov 2011	Dec 2011 – April 2012	April 2012 – April 2013
Setting	Pilot experimental setting	Natural school and museum settings	Natural school and museum settings
Participants	8 students + 1 teacher	24 students + 1 teacher	32 students + 1 teacher

Table 1: Settings and participants.

During the second iteration, the tools tested in the pilot study were refined and expanded for implementation in authentic school and museum settings. An entire class of 24 students between 16 and 17 years old from a public combined lower/upper secondary school in Oslo and their teacher of natural sciences participated in the study. The curriculum, implemented over a four-week period, consisted of 20 lecture hours spread across eight days, including a day visit to the Norwegian museum of science and technology. Study I (Jornet et al., submitted) draws from data collected during this implementation to examine an episode of transfer in which a group of students identified conceptual connections between a prior hands-on activity, a digital visualization, and a scientific law.

The third iteration involved an expansion of the SciHub functionalities, including distinct interfaces for the teacher and the students, improved flow across the activities and documents available in the platform, and a tweeting functionality. In addition, a digitally enhanced exhibit was included in the museum space, and the digital simulations in the classroom were updated to correspond with the simulation in the museum. These developments were implemented in the same school and museum as the prior iteration. This study comprised 32 students and their science teacher. In Study III (Jornet, submitted), I draw from data collected during this implementation to investigate the teacher's and the students' communicative and bodily practices during sum-up plenary sessions in which videos, tweets, and other products were retrieved for discussion.

Data collection procedures and data corpus

The data sources from which my thesis draws have been collected as part of the MIRACLE project, and therefore they have been partly the result of collective decisions taken together with the larger group of researchers involved in the project. Prior to each implementation, the team met to discuss our respective research interests and to agree on the data collection procedures. To coordinate our activities, we generated data collection protocols in which the schedule, the tasks for each researcher involved in data collection, and the objectives of the data collection were specified. Common to all researchers in the MIRACLE team was an interest in cultural-historical approaches to design-based research (Krange & Ludvigsen, 2009), according to which the focus is on analyzing how the curricular interventions come to be taken up as mediational means of institutional practice. To document such processes of mediation, we collected different kinds of data sources throughout the three project implementations, as shown in Table 2. In the following, I describe those that had either core or secondary status in my thesis' investigations.

Type of data source	Iteration 1	Iteration 2	Iteration 3	Status in my thesis
Audio-visual recordings of classroom/museum interactions	07:00 hours	26:05 hours	26:51 hours	Core
Audio-visual recordings of pre- and	04:25 hours	05:20 hours	06:47 hours	Secondary

post-interviews				
Pictures of settings, documents, and field notes	Yes	Yes	Yes	Secondary
Digital log data and digital repository	No	No	Yes	Secondary
Screen recordings	No	No	02:00 hours	Secondary
Pre- and post-questionnaires	No	No	Yes	Not used

Table 2: Data corpus

During the data collection, typically two to four researchers were present in the settings. We *video recorded* all curricular activities using one to four high-definition digital video cameras, depending on whether activities took place as plenary sessions or as work in groups. The use of video recording has increasingly been adopted as a research tool in the learning sciences for studying both classroom and out-of-school learning situations (Derry et al., 2010). Video recording is a valuable tool for study of learning as social practices because, by contrast to field notes and other ethnographic materials, video recordings allow study of events in the detail of their actual production (Jordan & Henderson, 1995). In addition, gazes, facial expressions, bodily performances, and their relations to the material features of the environment can be examined in great detail.

As a general guideline, all video recordings were intended to capture *social interactions* rather than individual actions or isolated features of the environment, such as a computer screen or an artifact during the students' experimentations. When possible, a main camera was used to record the main interactions between people and artifacts, and a second camera was used to capture either closer details or aspects of the larger context (such as an illustration projected on a wall) without losing the main interaction. Because the curricular activities involved several digital surfaces, to avoid missing important data while attempting to capture the details of the students' references to these surfaces, we used video recording software to capture the events taking place in the *digital screens* during activities in which these were particularly relevant. To ensure an appropriate-quality sound without interfering in the natural organization of the classroom and the museum activities, sound was captured by several microphones, including camera-mounted microphones, flat microphones positioned on tables or adhered to walls in the classroom and the museum space, and lapel microphones clipped onto the clothes of some participants, such as the teacher or particular students during activities in which the students moved throughout the museum space.

In addition, we conducted *ethnographic observations* that we documented in *field notes* and *photographs*. Field notes allowed us to record initial assertions about the social and learning processes taking place that could later be tested and developed with regard to the entire database. Photographs were used to document the settings and activities in high detail and allowed us to digitize all of the participants' produced

and/or utilized artifacts and documents. Finally, *semi-structured interviews* with the teacher and the students were conducted before and after each of the iteration implementations. The semi-structured interviews included two main parts. First, personal experience and interests regarding school life, technology, and science and science museums were discussed. During the interviews, specific episodes that took place during the curriculum implementation and were of particular relevance to the researchers and/or to the participants were also discussed. The second part of the interviews consisted of a discussion about the conceptual domain of energy and of how particular aspects had been topicalized during the curricular activities. During this part, and in line with research showing the tool-mediated and formative nature of interview situations (e.g., Schoultz, Säljö, & Wyndhamn, 2001), artifacts and documents that were produced during the curricular activities and/or extracted from the students' textbooks were used as material resources for anchoring and motivating the discussion.

Analytical procedures and approach

In this section, I describe the analytical procedures that have led to the selection and analysis of the case studies included in this thesis. Each of the three articles included in this thesis constitutes a *case study* selected from each of the three iterations described above. A case study is a type of inquiry that "investigates a contemporary phenomenon in depth and within its real-life context" (Yin, 2009, p. 18). Thus, case studies allow for producing the kind of intimate understandings of situated activity that the transactional framework developed in Chapter 3 demands.

In the following, I first discuss the relation between my interest in analyzing conceptual coherence as an endogenous social organization of the participants on the one hand, and the pedagogical interests that derive from being part of a larger design-based research project on the other. Within that context, I introduce the notion of *bracketing*, which describes the practice by means of which researchers put aside preconceived categories that respond to their own natural inclinations or professional interests and, instead of using them to explain particular instances of conduct, focus on how the participants produce the resources necessary for recognizing those categories as observable facts of social interaction. In two following sections, I describe the procedures that led me to select particular instances of social interaction and the analytical approach by means of which I examined their moment-by-moment production.

Design-based research, bracketing, and analyses of social interaction

As part of MIRACLE's design-based research agenda, an orientation towards issues of conceptual coherence and continuity preceded my first approaches to the data corpus. However, in line with a cultural-historical approach that takes interest in design interventions as mediational tools (Krange & Ludvigsen, 2009), I have made important efforts not to bring preconceived ideas about coherence and continuity to bear on my analytical work. In this regard, and as ethnomethodologically informed approaches to video analysis in design-based research recommend (e.g., Koschmann, Stahl, & Zemel, 2007), I have kept a division of labor between the analytical accounts of social interaction on the one hand, and an acculturated interest of what is educationally important to study in a design-based project on the other. The latter

interest guides the identification of the kinds of social phenomena that become the focus of the analyses. However, to address the emergent and material aspects of interaction that are the object of my research questions, further accounts of the participants' endogenous coordination work that makes such social phenomena recognizable categories of analysis must follow. This procedure is captured by the notion of *bracketing,* which originates in Husserl's phenomenology, and which has been taken up in sociology (Schutz, 1967; Garfinkel & Sacks, 1986) and, more recently, also in educational research (Koschmann et al., 2007; Roth, 2013b). Bracketing involves a researcher putting aside her own natural or professional inclinations to categorize particular instances of activity, and, rather than uncritically accepting those categories as explanative forces, retracing the history of their emergence as observable social facts. In this regard, the notion of bracketing directs attention to "the actual labor and living work" (Roth, 2013b, p. 15) that comes to constitute phenomena as the recognizable social facts that we, as researchers, come to categorize by means of formal analyses.

Importantly, bracketing does not imply a negation of the value of formal analyses and of the resulting categories by means of which may gloss courses of action of particular interest. Thus, the researcher does not reject her culturally competent recognition of a particular episode of activity as being an instance of, e.g., transfer. On the contrary, she "continues to accept what is being bracketed" (Roth, 2013b, p. 12). Once having bracketed a particular aspect or conception about a social event, however, "the researcher focuses on *how* this or that aspect of the world … becomes a phenomenon such that her natural attitude or natural concepts include and index it" (p. 12, original emphasis). This implies providing a detailed account of how recognizable social achievements such as successfully transferring something learned in one setting into another (which I explore in Study I), or drawing a conceptual connection between a hands-on experiment and a digital simulation of a heat pump (which I explore in Study II), are produced as observable, accountable facts in and through the participants' situated interactions. In this way, the researcher provides an intimate and detailed understanding of the endogenous practices by means of which participants make us of and appropriate the designed (technical, cultural, pedagogical) tools and can use this knowledge to further inform design (Dourish & Button, 1998; Suchman, 1995).

In line with the perspective sketched above, and following practices described by *interaction analysis* (Jordan & Henderson, 1995) and more recent guidelines on video research in the learning sciences (Derry et al., 2010), I have followed a two-step procedure. First, I have used video recordings of interaction and other ethnographic materials to identify particular episodes of activity or discursive patterns of interest to the questions of conceptual coherence and continuity—*events* in Jordan and Henderson's terminology. Once particular events or a class of events were identified, I have performed detailed microgenetic analyses to account for the endogenous constitution of those episodes or practices. In the following sections, I describe both moments of the analytical practice.

Selecting the cases

To identify particular events (or classes of events) relevant to the problems of conceptual coherence and continuity, I followed a *whole-to-part inductive* procedure, as described by Jordan and Henderson (1995) and Derry et al. (2010). This involves

drawing from (a) ethnographic materials recorded during the field work and (b) repeated viewings of the corpus of video recordings, to achieve a *framing context* and to identify "interactional 'hot spots'" (Jordan & Henderson, 1995, p. 43), namely, "sites of activity for which videotaping promises to be productive" (p. 43). This context then serves as background for the microanalyses of interaction (part), which, in turn, come to inform the general ethnographic whole.

To facilitate this process, I digitized all collected materials and created a catalogued database using Nvivo 9 (Iteration 1) and Transana software (Iterations 2 and 3). All video recordings were transcribed, and the transcripts were added to the catalogue along with the video recordings. Transcribing and cataloguing the database allowed me to gain a very intimate contact with the materials, and many initial assertions about events of interest emerged during this process. In addition, design-related interests in particular aspects of the curricula and insights gained through the ethnographic observations gathered during the fieldwork also guided my first annotations about the materials. Using the notational facilities in the Transana software, I created a set of assertions and hypotheses about particular events of interest and a corresponding set of video clips that supported the generation of such assertions. I then began to test the assertions in the rest of the materials. Thus, in Study III, for example, I identified particular recursive questioning practices, as part of the teachers' methods during summary plenary sessions. I tested the adequacy of this finding by systematically searching for similar patterns in the entire database of plenary sessions. In Study I, I complemented the analyses of video recordings with analysis of field notes and recordings of the pre- and post-interviews to provide consistent evidence that a group of students had successfully made use of a particular scientific law in a number of different activities and settings.

In addition to the repeated viewings and the ethnographic contextualization of the materials, I made use of my multidisciplinary collaborative network, both within the MIRACLE project and through the InterMedia research group at the University of Oslo, and arranged several *data sessions* in which I presented selected excerpts for collective analysis. In these sessions, I could test my own hypotheses against other researchers' observations and hypotheses. Importantly, not only researchers familiar with the setting, but also professionals and other PhD students participated in these sessions, including professors and students at the LinCS institute at the University of Gothenburg, educators at the French Institute of Education in Lyon, and an international group of students working with professor Roth at the University of Brisbane, Australia. Once I selected specific events or sets of events of interest, I proceeded to prepare corresponding video clips for detailed microgenetic analyses. To conduct a most detailed transcription of interaction, including gestural and prosodic aspects of communication, I exported the clips to ELAN, a program for linguistic analysis that enables annotating and visualizing multiple layers of interaction, such as lapses, overlapping talk, and gestures, in a time-line axis. In addition, I used PRAAT, a tool developed for the analysis of phonetics, to perform detailed analyses of pitch and other prosodic aspects of talk.

Microgenetic analyses of interaction

In line with the analytical framework described in Chapter 3, the purpose of the microgenetic analyses is to investigate coherence and continuity achievements as *transactional* phenomena. Accordingly, the analyses of the selected episodes of

interaction must capture persons and settings as they *develop* over time in mutual relation. It is in this sense that I refer to them as micro*genetic*. This involves *taking the endogenous first-time-through perspective of the participants*, who are implicated in the production and understanding of the events under analysis. To that aim, and in line with *interaction analysis* practices (Jordan & Henderson, 1995), and with the conversation analysis tradition that informs them (Sacks, Schegloff, & Jefferson, 1974), I have taken the organization of *turn-taking* as the most fundamental constitutive phenomenon of social order. Here I use the notions *interaction* and *conversation* indistinctly to include what Psathas (1995) refers to as talk-in-interaction, and which Jordan and Henderson (1995) describe as "encompassing the whole range of behaviors through which people can 'take a turn'" (Jordan & Henderson, 1995, p. 64), which may involve not only talk, but also "'turns with bodies' and 'turns with artifacts'" (p. 64).

The idea that the social organization of conversation is primary in the constitution of cognitive life underlies the philosophies of influential *dialogical* thinkers, including Vygotsky, Wittgenstein, and Bakhtin (Shotter, 1993; Wertsch, 1991). The organization of turn-taking always involves at least two participants. Therefore, it always implies a *social relation* as an *irreducible* unit of analysis. Accordingly, and consistent with the transactional framework elaborated in Chapter 3, any single utterance or action performed during social interaction is to be analyzed with regard to the interactional whole of which it forms part. *A minimal unit of analysis always involves at least two turns*. Taking two turns as the minimal unit of analysis allows for adopting the participants' shop floor perspective, where relations of significations and the function of particular tools can be inspected in their *becoming* significant in and through situated action.

To investigate how the functions of signs and tools emerge as developmental and unforeseeable aspects of lived-in activity (i.e., *experience*), I have examined the organization of turn-taking at three different but mutually constitutive *levels of analysis*. These three levels are three different *time-scales* (Lemke, 2000) in which the same unitary process of microgenesis is assumed to take place. That is, the three levels are elaborations of the internal forces that constitute the unit of transaction depicted in Figure 3A.

The first level is that of *structuring* (Roth & Bowen, 2001), which involves at least two turns, the initiation of an action and its reception. It is at this level that structures in a situation emerge as salient elements of activity in the first place. It is in being perceived and responded to by others as acts of signification that individual actions emerge as meaningful means-consequence relations of activity (Dewey, 1938). As in Vygotsky's illustration, an individual's gesture acquires its intentional sense *in and through* its being responded to by others rather than by virtue of its production alone. Examining this level brings attention to the transition from immediate experience and action-related engagement to culturally mediated experience. A second level of analysis is that of *grounding* (Roth & Bowen, 2001), which involves those larger, yet unitary stretches of interaction in which emerging structures come to be related, by means of yet other gestures or language signs, to accountable ways of talking about the world (discursive practices). It is at this level that relations of signification emerge between concrete actions during, for example, science learning activities and scientific-like ways of talking. Finally, at a third level of analysis, I have examined

how practices involved in structuring and grounding come to produce a larger *context of relevance* as part of which both structuring and grounding signs are reflexively negotiated and made accountable.

Research credibility and ethical considerations

In this section, I discuss issues of research credibility and ethical considerations. Research credibility concerns the question of whether findings reported in an investigation are "confirmable, valid, and reliable" (Denzin, 2009). In the following, I discuss how my analytical and data presentation procedures deal with possible threats to reliability, validity, and generalization.

Reliability

The notion of reliability, most commonly used in quantitative paradigms to refer to how consistent a measuring instrument is across time, relates to the notion of *construct validity*, that is, how well a measurement captures the phenomena it is designed to capture. In much qualitative research, however, where the goal is not measurement but rather "generating understanding" (Stenbacka, 2001, p. 551), alternative notions, such as that of *dependability* (Lincoln & Guba, 1985) or *descriptive validity* (Maxwell, 1992), have been developed. In qualitative research in general, increasing the reliability of an study involves describing the methods by means of which "fidelity to real life, context- and situation-specificity, comprehensiveness, detail, honesty" (Cohen, Manion, & Morrison, 2007, p. 149) has been granted through the research process.

A first important aspect that has implications for reliability in my research has been the use of audiovisual recordings as the main data source. Video has qualities that strengthen reliability because it records social activities in real time, as they actually happen (Heath, Hindmarsh, & Luff, 2010; Jordan & Henderson, 1995). Moreover, video preserves the original record for further scrutiny, and a particular segment of video can be played over and over again so that "questions of what is actually on the tape versus what observers think they saw can be resolved by recourse to the tape as the final authority" (Jordan & Henderson, 1995, p. 45).

Throughout my treatment of the video materials, I have engaged in several practices that strengthen the reliability of my accounts. First, in inspecting and transcribing the video materials, I have relied on specific software designed for transcription and annotation of video, which allows for systematic and repeated viewing and annotation, as well as for modification of several parameters that facilitate detailed inspection, such as the playing pace or the sound quality. Second, collective data sessions have given me further opportunities not just to contrast hypotheses about social phenomena as such, but also to secure agreement about observations of precisely *what* the participants were doing or saying. Third, in transcribing and presenting my data, and consistent with an interest in embodied interaction, I have relied on standardized Jeffersonian notation conventions (Appendix 1), which allows for including great detail with regard not only to talk but also to gestures and prosodic aspects of talk, and which make it possible for anyone familiar with these conventions to inspect the accuracy of my descriptions. In addition, and related to this last point, I have made significant efforts to furnish my transcriptions with visual presentations of the materials, such as gestures and body positionings, which were

important to my accounts. In doing so, I have relied on specific software (as described in Studies I and III) and techniques to present the events as accurately as possible with respect to the original video footage.

Validity

Validity refers to the question of "how accurately the account represents participants' realities of the social phenomena and is credible to them" (Creswell & Miller, 2000). It is a question of how researchers draw *inferences* connecting their accounts and the phenomena their accounts are claimed to be about (Maxwell, 1992). In this regard, it is important that the researchers provide a careful and transparent account of "the ascent from the data source to the claim establishing a tight chain of argument" (Roth & Hsu, 2010, p. 142). To that aim, both throughout my empirical studies and throughout this dissertation, I have made significant efforts to keep my analytical assumptions visible with regard to the choice of methods and data sources, and to discuss how they relate to different premises in other empirical studies. Throughout extended analyses of moment-by-moment interaction, I have made my argumentative moves between the transcribed materials and the analytical accounts transparent. This, and the use of detailed conventional transcription, makes the move among premises, data, and account traceable and repeatable by others, making it possible for the reader to check the validity of my claims.

An important issue when analyzing social interaction involves providing guarantees that an *emic* rather than an etic perspective is being achieved (Maxwell, 1992). That is, that the participants' perspective is being accounted for adequately. In this regard, the interaction analysis framework from which my analyses have drawn, described in the previous section, provides several resources. First, the *next-turn proof procedure,* implied by the two-turns minimal unit of analysis described above, involves analyzing the particular sense, meaning, or intention of any single utterance by reference to how it is taken up and followed up by the producer and her co-participants through extended interaction. In this regard, I have avoided using categories external to the participants' own ways of elaborating their own situation to and for each other. Second, in taking a first-time-through perspective, I have avoided reading interaction *backwards,* namely, taking something said or done by the participants later as a resource to explain something said or done before, and have performed a forward reading, as discussed in the *analytical approach section* and in Chapter 3. Finally, I have revised my own readings of the sequentiality and consequential relevance exhibited by the participants by testing my observations in collective data sessions.

In addition to the points made above, granting the credibility of a study involves showing that "the claims are supported across the different forms of data sources" (Roth & Hsu, 2010, p. 142). In this regard, when claims about social interaction have concerned the identification of recurrent patterns or categorical observations—such as cataloguing an episode as one of "successful transfer"—I have established the frequency of the phenomenon, and have tested the hypotheses in multiple data sources, including documents generated by the participants, video recordings of the students' curricular activities, and video recordings of the pre- and post-interviews. This latter aspect has most directly contributed to supporting the *generalizability* of the findings, a topic that I address in the following section.

Generalizability

In broad terms, the issue of generalizability refers to "the extent to which one can extend the account of a particular situation or population to other persons, times, or settings than those directly studied" (Maxwell, 1992, p. 293). Because case studies focus on the context-bound detail of single cases rather than on the relative frequencies across multiple cases, the generalizability of the claims resulting from such studies has been a debated issue in the literature (e.g., Campbell, 1975; Flyvbjerg, 2006; Lincoln & Guba, 1985). Yet, whereas case studies do not represent adequate "samples" of given populations—as is required in the statistical generalization—case studies can lead to *analytical generalizations* (Yin, 2009). That is, case studies are "generalizable to theoretical propositions and not to populations" (p. 15).

Analytical generalizations imply approaching cases as particulars of the general. As Bourdieu (1992) poses it, "to construct a scientific object also demands that you take up an active and systematic posture vis-à-vis 'facts'… [it requires] that you tackle every concrete empirical case with the purpose of *building a model* (Bourdieu, 1992, p. 233, original emphasis). From this view, concrete cases of social interaction should be considered "particular instance[s] of the possible" (p. 233) and culture in general "constitute[s] generalized possibilities but [is] available only through the ways in which [it] is actually realized" (Ercikan & Roth, 2006, p. 14). Accordingly, I have approached the analyses of concrete cases with the aim of building models that describe general ways in which teachers and students generate conceptual connections between events within and across situations. On the one hand, I have elaborated how the detailed descriptions of the "hesitant and momentary contexts" (McDermott, Gospodinoff, & Aron, 1978, p. 246) that teachers and students exhibited to each other to organize joint activity could be seen as the realization of general cultural possibilities related to the achievement of conceptual coherence in and across science learning situations. On the other hand, in providing intimate knowledge of specific cases, the studies have contributed to a growing body of empirical research that provides other researchers with the type of "context-dependent knowledge and experience [that] are the very heart of expert activity" (Flybvjerg, 2006, p. 222).

Ethical considerations

Video-based ethnographic research poses a number of challenges that we as researchers must deal with to grant ethically sound practice. In compliance with national guidelines, an appropriate notification request was sent to and subsequently approved by the Norwegian Social Sciences Data Services (NSD). Following national and international guidelines, the researchers in the MIRACLE project as a collective agreed upon several measures to guarantee the potential participants' freedom to decide their participation without pressure, and to inform them about their right not to participate. Because teachers and students do not have the same institutional roles in schooling, and because their participation in the study differed in that the teachers were also involved as part of the curriculum design, we created different information letters for "teacher participants" and for "student participants." In the letters, we provided information about who the researchers and partners involved in the MIRACLE project were, what our purposes were, what their participation would consist of, and the kind of data that we were going to collect. In

the letter, their right to *not* participate and their right to withdraw from participation at any time were emphasized. To make sure that the content of the letter was properly communicated to the students, and to reduce pressure or a sense of obligation, a researcher—and *not* the teacher—elaborated on all the aspects of the letter orally in the classroom. All researchers involved were present and introduced themselves to the students and teachers.

Important ethical aspects concerned maintaining the participants' anonymity and storing sensitive data. In this regard, the potential participants were given the choice to mark two options. One granted the researchers the right to use the data obtained during the study for research purposes; the other gave them the right to also use visual or audio material in "illustrations, journal articles, talks, and presentations on the web as well as in other media related to dissemination of the project's results" (quoted from the consent letter, my translation from the original Norwegian). Throughout all publications, all participants have been given pseudonyms. Although the project did not collect any *sensitive personal information*—information about race or ethnic background; political, philosophical or religious opinion; health condition; sexual orientation" or membership in associations—the data collected in the MIRACLE project is sensitive in many respects. First, in video recordings, individuals can be directly identified by their unique personal characteristics, and their identity further traced back as it may become disclosed during interaction. In addition, because our ethnographic observations were most often conducted not in experimental conditions, but in their natural school and out-of-school settings, participants were recorded as they spontaneously performed during their everyday conduct, thus often spontaneously disclosing private aspects that may involve sensitive information. All data were stored in a secured server at the University of Oslo to ensure proper care. Only researchers with the proper credentials can access the server, and access is secured by an individual password for each researcher. Only one of the researchers (myself), in addition to one of the technical stuff that maintains the server, was given the right to modify any entry in the database, to guarantee the originality and integrity of the materials.

Chapter 5: Summary of the Studies and Discussion

In this chapter, I summarize the findings from the three studies that form part of this thesis and discuss their empirical, theoretical, and methodological contributions to the fields of research on conceptual coherence and continuity in general, and of inquiry-based science education in particular.

I began this thesis with an episode of learning in which a young child was drawing a face for the first time. In discussing the episode, I drew attention to its emergent and unexpected character, where an affective element of surprise seemed to perfuse the learning event and contribute to its development. Through my observations of K–12 students' engagement in MIRACLE's inquiry activities, I have observed similar instances in which the students were surprised by the outcomes of their own actions. In these situations, the students were not unlike the young child in the opening vignette, who could not aim at doing something that she did not know she could do. By engaging in the inquiry activities, the K–12 students found themselves in the midst of new and unexpected situations that their own actions had brought them into without yet being capable of articulating in any formal terms what these situations were about. Yet, it was by virtue of being immersed in such unexpected situations that new ways of accounting for the situations emerged. In such situations, therefore, the conditions for growing intellectually appeared to be already present in the material situations that the learners themselves had jointly produced.

Each of the three studies included in this thesis represents an attempt to understand the relation between the individual learners and the developmental situations within which they find themselves when conceptual coherence and continuity are outcomes of activity. Each study addresses the problematic in the context of a larger field of inquiry. Study I addresses the problem in the context of research on *transfer*, Study II is most relevant to the field of learning with *multiple representations*, and Study III looks at the achievement of coherence and continuity in the context of *classroom talk* studies. In the following, I first briefly summarize the context, goal, and conclusions of the three studies. In a subsequent section, I describe their empirical, theoretical, and methodological contributions in more detail.

Summary of the studies

Study I

Jornet, A., Roth, W.-M., & Krange, I. (submitted). A transactional approach to transfer episodes. *Journal of the Learning Sciences.*

Although this study was not the first chronologically, I include it first because it articulates some of the most fundamental conceptual and analytical grounds on which all three studies rest. In the study, we draw from Vygotsky, Dewey, and contemporary phenomenology (e.g., Romano, 2009; Sheets-Johnstone, 2011) to elaborate the transactional analytical framework that has informed this thesis, paying particular attention to the notion of *(an) experience* as an analytical category. In the study, we discuss the framework as an analytical tool for approaching episodes of successful transfer during classroom activities—episodes in which the participants declare or can be declared to bring prior experience to bear on the current organization of (school) activity. Central to the analytical framework is the premise that, in bringing prior experience to bear on current activity, it is not that some *known* thing is carried over, but that the whole person-in-setting is transformed. Accordingly, the relevant moments of activity need to be accounted for by categories that retain such transformation, by means of *process categories*.

Drawing from video recordings of the curricular activities, ethnographic materials documenting the teacher's evaluations of the students, and video recordings of the post-test interviews, we identify a case of transfer in which a group of students identify (a) a hands-on experiment and (b) a set of digital simulations as instances of (c) a scientific law relating pressure, temperature, and energy. We then provide detailed analyses of the moment-by-moment interactions that take place as the students draw conceptual connections between these different aspects of the curriculum (hands-on experiment, digital simulation, and scientific law) for the first time. The analyses reveal how cognitive processes that are considered central in the transfer literature and that often are invoked to account for aspects of individual classroom activity, namely *recognition*, *analogical inference*, and *applying theoretical knowledge*, take place as bodily achievements that extend in time and across participants. The analyses show that drawing conceptual connections between different aspects of the material setting and across different curricular activities involves perceiving similarities as much as it does being *uncertain* about how the perceived similarities may be articulated in conceptual (i.e., linguistic) terms. Thus, categories that describe the stretches of activity during which conceptual connections are elaborated and stabilized in terms of synchronic cognitive processes—i.e., recognizing, inferring, applying knowledge—do not capture such uncertainty and its role as part of the process. Rather, to account for how such uncertainty is resolved through extended inquiry, a detailed description of the organization of talk and gesture in the course of the episode is required. We provide such specification for each of the three cognitive processes mentioned above and discuss the findings with regard to other research that also takes a sociocultural and situative stance.

Study II

Jornet, A., & Roth, W.-M. (in press). The joint work of connecting multiple (re)presentations in science classrooms. *Science Education.*

Study II addresses the question of emergence of conceptual coherence as it relates to the use of *multiple representations* during guided inquiry and during teacher-led summary lessons. Representations, also referred to as *inscriptions,* are central to scientific practice (e.g., Knorr-Cetina & Amann, 1990; Latour, 1987) and an important element in science learning and teaching (e.g., Kozma & Russell, 1997; Roth & McGinn, 1998). With the increasing adoption of computerized means to visualize scientific content in inquiry-based curricula, educators and researchers have explored multimedia teaching practices directed to foster the competence of relating and coordinating multiple representations with each other and with the phenomena they stand for (e.g., Ainsworth, 2008; van der Meij & deJong, 2011).

A more-or-less tacit assumption in much of the literature about learning with multiple representations is that representations *encode* information and that learning from those representations involves a mental process of decoding. Thus, it is often argued, "only when learners identify these references within and between the external representations can they construct a coherent mental representation and come to a deeper understanding of the subject matter" (van der Meij & de Jong, 2006, p. 321). However, an increasing number of studies have begun to investigate learning with multiple representations as a social *semiotic* process (for a review, see Waldrip et al., 2010). The study aims to expand research from these emerging perspectives by providing empirical and analytical accounts of the social and semiotic processes that are involved in drawing conceptual connections between teaching materials and across situations.

In this study, we elaborate on a cultural-historical approach to *semiotic mediation* to investigate the transactional processes by means of which students and teachers jointly come to draw connections of signification between the different teaching materials (i.e., a set of hands-on experiments and a set of digital visualizations) and the scientific contents that are the object of the curriculum through both inquiry-based and teacher-led summary sessions. From this perspective, the relations between any two materials are the result of *practical work.* Accordingly, we trace in our analysis the *emergence* of students' interpretations of the relations between phenomena and their diverse *presentations* without committing to any preconceived notion of what these presentations stand for. Our analyses reveal the practical work by means of which presentations—a physical experiment, a digital simulation—come to be treated as *re*presenting something other than themselves in and through the joint inquiry activities that teacher and students perform. We provide detailed analyses of the *coordination work* by means of which material aspects of the setting (i.e., the artifacts in a hands-on experiment, the digital simulations) *move from being aspects of immediate experience to being mediational means* constitutive of science teaching and learning practices. In this, the role of bodily engagement in actual praxis emerges as a constitutive moment in the process of mediation. We conclude the article by discussing how these findings are in line with, but also expand, research from other sociocultural and situative studies that also highlight the role of representations as *semiotic resources* (e.g., Furberg et al., 2013).

Study III

Jornet, A. (submitted). Bodily performances of coherence facilitation: The role of the body during teacher questioning in science classrooms. *Journal of Research in Science Teaching.*

The aim of the third study included in this thesis was to investigate how teachers' bodily performances are involved in the constitution of coherent question-answer sequences during teacher-led summary sessions in the classroom. The study was initially motivated by (a) an interest in examining in more detail how conceptual relations of coherence and continuity are elaborated during teacher-led summary plenum sessions, and (b) an interest in the role of bodily engagement—which became salient in Studies I and II—in establishing such relations. Early during the preliminary analyses of the teacher-led summary lessons, the role of teacher-initiated *questions* in organizing classroom interaction became very salient. Through closer analysis of the entire set of teacher-led summary sessions in the database, the interdependence among (a) talk, (b) bodily performance, and (c) the emergence of conceptual relations of coherence became salient. The study investigates the intersection of these three aspects.

Teacher questioning, and in particular sequences where the teacher *i*nitiates a question, the students *r*eply, and the teacher subsequently *e*valuates (IRE) or *f*ollows up (IRF), have been recognized as a resource for facilitating that connections between everyday experiences and scientific ways of talking emerge in the classroom (e.g., Mehan, 1979; Mercer & Littleton, 2007; Wells, 1993). The role of bodily performances (i.e., gestures) in the development of scientific literacy has received increasing attention during recent years (e.g., Alibali & Nathan, 2007; Roth, 2000; Novack et al., 2014). However, research has not yet addressed the intersection of these two aspects in bringing forth conceptual discourse during science classroom interactions.

In Study III, I examine teacher-initiated IRE/F question-answer sequences during a set of sessions in which videos that had been recorded by the students during inquiry activities were retrieved and displayed in plenum and discussed. The analyses detail how a teacher's bodily performances provide material resources for displaying topic coherence and continuity during question-answer sequences despite the students' initial lack of conceptual understanding of the curriculum. Through bodily performances, the participants produce a *framework of reference* or *substrate* that becomes an important resource for drawing conceptual connections. It is argued that achieving relations of conceptual coherence and continuity through IRE/F sequences involves an *education of attention* (Ingold, 2001) to material, concrete aspects of the immediate environment, which could then be indexed to the classroom's immediate history of referential performance.

Discussion of findings and contributions

In this section, I detail the analytical and empirical findings of the three studies and discuss how these contribute to the fields of learning science and science education. First, I discuss the theoretical and analytical contributions that derive from our elaborations on the connections between Vygotsky's notions of *perezhivanie* and *unit analysis* and Dewey's notions of *experience* and *transaction.* While in chapter 3 I use the metaphor of a *black box* to refer to the practice of stopping specifying the detail of joint interaction to account for social phenomena, in a second subsection I describe how the empirical studies, in specifying the detail of moment-by-moment social transactions, contribute to an understanding of the microgenesis of mediational processes, that is, of the transition between immediate and mediated action. In doing

so, attention is focused on the relation between bodily and performative aspects of activity and the constitution of conceptual coherence. In a third and final subsection, I discuss the methodological contributions.

Exploring new productive connections between Dewey and Vygotsky

Dewey and Vygotsky are two of the most influential and often-cited scholars in research literature about learning and education. As discussed in chapter 3, similarities and complementarities between the two scholars have been the topic of considerable literature during the years (e.g., Garrison, 2001; Miettinen, 2001). Although Dewey's ideas are often invoked in science education literature, few researchers indeed provide elaborated analytical tools as a result (cf. Wong et al., 2001). Similarly, whereas the importance of Vygotsky's ideas about *perezhivanie* has been highlighted as a potential asset in developmental (e.g., Rey, 2011; Smagorinsky, 2011) and clinical (e.g., Vasilyuk, 1991) psychology, its adoption as an analytical resource in science education has been much more modest (cf. Fleer, 2011). Exploring further connections between Dewey and Vygotsky as a potential means to improve our understanding of processes of development and transformation in activity in general (Miettinen, 2006), and in science education in particular (Stetsenko, 2008).

In two of the empirical studies conducted during my doctoral scholarship, including Study I (Roth & Jornet, 2014; Jornet et al., submitted), my supervisors and I have elaborated conceptual connections between Vygotsky's cultural-historical and Dewey's pragmatist frameworks, which have led us to the development of analytical tools for the study of concrete episodes of learning and development. Although informed by previous treatments, the resulting framework presents novel aspects that contribute to the general goals of (a) further exploring productive connections between Dewey and Vygotsky to inform research on learning and cognition (e.g., Miettinen, 2001; Stetsenko, 2008) and (b) expanding the analytical technologies for studying learning as situated social achievements (Brown, Collins, & Duguid, 1989; Lave, 1988).

First, we expand prior characterizations of the connections between the two authors by exploring both dialectical and phenomenological aspects in their respective approaches to the relation between situations and subjects, and to the *experience* as a category of analysis. Many of the commonalities that we discuss regarding Vygotsky's and Dewey's works can be traced back to a common interest in Hegelian dialectics, which other researchers have also explored in great depth (e.g., Miettinen, 2006). In addition, however, we acknowledge phenomenological aspects underlying both researchers' conceptualizations. These phenomenological aspects are less often discussed in the literature with regard to Dewey (e.g., Løvlie, 2014) or Vygotsky (Macdonald, 2000; Roth, 2011). Yet, they allow us to read the works of these two important scholars in the context of more recent developments in continental philosophy, where scholars have developed accounts of *experience* as a unity of intellect, praxis, and emotion that most fundamentally involves movement and change (Romano, 2009; Sheets-Johnstone, 2011). These aspects also make it possible to draw further connections with phenomenological and pragmatist incursions into dialogical thinking, such as those elaborated by Bakhtin in *Towards a philosophy of the act* (Bakhtin, 1993). We discuss such connections in Roth and Jornet (2014). Most importantly, and as discussed in chapter 4, attention to these aspects allows for

elaborating, analytically and empirically, the subject as a moment in the irreducible subject-environment dialectical relation, a challenge that sociocultural and situative frameworks have been called to address in the recent literature (Packer, 2001; Silseth & Arnseth, 2011; Stetsenko, 2005).

Second, our discussion does not remain in a theoretical plane alone but is grounded in empirical materials and leads to specific analytical tools to address analyses of situated transaction. Connections between Dewey and Vygotsky have most often been drawn at the theoretical level. Less often, these connections are elaborated in their application as analytical technologies and by reference to concrete empirical materials. Both in the empirical studies and throughout this thesis, I make efforts to elaborate on how the theoretical discussion leads to analytical tools for approaching learning and development in situated action and to ground the discussion in concrete empirical materials. Important in this regard has been not to lose sight of an overarching cultural-historical methodological framework, grounded in a unit analysis approach and a focus on tool-mediated activity. Also important, as discussed in more detail below, has been the drawing from affinities with ethnomethodologically informed techniques of interaction analysis. With regard to this last point, the contributions of my work can be seen as an analytical and empirical expansion of work advanced by Roth in science education during recent years (e.g., Roth 2011, 2013). In this, precisely the incorporation of Dewey's ideas about experience and transaction, and a focus on conceptual coherence and continuity, can be seen as important novel elements of that expansion.

Opening the black box: Microgenesis of mediation in science inquiry

One of the most important implications of the analytical framework elaborated throughout this thesis is that it allows us to address aspects of the inherently social, joint work involved in establishing conceptual coherence and continuity that otherwise remain unaddressed. As discussed in previous chapters, in analyzing social interaction, irrespective of the theoretical perspective, research tends to focus on language and the linguistic aspects of talk as the primary means of social relation. Throughout this thesis, I acknowledge the important contributions that such studies provide. Describing social practices by means of categories that allude to linguistic aspects of interaction, such as *discursive practices* in Lobato et al.'s study discussed in chapter 2, is an important task that answers many of the questions relevant to an ecological approach to learning and cognition. Yet, in focusing on linguistic and symbolic aspects of interaction as the primary cultural tools involved in intellectual development, these studies also leave unaddressed non-linguistic, performative aspects of social interaction that otherwise are central to the everyday (cultural) life in which linguistic and symbolic forms are mobilized. To achieve an account of how cultural mediation relates to the fullness of life in which participants are implicated during everyday activity, accounts of how mediation grows out of "organic activity" (Dewey, 1938, p. 19) are also required.

An important contribution of this thesis concerns its attention to the processes by means of which immediate aspects of the material environment *come to form part of mediational processes in and through the concrete practices by means of which they become mobilized during activity.* Specifying the relation between immediate and mediated action is important because, as British psychologist A. Costall (2007) argues,

> if we are going to make sense of *mediation,* how it originates and is sustained, we will need to find a place in our theories for the existence of both meaning and mediation *before and beyond* the realm of representations and symbols, and take their materiality much more seriously. (p. 120)

An approach that investigates how shifts from immediate to mediated activity take place is consistent with Vygotsky's method of *double stimulation,* where the aim is to observe how a *neutral stimulus* comes to acquire a semiotic function as an auxiliary means during problem-solving activities (Vygotsky, 1978, 2012). The notion of double stimulation has been applied in studies of organizational development (e.g., Cole & Engeström, 2007) and in computer-supported collaborative learning (e.g., Lund & Rasmussen, 2008). However, in these studies, accounts of the transitions from immediate to mediated activity have been given with regard to the collective level, and, when analyzing situated action, the focus has been on the linguistic and symbolic aspects. Thus, further research is required to provide microgenetic accounts of how individual actors come to be constituted and constitutive moments of mediational processes, and of how performative, yet-to-become-symbolic aspects of interaction may be involved.

The empirical studies conducted as part of this thesis contribute to a better understanding of the microgenetic processes by means of which diverse teaching materials and artifacts *become* cultural means that mediate the achievement of conceptual coherence and continuity during science inquiry learning. In what follows, I specify how each study provides empirical contributions in this regard:

Study I identifies a trajectory of conceptual development in a group of students, and then examines how the conceptual connections between artifacts and conceptual accounts emerge as a function of the turn-taking organization of talk-in-interaction. In doing so, it provides accounts of cognitive phenomena that are often evoked to describe individual aspects of interaction—recognition, inference, and applying theoretical knowledge—and describes these instead as time-extended, collective achievements. We show how *recognizing* a digital simulation as being an instance of a scientific law is not a synchronic act of a rational mind by means of which digital simulation and scientific law are conceptualized as being similar or related. Rather, recognizing is the beginning of a larger act of perception, which is itself a developmental phenomenon. Rather than a conceptualization of similarities, there is first what Nemirovsky (2011) calls an *episodic feeling,* that is, a bodily and context-bound sense of "having-been-there" (p. 311). It is only as part of addressing and being addressed by others during conversation that the initial connection comes to be developed as a conceptual one. In the process, we provide evidence that the students are as much active as they are subjected to the unexpected material and conversational events. Similarly, in drawing an *inference* as the students compare a hands-on experiment with the digital simulation, their prior understanding of the connection is not immediately "bootstrapped," as mainstream research characterizes it (Gentner, 2010). Rather, elaborating on an initially identified similarity between two events in the curricular trajectory brings about an *indeterminate* situation (in Dewey's sense) that leads to further bodily and material inquiry that transforms the objective situation. It is in transforming the situation and thereby being affected by the new objective circumstances that new conceptual understandings of the connection among events, artifacts, and the scientific law emerge. It is, therefore, not

that an inference brings about a new situation where new conceptual understandings are in place. Rather, an initial sense of similarity motivates action that transforms the situation, which in turn allows for the eventual achievement of a new conceptual way of accounting for a new existing order. Inference, as a cognitive process, does not precede, but rather is the outcome of, a larger unit of activity. The study, thus, provides us with an alternative account of the role that individuals play in constituting cognitive phenomena that highlights both the *performative* and the *affective* aspects of situated action. Individuals constitute and are constituted by the establishment of conceptual coherence because they are *subject to* the objective changes that bodily activity brings about in their attunement to the *accountable, collective organization of activity*.

Study II (Jornet & Roth, in press) examines how a number of analogical and digital artifacts *become signs* in and through social transactions that involve a teacher and a group of students. According to the transactional analytical framework that guides the study, we approach any material aspect involved in the constitution of conceptual coherence from the first-time-through perspective of the learners, who do not yet know the symbolic functions that those material aspects may have in the scientific and disciplinary discourses. Throughout the study, we show the processes by means of which a syntax that connects events and materials emerges in and through bodily social transactions and is not just a part of talk. We describe how pointing, gazing, and other deictic (pointing) gestures are the first fleshly forms by means of which the materials in the different situations come to be structured. These carnal aspects, therefore, emerge as a precondition for semiotic mediation to take place and, therefore, become integral to the process by means of which conceptual connections across talk, artifacts, and representations are drawn. As bodily orientation and action change, so do the structures that come to be the object of talk, even when the presentations and materials remain "the same." The analyses also describe how, as soon as participants come to use language to account for situational aspects made salient through bodily action, opportunities for making those situational aspects present again (that is, to become *re*presented) emerge. However, language does not just bring already known concepts by means of which participants can make sense of the conceptual connections. Using language also brings about new *contextual re-configuration* in which participants demonstrably orient to "a particular, locally relevant array of semiotic fields" (Goodwin, 2000, p. 1490). Those fields are constituted, in turn, by new orientations towards inquiry, where participants still need to perform bodily and discursive joint work to establish the adequacy of the emerging relations between forms of talking and immediate aspects of the material situations. As part of this work, the role of the teacher, who facilitates the emergence of particular structures and connections and the loss of others, appears as fundamental for the achievement of coherence that is in line with the curricular intentions. The findings thus suggest that an adequate understanding of teaching and learning with multiple representations requires an understanding of the pragmatics of joint action and of how the body and the materials come to form a *unitary situation* in the learners' experience (Dewey, 1938; Roth & Jornet, 2014). The framework and findings are in line with other studies from ecological perspectives, which emphasize the role of the different representations and inscriptions involved in science learning as *structuring resources* (Furberg et al., 2013), but also expand the latter by bringing attention to and providing accounts of how performative aspects of activity are *constitutive* and not just epiphenomenal during episodes of conceptual development.

Study III, building upon findings reported in the other two studies, provides empirical and conceptual contributions to the study of the joint work involved in the microgenesis of conceptual coherence achievements in science education. In particular, it specifies the work that teachers and students jointly perform during question-answer sequences of classroom talk so that video recordings of the students' experimentation with materials come to be accounted in terms of the conceptual content of the science curriculum. The analyses show how gestures, prosody, body orientations, and other aspects of the arrangement of material resources during conversation become important resources for the participants to achieve coherent topics during question-answer sequences despite the gap that exists between the teacher's knowledge about the scientific conceptual aspects involved in the experiments and the students' current knowledge that does not and cannot yet foreshadow what they will be knowing in the end. The analyses show how bodily resources that are produced in and through questioning sequences embody an internal coherence that is demonstrably shown in several occasions by and for the participants. To facilitate that conceptual connections between the students' prior experiments and scientific accounts thereof emerge in the classroom, the teacher enacts *narrative spaces* by assembling indexical, iconic, and metaphoric gestures that exploit, in a consistent manner, aspects of the immediate material environment across occasions. The study thus expands a long tradition of empirical studies on the role of teacher questioning in facilitating that students connect everyday experiences with conceptual aspects of the (science) curriculum by exploring the bodily and performative dimensions involved in the organization of IRE/F question-answer sequences. In doing so, the study also expands the recent literature concerned with the role of the body in bringing forth conceptual understandings in the classroom (Alibali et al., 2014; Novack et al., 2014; Pozzer-Ardenghi & Roth, 2010).

Analyzing transaction from the first-time-through perspective of the participants.

A final contribution that I wish to elaborate on involves the methods used as part of this thesis. Throughout my studies, and guided by prior works produced by my supervisors (e.g., Krange & Ludvigsen, 2009; Roth, 2013a, 2013b), I have paid particular attention to the relation between the theoretical premises and the analytical practices implied in my work when approaching the empirical materials. Whereas no new methods have been developed in this dissertation, my approach to the empirical analyses involves drawing from diverse techniques and traditions that are not commonly brought together in studies on inquiry-based learning. Although most of the aspects in this regard were thoroughly discussed in chapter 4, I wish to clarify here the ways in which these different methods and traditions have been combined.

The analytical framework developed throughout this thesis implies an attention to the genetic process by means of which immediate aspects of experience acquire signifying function in and through joint activity. This poses important challenges in the way we, as researchers, need to approach analyses of actual interaction. It implies that any assumption about what particular actions, utterances, artifacts, and representations "mean" as cultural tools needs to be set aside and instead requires taking a first-time-through perspective of the participants. This involves the practice of *bracketing,* which I described thoroughly in chapter 4. Importantly, as noted in that chapter, bracketing does not mean that we, as researchers, pretend to be somehow culturally agnostic. Preconceptions and interests regarding particular cultural

practices or outcomes are important to enable a first approach to the data, and to identify events of interest to the research questions. However, once particular practices and events are identified and further scrutinized to select relevant pieces of data, bracketing implies taking the perspective of the participants to understand how material elements first appear to the participants, and how they become implicated as significant aspects of their own everyday order and life.

To achieve *ethnographically adequate descriptions* (McDermott et al., 1978) of activity from the point of view of the participants, throughout the empirical studies in this thesis, and as part of a video-based interaction analysis framework (Jordan & Henderson, 1995; Derry et al., 2010), we have used analytical notions and techniques developed as part of the ethnomethodological program of sociological research (Garfinkel, 1967) and the empirical work of *conversation analysis* (Sacks, Schegloff, & Jefferson, 1974; Schegloff, 2007). This includes (a) the policy of bracketing our own preconceptions and interpretative frames when approaching interactional data and (b) relying on the next-turn proof procedure rather than on a priori categories or institutional knowledge to validate our observations about what the participants are saying or doing with regard to particular aspects of their context. The use of the latter methodological approaches, however, has been problematized in the literature on research about learning, and particularly from a sociocultural perspective that I nonetheless consider fully consistent with the approach taken in my studies (Mäkitalo & Säljö, 2002; Mercer & Littleton, 2007). In this regard, a concern has been that ethnomethodological analyses do not consider the historical aspects of the cultural tools involved in social interaction, such as institutional ways of talking. The concern is that, if researchers are interested in investigating the temporal emergence of conceptual competences in and across learning activities in educational contexts,

> methods for analyzing discourse in which the analyst only attends to the relationship between contributions made by participants in one recorded conversation, without applying available information about previous related interactions and historically contextual knowledge shared by participants (as seems to have been advocated by some conversation analysts…) would simply not work. (Mercer & Littleton, 2007, p. 116)

However, ethnomethodologically informed analytical approaches do not necessarily imply that analyses must ignore the "historically contextual knowledge shared by participants." On the contrary, one explicit analytical policy is that analysts *must* share with the participants the social competences exhibited during interaction. As McDermott et al. (1978) note,

> people manage to know for sure what is going on only in relation to specific interactional environments, and they usually know a great deal about these environments because they have helped to construct them as predictable contexts for plying whatever it is that they know. Such framing takes considerable work, and it is by that work that we are able to locate what it is that members of a group are up to at any given time. (p. 247)

The aim of the analyst, thus, is not to ignore such knowledge, but to "use the ways members have of making clear to each other and to themselves what is going on to locate to our own satisfaction an account of what it is that they are doing with each other" (p. 247). However, the policy requires *specifying the work* by means of which

such knowledge is actually shared and made relevant during activity rather than providing it as encapsulated in already given categories of which the evidence in the data materials is not articulated. Key to understanding how ethnomethodologically informed analyses may fit in the broader ecological framework elaborated through this thesis, which aims to retain a focus on signs and tool mediation, is to acknowledge that often, sociocultural and ethnomethodological approaches focus on different levels of analysis. Thus, as Mäkitalo and Säljö (2002) note, "ethnomethodologists have an interest in unpacking members' methods for accomplishing social interaction in terms of some basic fundamental patterns of the organization of talk … and of the orderliness of categories … in conversations," whereas "sociocultural studies … analyze the sociogenesis, meaning and consequences of social action in society" (p. 65).

In the analytical work developed throughout this thesis, these two alternate interests are joined within a transactional perspective. In this regard, the notion of *unit analysis*, according to which events of development are to be understood by reference to their internal constitution and organization, has served us for elaborating how the endogenous methods by means of which situated action is organized relate to the establishment of longer episodes of sign-mediated activity that are the minimal unit of analysis. The notion of *experience* as having social and temporal extension has served us, in turn, to elaborate how individuals come to constitute and be constituted through the moment-by-moment actions as part of episodes of meaningful, institutional (science learning) activity. In addition, as Roth notes in several works (Roth, 2011, 2013b), conversation analysis techniques are consistent with the dialogical premises based on authors such as Bakhtin (1981), which underlie much of current sociocultural research in that they take two consecutive turns during conversation—i.e., a social relation—as the minimal possible unit of analysis. As a result, the studies included in this dissertation expand the analytical possibilities for studying how conceptual relations of coherence emerge and develop throughout inquiry-based learning activities from the perspective of the learners, who do not yet master the required conceptual competences to perform competent scientific practice, but who have an array of everyday, bodily, and linguistic competences to engage with others and with materials.

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Appendix 1: Transcription conventions

,?;. Punctuation marks are used to indicate pitch toward end of an audible unit: slightly rising, strongly rising, slightly falling, and strongly falling

[ ] Square brackets indicate beginning and end, respectively, of overlapping speech

(.) Clearly audible pause of unmeasured length, evt. time in seconds (e.g. (2.0))

(()) My own comments and observations

(??) Words missing. As many ”?” as words missing

- dash marks unfinished or interrupted utterance.

(h) laughing inserted in talk

word an underlined word signal stress in the spoken utterance

°word° a word pronounced at low volume

wo:rd colon indicates the prolonging of the prior letter or syllab

<word> brackets pointing outward indicate word or phrase spoken more slowly than the surrounding discourse

>word< brackets pointing inward indicate word or phrase spoken more quickly than the surrounding discourse

PART II:
THE STUDIES

Study I

Jornet, A., Roth, W.-M., & Krange, I. (submitted). A Transactional Approach to Transfer Episodes. *Journal of the Learning Sciences.*

A Transactional Approach to Transfer Episodes

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Study II

Jornet, A., & Roth, W.-M. (in press). The joint work of connecting multiple (re)presentations in science classrooms. *Science Education.*

The Joint Work of Connecting Multiple (Re)presentations in Science Classrooms

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Study III

Jornet, A. (submitted). Bodily performances of coherence facilitation: The role of the body during teacher questioning in science classrooms. *Journal of Research in Science Teaching*.

Bodily Peformance of Coherence Facilitation: The Role of the Body During Teacher Questioning in Science Classrooms

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