This book is about the sensuous, living body without which individual knowing and learning is impossible. It is the interface between the individual and culture. Recent scholarship has moved from investigating knowing and learning as something in the mind or brain to understanding these phenomena in terms of the body (embodiment literature) or culture (social constructivism). These two literatures have expanded the understanding of cognition to include the role of the body in shaping the mind and to recognize the tight relation between mind and culture. However, there are numerous problems arising from the ways in which the body and culture are thought in these separate research domains. In this book, the authors present an interdisciplinary, scientific initiative that brings together the concerns for body and for culture to develop a single theory of cognition centered on the living and lived body. This book thereby contributes to bridging the gap that currently exists between theory (knowing that) and praxis (knowing how) that is apparent in the existing science and mathematics education literatures.
SCIENTIFIC & MATHEMATICAL BODIES
NEW DIRECTIONS IN MATHEMATICS AND SCIENCE EDUCATION
Volume 22

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Scope
Mathematics and science education are in a state of change. Received models of teaching, curriculum, and researching in the two fields are adopting and developing new ways of thinking about how people of all ages know, learn, and develop. The recent literature in both fields includes contributions focusing on issues and using theoretical frames that were unthinkable a decade ago. For example, we see an increase in the use of conceptual and methodological tools from anthropology and semiotics to understand how different forms of knowledge are interconnected, how students learn, how textbooks are written, etcetera. Science and mathematics educators also have turned to issues such as identity and emotion as salient to the way in which people of all ages display and develop knowledge and skills. And they use dialectical or phenomenological approaches to answer ever arising questions about learning and development in science and mathematics.

The purpose of this series is to encourage the publication of books that are close to the cutting edge of both fields. The series aims at becoming a leader in providing refreshing and bold new work—rather than out-of-date reproductions of past states of the art—shaping both fields more than reproducing them, thereby closing the traditional gap that exists between journal articles and books in terms of their salience about what is new. The series is intended not only to foster books concerned with knowing, learning, and teaching in school but also with doing and learning mathematics and science across the whole lifespan (e.g., science in kindergarten; mathematics at work); and it is to be a vehicle for publishing books that fall between the two domains—such as when scientists learn about graphs and graphing as part of their work.
Scientific & Mathematical Bodies
The Interface of Culture and Mind

By

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and

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A stone is the exteriority of singularity in what would have to be called its mineral or mechanical actuality (litteralité). But I would no longer be a “human” if I did not have this exteriority “in me,” in the form of the quasi-minerality of bone: I would no longer be a human if I were not a body, a spacing of all other bodies and a spacing of “me” in “me.” A singularity is always a body, and all bodies are singularities (the bodies, their states, their movements, their transformations). (Nancy, 2000, p. 18)

In this introductory quote, Jean-Luc Nancy, perhaps the most prominent living French philosopher, points to the role of the body not only in knowing but also in being human tout court. It is the living body that makes me human, but within this living body, there is also an exteriority, such as a stone; and without this exteriority within me, I would not be able to relate to anything that is outside of my body, like the world. This living body in science and mathematics learning is precisely the central phenomenon of the present book. Whereas other science and mathematics educators focus on the mind and mental constructions or treat bodily experiences as stepping-stones to formal and abstract reasoning, we insist that without the sensuous, living and lived body, human beings would not be able to know anything at all. This book, therefore, is about the living and lived body in mind and culture with a particular perspective on science and mathematics.

Since the beginning of 2003, the two authors have worked together on a variety of projects, held together by a singular concern for the role of the body in communication, learning, and literacy. Our work has always been characterized by close attention to and work with data, which served for us as the ultimate testing ground for any theory that was to emerge from our work. We spent many hours, days, weeks, and months watching and analyzing videotapes featuring children and students of various ages engage with the tasks that their teachers (professors) had provided them with for the purpose of learning one or the other science or mathematics. This book constitutes the most current common conceptualizations that we have worked out over the past two years. In fact, we took the opportunity to take already published work and opened up our discussions for revising and reworking what we had done to take into account what we have learned since their original conception and publication. We found ourselves with words that we no longer are using today because of their problematic nature – e.g., “meaning” or “construction” – and we replaced them as part of our conceptualization of this book.
In this book, we draw on the original versions of French and German philosophical texts. When we quote from these texts, all translations are our own, though, where available, we have checked our version with the one published in the English language. Because of the non-equivalence of languages, translators have to make choices, which generally orient themselves to the intended audiences – philosophers. In our translations we have attended to the suitability of the translation for our audience: mathematics and science educators.

The original texts underlying the eight chapters of this book have previously been published in conference proceedings and academic journals before we further and extensively revised and expanded them for this book project. The first versions of chapters 1 and 3 have been presented at the first and second International Science Education Conference, which were held in 2006 and 2009 at the National Institute of Education, Singapore. The annual meetings of the American Educational Research Association in 2008 and 2010 provided the opportunities to present and discuss the initial versions of chapters 2 and 5 of which the former was subsequently published in Research in Science Education. An article that appeared in Pedagogies: An International Journal served as the basis for chapter 4. Cultural Studies of Science Education published ideas discussed in chapter 6 and 7 and earlier on, the latter had been presented as part of the first Springer Forum on Science Education on the topic of globalization (Chicago, 2007). Chapter 8 first appeared in Forum Qualitative Sozialforschung / Forum Qualitative Social Research.

This book would not have been possible without various research grants and supports from individuals. Several research grants from the Social Sciences and Humanities Research Council of Canada (to W.-M. Roth) enabled collecting the data for all chapters and supported the writing of the initial papers and presentations. We thank our research participants for making their everyday lives available to us and welcoming our presence in their settings. A research grant from the Office of Educational Research, National Institute of Education, Singapore (OER 7/09 HS) provided the opportunity to plan this book project and develop the integrated framework for encompassing the entire chapters. We are grateful to the individuals who contributed to the earlier drafts of the chapters. Mijung Kim co-authored the initial versions of chapters 1, 4, 5, and 6 and collaborated on the OER research project. The members of CHAT@UVic provided SungWon Hwang with numerous discussion opportunities during her stay in Victoria in 2007. These individuals include Peilan Chen, Michiel W. van Eijck, Gholamreza Emad, Maria Inês Mafra Goulart, Pei-Ling Hsu, Bruno Jayme, Jean-François Maheux, Giuliano Reis, and Eduardo Sarquis Soares.

Singapore and Victoria
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INTRODUCTION

TOWARD A THEORY OF THE BODY IN SCIENTIFIC AND MATHEMATICAL COGNITION

And how will you enquire, Socrates, into that which you do not know? What will you put forth as the subject of enquiry? And if you find what you want, how will you ever know that this is the thing which you did not know? (Plato, 380 BCE)

Reason, the human capacity to make sense of the world, has long been the goal of science and mathematics education. Science and mathematics educators have taken forms of reasoning – including questioning, hypothesizing, and justifying – with empirical data central to cultural development of individuals and societies. Investigations of how people know and learn have been conducted from a variety of theoretical perspectives. Traditionally the discussion of reason often has been restricted to accounts constructed after the sense-making event as if a thought were a thing that could stand independently of the concrete praxis of talking, writing, or doing in a particular setting. More recently, the notion of reason has been expanded to that which is inseparably conditioned by culture and language and also the body engaged in the praxis. The cultural nature of knowing science and mathematics (i.e., social constructivism) and the primary role of the body in shaping the mind (i.e., embodiment) contributed to incorporating the actual ways in which humans act and interact in and with the everyday world. Crucial to this transition from the static (absolute) notion of reason to the living process of sense making is the acknowledgement of the mundanity of knowing and learning science and mathematics, which pertains to the ontological conditions that also have made possible the establishment and development of disciplines such as science and mathematics. The ordinary, taken-for-granted, everyday life that human agency is inescapably caught up in materially and culturally while doing and talking science or mathematics has been acknowledged as an inseparable and central moment of scientific and mathematical sense making.

The theoretical orientation to everydayness in learning theories commonly admits that the human being is not a machine, like a computer, which mechanically transfers information. Rather, a recognition now emerges that being human means being in the flesh, acting in the world with feelings, emotions, and corporeal forms of knowing. The classical theory of reason, which explains learning as the product of the conscious (rational) mind configuring itself, does not fully explain how real people learn by means of sense experiences, affect, and uncertainties. Like the paradox that Meno articulates for his mentor Socrates in the opening quote of this
INTRODUCTION

introduction, knowing and learning theorized in terms of a rational mind would come to an unsolvable problem: We cannot take the unknown thing as the object of an intentional learning act: How can we aim at learning something that we do not even know that it exists? If learning consists of rational processes despite this inescapable problem, this learning paradox, then it is because humans have a world of possibilities ready at hand in its mundanity. The unknown learning object reveals and gives itself as learners engage in activity the purpose of which is not entirely clear to them. For example, students learning Newtonian mechanics for the first time in their lives do not directly encounter “abstract” physics concepts (e.g., inertia) but come face to face with concrete human artifacts including mathematical equations, visual representations, scientific equipment, and text- or sound-words. For students who do not yet grasp a concept, who do not even know what the intended concept involves, there is no magical solution for learning scientific concepts such as inertia. They can only engage in talking with and about these concrete objects (e.g., seeing, hearing, and touching) and in letting sense appear to them from this everyday (ordinary) experience of the world. Thus, students doing an experiment in a science laboratory grapple with mathematical equations and scientific equipment, and thereby evolve a better sense of some scientific phenomenon. In this way, learning science and mathematics occurs in their everyday lifeworlds rather than in some metaphysical conceptual netherworld abstracted from reality. Students’ power to act knowledgeably in their familiar world is inseparably intertwined with their everyday experiences. Everydayness, which refers to the condition that real people (embodied creatures) inhabit in and for their everyday practice, constitutes both the context of and resource for expanding the sense of the world and therefore for learning science and mathematics.

MIND IN CULTURE = CULTURE IN MIND

[A]ll higher functions evolve in phylogeny not biologically, but social; (4) the crudest meaning – the mechanism of such functions is a copy of the social. They are internalized relations of a social order, transferred to the individual personality, the basis of the social structure of the personality. Their composition, genesis, and function (mode of action) – in a word, their nature – are social. Even transformed in the personality into psychological processes, they remain quasi-social. (Vygotsky, 1989, pp. 58–59)

Contemporary sociocultural theories of science and mathematics education use the term literacy to conceptualize the goal of teaching and learning science and mathematics (i.e., scientific or mathematical literacy). As an extension of the initial sense of the term “knowledge of letters” and “being able to read and write,” the notion of literacy generally accepted in education research, practice, and policy-making refers to a cultural competency. This competency is not limited to the traditional notion of knowledge (e.g., pieces of information) and (transcendental) rationality but indicates the competency of communication and thinking in and across various cultural settings (e.g., school, workplace, or place of residence). Rather than the simple acquisition of information, the notion of literacy acknowled-
edges that learning science or mathematics means becoming part of a community of cultural (linguistic) practice. That is, learning science and mathematics is like learning a new (foreign) language. This learning is not unlike what Lev Vygotsky (1934/1986) proposed a long time ago in his studies of children’s scientific concept development. This form of growth requires the development of everyday rationality, which means that one participates in talking science and mathematics and becomes knowledgeable in her ordinary, day-to-day life. The equivalence of learning science or mathematics to learning a new language – implied also by the linguistic root of the term literacy – does not only mean that educators need to attend to everyday language and linguistic resources deployed in the communication of new scientific concepts. More than that, the core issue of linguistic and cultural approach to learning science is that learning a new (foreign) language presupposes the human capacity to know the world and going beyond the learner’s current understanding. Learning a language is not a purely linguistic process. For example, anyone who has had the opportunity to observe a child learning a language sees that a newborn comes to be able to speak a language not only because someone tells her how to speak or what the sense of each word is but also because a child has opportunities to be part of everyday events that are brought about in and through the use of the language. Language and life are interwoven like warp and weft, and pulling one means that the cloth falls apart without anything left. From a pragmatic perspective, there really is no difference between knowing a language and knowing one’s way around the world generally. The difference between the two – knowing a language and knowing one’s way around the world – is undecidable.

Anyone having experienced the learning of a language other than her mother tongue knows that one does not grasp the sense of a foreign word through reading the word definition in a dictionary until she experiences the word really in making an event happen or getting things done. For example, one of our research projects took us into a fish hatchery. Initially, everything appeared foreign and strange and we did not understand what the inhabitants of this place were talking about. But over time, we not only knew what they were saying but we were also able to replace them in their daily tasks. Perhaps this is why students may mechanically memorize the textbook definition of scientific or mathematical terms but this does not necessarily show that they can cope with real, everyday events.

To sum up, we propose thinking and theorizing scientific and mathematical sense making in terms of two ideas: learning science and mathematics is comparable to learning a foreign language, on the one hand, and knowing a language is equivalent to knowing one’s way of living in the world, on the other hand. The following two propositions summarize the two moments of sense making from a cultural (literacy) approach:

a. Knowing science and mathematics means knowing ways of talking science and mathematics and knowing to talk about scientific and mathematical objects.
b. Knowing a language is equivalent to knowing one’s way around the world. That is, knowing how to talk scientifically or mathematically means knowing one’s world around science or mathematics.

The two statements, each of which describes a different aspect of knowing (language, practical sense of life), are not independent but interrelated. Once the role of language (communication) is taken for granted (as a transparent medium between statement a and b) we are led to notice that the cultural significance of learning science and mathematics lies in expanding one’s room to maneuver in the world. At the same time, one expands one’s ways of getting around the world (i.e., collective social life) by learning to knowledgeable participate in talking science or mathematics. Many scholars in the fields of language philosophy, phenomenological sociology, and cognitive psychology point out the mutually constitutive relation between knowing how to speak a language and knowing one’s way around the world. Thus, an individual whose major is social science may experience physics as a strange culture and as a very different language to learn. She may decide to study physics because of her enthusiasm about knowing the beauty of physics. However, to be knowledgeable about the field she needs to participate in various practices and find her way of getting around this culture. This is what we could observe when we followed one student for an extended period of time across very different activities including lectures, doing homework, consulting with a lecturer, doing a group project, presenting a project in class, and doing laboratory work (Figure 0.1). She developed familiarity with physics as she engaged in the activities that played themselves out in the different places that constitute a university physics department.

**BODY IN MIND = MIND IN BODY**

There is an experience of the visible thing as pre-existing my vision, but it is not fusion, coincidence: because my eyes that see, my hands that touch, can also be seen and touched, because, therefore, in this sense, they see and touch the visible, the tangible, from the inside, that our flesh pervades and even envelops all things visible and tangible of which it is nevertheless surrounded, the world and I are one in the other, and of the percipere to the percipi there is not anteriority, there is simultaneity to the same delay. (Merleau-Ponty, 1964, p. 162)

The flesh [is the] immemorial memory of the world. (Henry, 2000, p. 206)

Both opening quotes lead us to the core issue of this book: the living body, flesh, as the necessary condition for knowing, memory, and representation. Without the living body, there is no consciousness of life to become conscious of itself. Flesh is the immemorial memory so that body and mind are two manifestations of the same thing: the flesh. The two moments of knowing science or mathematics have been topics of phenomenological studies over the past decades. These studies – unlike science or mathematics education research that is concerned with stuff in the heads of students – are interested in the way in which students are situated in their life-
worlds. This research is interested in learning from the perspective of the individual student, in the way that the world appears to her, her needs, and so on (e.g., Roth, McRobbie, Lucas, & Boutonné, 1997).

A few educational researchers have acknowledged the role of the human body in learning science and mathematics. Studies on gestures and on the multimodality of communication have shown the crucial role of the body in teaching and learning. Of these, an increasing number of investigations have taken an anthropological framework with respect to the question of what it means to be part of a cultural practice and to be knowledgeable about science or mathematics. These studies have theorized the bodily dimension of human practice and, therefore, of human knowing which researchers also approach from the perspective of the embodied mind (e.g., Lakoff & Núñez, 2000). Whereas traditional psychology conceives of knowing (and learning) as a mental phenomenon (e.g., information processing) to which the body is subordinate or constitutes only an external condition, some contemporary theories accept that the body is a constitutive moment of thinking. What and how we know involves the body. This means that once one pulls bodily knowing from the equation, there would not be any concepts left (e.g., Roth & Thom, 2009a). Therefore, the body is essential to conceptual communication, on the one hand, and to the experience of the world, on the other hand. The following two
statements propose that the body is an irreducible moment of what we know as knowing – even though we might fail to acknowledge it. The two statements are:

a. The body constitutes hub relating inside and outside in producing communication, that is, in hearing, speaking, and making sense.

b. The body constitutes the hub relating inside and outside in the experience of the world and its objects: “Relative is a movement necessarily that is experienced with respect to another ‘grounded body’ experienced as in rest, with which my own corporeal living body is one.” (Husserl, 1940, p. 311)

The two propositions complement the previous two about knowing science or mathematics, which exhibits itself as mundane knowledgability in cultural and linguistic events. Together, the two sets of propositions provide an explanation of how individual minds make contact with culture. Human beings corporeally (e.g., visually) communicate and experience the world before they are capable of talking about it. If they were talking about a world they do not know, they literally would not know what they are talking about. For example, in/with my sensuous, living and lived body that is capable of knowing as much as of suffering I take up a spatiotemporal position at every instance of my life. (We follow the general approach in the phenomenological literature to use the first person pronoun, because to the individual, the body of reference is always mine. It is with respect to my body that I experience the spatiality and temporality of the world [Husserl, 1940].) This taking a position constitutes the condition for my everyday knowing, experience of time and space, and communication (i.e., the body as the very condition for taking a standpoint). My position not only determines my disposition, but also makes me subject to exposure. Through my body, as Merleau-Ponty points out in the introductory quote to this section, I perceive the material world in a specific way of which the (perception) process also structures my body and allows my body to sense the world differently. It is precisely this subjectivity that I share with others as well as the knowing about this subjectivity (rather than the contents of our knowing). This explains students’ concept development, for example, pertaining to the question of how they come to see (hear, feel) something that has not been seen (heard, felt) before. The expression I produce allows me to see/hear myself thinking, and this, according to Vygotsky (1934/1986), allows me to change my thinking. One might therefore ask how a third-year university student develops when she writes up an experiment she has done in a laboratory report, and how she is learning should she recognize her graph (Figure 0.2) as standing in for and exhibiting the cyclic motion of an engine. But she – as any other human being would be – is unable to anticipate this future knowing, because such anticipation requires knowledge of the knowledge. Or, to state the problematic in the terms of more classical theories, anticipation requires representations and these representations precisely constitute what does not yet exist for the learner, who, again in traditional terms, “first has to construct these representations.”

The phenomenological approach to culture opens up new avenues for thinking our sensuous bodies as the places where culture and mind are articulated. My body
is open to the social and material world, and, because of its senses, it is subject to be affected (Bourdieu, 1997). My body constitutes the interfaces between culture and my mind, which mediates the everydayness of communication and the mundanity of experiencing the world in various situations that I come to be in when I learn science or mathematics. In fact, there is no difference between mind and culture (society), for culture is in the mind as much as mind is in culture. If it were not like this, no cultural learning would be possible and nobody else would be able to recognize in my doing something that they also could do. The general (virtual) possibilities of culture exist concretely only in the real, corporeal action of individuals such as myself.

My body is constitutive of my participation in everyday practice. It has been noted that all higher psychological functions have been social relations first (Vygotsky, 1989). While taking part in science or mathematics learning tasks, students engage in relations so that what they know as scientific and mathematical ideas simply is a reflection of these relations. The mediating role of my body as the interface with others and the world means that it is actively involved in inscribing the sense of things (bodies) including language, mathematical representations, and scientific equipment. My body therefore is integral to my sense making. Following

Figure 0.2. An excerpt from a physics laboratory report written by a third-grade undergraduate physics student: If she sees in this graph a cyclic motion of a thermodynamic engine, what would make it possible?
INTRODUCTION

phenomenological philosophers my living body – that is, my body that is capable of suffering, of being affected, of affect – is the source of sense. In the phenomenological literature, this body is referred to as “the flesh” (e.g., Merleau-Ponty, 1945). The living body relates to other scientific or mathematical bodies and simultaneously translates some communicative actions into forms of knowing the world and some of forms of experiencing the world into communicative actions.

The incorporation of the body into a theoretical framework of sense making is consistent with a cultural-historical psychology that aims to develop a comprehensive theory of thought and communication (Vygotsky, 1934/1986). Vygotsky points out the existence of a dynamic relation between communication and conception by theorizing the phenomenon of “word-meaning” and its development. Because the term “meaning” derives from a primitive conception of language, however, we do not use this term in this book (unless in quotation marks to refer to the use of the term by other scholars). Rather, instead of Vygotsky’s term “word-meaning,” we draw on the equivalent concept of participative (unindifferent) understanding (Bakhtin, 1993). Instead of “meaning” we sometimes also use “signification” or “sense,” terms that are consistent with the French and German translations of the Bakhtin’s work and with its origin in the writings of Ferdinand de Saussure.

The dynamic relation of participative (unindifferent) understanding further develops to the concept of growth point in psycholinguistics (McNeill, 2002). Grounded in a dialectical theory, the growth point of an idea is analogous to the seed of a tree. It is only a beginning in which the mature thing cannot yet be seen. Moreover, what this mature thing will look like depends on contextual factors that influence the phenotype of the growing idea (tree). The following two propositions summarize the central role of the living body in the dynamic process of sense making at the interface of culture and mind:

a. Communication is distributed within a communication whole that is produced by the sensuous, living/lived body (e.g., words, gestures, body movements, and prosody).

b. Gestures, body orientations, positions, and movement, prosody, and other communicative modalities constitute one-sided manifestations of an irreducible communicative whole.

First, the sense of communication is made available in and through actions such as sound-words, gestures, eye gaze, body positions, and body movements. That is, any one of them is not additional or subordinate to the other moments. Communication is distributed over the entire communicative unit that encompasses them. In fact, from a phenomenological perspective, my body in its entirety is the expression of thought; there is no thought apart from what my body expresses for others and for myself.

Second, these performances are observable not exclusively in communication. They are also constitutive of the ways by which people encounter and undergo during events in which science or mathematics is context or topic. I experience the world with my words, hands, eyes, and body. This is also the way in which any
other “I” expresses itself. This double function of my living body implies that an expression made toward the other is potentially the way by means of which I practically experience the world. In fact, both Merleau-Ponty and Vygotsky point out that it is through our expressions that I come to know my own thoughts. Initially, when I begin to express myself, these thoughts consist only in nuclear and undeveloped form. As it were, I discover what I think precisely only in speaking. That is, my bodily expression *precedes* the recognition of the thought said to lie behind it. Every thought, in its mature form, literally is an afterthought, in its seed form at the moment of the growth point.

Certainly, there is the question of knowing how the “ideas of intelligence” install themselves from above, how we get from the ideality of the horizon to “pure” ideality, and by means of which to the miracle notably a created generality adds itself to the generality of my body and the world, a culture, a knowledge that takes up and rectifies the first. (Merleau-Ponty, 1964, p. 197)

In this introductory quote, Merleau-Ponty problematizes a question that many critics of the embodiment approach legitimately ask. How do you get from the experience of the body, which is always a singular experience, to the generalities of the culture? Many years later, using almost the same language, Bourdieu (1997) would articulate the living body as the condition for culture. Impressible because of its senses, my living body is fashioned by and according to culture and material world such that a homology develops between the experienced and experiencing structures.

When we talk about knowing, developing, and learning then we presuppose body, mind, and culture. There is no learning or development without the living bodies, which are endowed with senses and therefore with the resources for making sense. There is no learning and development without the mind, which in fact is a feature that provided an evolutionary advantage and that natural selection therefore chose. There is no learning and development without culture, because it is only in collectivity that we have consciousness (= con-, with + sciere, to know), a language, a means of handing down knowledge and practices to future generation – including the use of tools, such as physical apparatus, geometrical objects, or language.

The practice with physical artifacts may also constitute an expression toward the other. This is so because the (same) living body expresses, and thereby translates experiences (or acts and translates expressions). Therefore, making thematic the role of my sensuous, living and lived body in my sense making has the potential to lead to a comprehensive perspective on everyday learning in science or mathematics. Such a perspective does not dichotomize the different constituents in a phenomenon, such as cognition and emotion, everyday and scientific concepts, and individual and collective subjects. Thus, a theory of the living body constitutes a theoretical alternative to constructivism and other psychological orientations, which conceive of the rational mind as the only source of sense. The living human
being, who experiences, emotes, feels, and develops, constitutes a firm theoretical or practical basis for a theory of rationality that is grounded in the mundane ways in which I actually experience myself. The following three assertions summarize the advantage of taking the living body as the center of a theory of sense making: radical passivity, heterogeneity, and solidarity.

**Assertion 1** As we participate in the everyday world, we cannot anticipate what we do not yet know, including what we will be seeing and the sense we will be making. That is, we are in a situation of radical passivity with respect to absolutely new ways of perceiving and with the sense we can make of it.

The shift made from the transmission model of learning to students’ agency to construct cultural knowledge (in social interaction) has been the major achievement of science and mathematics education theory over the past several decades. Yet, the relation between culture and the individual mind, for example, how individual students discover the knowledge that humans have developed over the long cultural-historical time span has been one of the critical questions posed to constructivists long before this movement came about in science and mathematics education – as our introductory quote shows. In quite a number of studies, learning is considered as if it were a process of constructing a building with a set of blocks and students are assumed to see these blocks without any problem. That is, the child is said to know what kind of blocks there are in her toy box and, if needed, is able to display and see them all at once as competently as curriculum designers. If this is the real case of sense making, learning would simply be consisting of selecting some blocks among the whole set and constructing a building according to a plan. However, this metaphor has limitations (Roth, 2011b): When students learn about something really new, they actually cannot see either what building they are going to construct or what blocks are available for them yet. Both the building and the block pieces are invisible.

For this problem the theory of the living body provides a solution: sense making is possible because the child is capable of feeling (suffering) something that happens to or comes into contact with the body – being touched. Students actively engage in knowing the world by making their living bodies contact with the world while seeing, hearing, touching, and moving. Becoming aware of something through the senses (i.e., perception) is a by-product given to students in the course of their sensuous labor. That is, sense making involves a radically passive moment in which acting constitutes the possibility to be affected by the unknown and therefore not-yet-known, by the unseen and therefore unforeseen. This experience is similar to learning a new language and therefore to make a completely new sounds. In fact, a new language speaks through the person one day when she finds herself being able to pronounce the sound that she could not make before. This is also similar to traveling in an area that is totally new to a person. The new world (objects) appears to the person’s vision one day when she finds herself seeing things that have not been visible before.
Assertion 2  We communicate by various modalities including sound (words), intonation, hand-arm movements (gestures), body movements, body positions. These modalities communicate differently (form) and are different (things). Communication therefore is heterogeneous. We cannot conflate all other modes to the verbal but need to seek the unity at a higher level. From the perspective of the higher level, all forms of expression are one-sided manifestations of the whole — and therefore constitute only partial truths.

The significant role of our bodies in sense making has been acknowledged in some educational studies in such key terms as embodied knowing, situated learning, learning-in-practice, and so on. Common to these concepts is the inseparable relation between individual knowing (e.g., being able to do arithmetic) and social and material context in which this knowing plays itself out (e.g., in grocery shopping). That is, neither the mind nor the context can be a complete unit for understanding everyday rationality other than the praxis that encompasses the dynamic relation between the two. Thus, communication is not a simple dumping of mental content into the public arena of a conversation. Rather, it is a process in which talking, gesturing, placing bodies, moving bodies, and intonating bring out contextual possibilities. Simultaneously, these contextual possibilities change, as talking adds new resources for thinking and for further talking.

This way of understanding provides a different perspective of communication: the role of communication in sense making is not to code-switch from one way of talking (e.g., the vernacular) to another (e.g., the scientific/mathematical) but to produce resources that problematize the boundary between the two. Communication brings about culture not in a self-identical manner but in heterogeneous ways. In the classroom, the heterogeneous nature of language and culture constitutes the very condition for knowing and learning science and mathematics. In fact, the double role of my living body in communication and practical experience of the world indicates two (inseparable) roots of sense making resources and therefore their heterogeneous nature. The way an individual participates in communication and learns should be studied by considering all the practical actions involving not only speaking/listening but also the interaction with visual and textual representations mobilized as part of the ongoing communication. The acknowledgement of the heterogeneous communicative performances as legitimate sense making resources brings about a different understanding of culture and language — language and culture are inherently heterogeneous because of the very possibility of their role in making sense of the world.

Assertion 3  Language, sense, consciousness, and knowledge inherently are cultural (societal, collective) forms. They exist only in and as collective forms. Without the collectivity, there is no language, sense, consciousness, or knowledge. Collectivity, however, is equivalent to solidarity, which thereby is a condition of sense making.

The double function of my body across two developmental lines – communication along the line of linguistic practice, on the one hand, and experience of the
INTRODUCTION

world along the line of object-oriented practice, on the other hand – raises a ques-
tion: What condition makes this encounter possible on the first place? The living
body that is distinguished from the material body by the fact of its being alive (i.e.,
life) constitutes the answer: The material body and the living body (flesh) are two
moments of praxis for expanding one’s condition of life. Making sense of the
world does not mean practicing individual intelligence but it means improving the
collective condition that also makes the individual intelligence possible in the first
place. That is, the power to make sense of the world derives from the praxis that
expands the collective condition of life. To live life means that I have to fulfil the
basic needs that come with my body, food, shelter, clothing, love, and so on. Af-
flect is a measure to which the basic and extended needs are fulfilled. All my ac-
tions in this world not only are reflected in (verbal) consciousness but also in affective terms. We can understand learning and development only when we take the
perspective of the whole person, in her flesh and blood, and recognize that cogni-
tion is only a one-sided part of this whole (Vygotsky, 1989).

The perspective of the sensuous, living and lived body theorizes sense making
in its unity with affect. We thereby respond to Vygotsky (1934/1986), who sug-
gests that “when we approach the problem of interrelation between thought and
language and other aspects of mind, the first question that arises is that of intellect
and affect” (p.10). Life is realized in my sensuous body so that it is precisely in
and through my sensuous body, its affectability, that I share life with others (Henry,
1990). Emotions are a direct reflection of our situation in the world – I do not have
to think but experience fear in certain situations and I tend to flush before I am
conscious of being embarrassed. Cultural-historical psychology finds the condi-
tions for this inseparability in the orientation toward a collective motive that any
participation inherently presupposes and realizes in and through a concrete action
(Leont’ev, 1978). Collective emotions are always part of social interaction precisely because life is realized in a sensuous, affective body – my own emotions can
change when I have a good time, when my team goes ahead in a game, or when my
nation wins another gold medal. This approach opens possibilities to study teach-
ing and learning in science and mathematics. Sense making changes the condition
for knowing my way around the world and therefore changes the way in which I
experience the world as well.

OVERVIEW OF THE CHAPTERS

This book consists of eight chapters grouped into three sections, each of which
fleshes out the dialectic approach to sense making. Although science and mathe-
matics educators will find the topics familiar, they will also note that we introduce
new ways of thinking about them. In Part A, we articulate the double relation of
body and sense: there is a sense of the body and a body of sense. The two moments
of sense (ideal, material) are theorized to constitute one another – rather than inde-
pendent – in and through our living bodies. In chapter 1 we articulate how the
category of the living body realizes and extends existing approaches to participa-
tive (unindifferent) understanding and therefore succeeds in responding to the
learning paradox – how learners can arrive at forms of knowledge of complexities higher than their ground, material, and tools. (The constructivist approach currently does not have an answer to the learning paradox, even though some eminent scholars including Ernst von Glasersfeld and Les Steffe have tried their hands at it.) The “construction of meaning” tends to be the main pedagogical goal for the teaching of concepts. Yet, the metaphor of “construction,” which is also used to theorize the development of participative (unindifferent) understanding, articulates only some among the different possible forms of knowing. The purpose of this chapter is to articulate a more comprehensive approach to development than exists in Vygotsky’s framework and its logocentric approach. That is, this study takes Vygotsky’s theory and develops it to include not only the words that he focused on but also the living body as a whole to arrive at a more holistic approach. We draw on phenomenology to develop a new way of understanding the nature of concepts. We substantiate our theoretical position by presenting exemplary case studies that exhibit the children’s trajectory of learning geometry in a second-grade mathematics classroom. We conclude that the extended framework of participative (unindifferent) understanding allows theorizing the role of emotion in learning mathematics without separating it from cognition.

In chapter 2, the living body is proposed as a category that captures lecturing activity better than information processing approaches – many science professors tell us that they try to “get” their “points across” – and therefore as the venue for conceptual gains. Lectures are often thought of in terms of information transfer: students (do not) “get” or “construct meaning of” what physics professors (lecturers) say and the notes they put on the chalkboard (overhead transparency). But this information transfer view does not explain, for example, why students appear to have a clear sense of understanding while they sit in a lecture and their subsequent experiences of failure to understand their own lecture notes or textbooks while preparing for an exam. Based on more than a decade of studies on the bodily nature of science lectures, the purpose of this chapter is to articulate and exemplify a different way of understanding physics lectures. We show that there is more to lectures than the talk plus notes. This “more” may indeed explain (part of) the gap between students’ participative understanding that exists in the situation where they sit in the lecture, on the one hand, and the one where they study for an exam from their lecture notes, on the other hand. Our results suggest that in lectures, concepts are heterogeneous performances in which sense arises from the synergistic and irreducible transactions of many different communicative modes, including gestures, body movements, body positions, prosody, and so forth.

In Part B, the role of the body in sense making is articulated and elaborated. Sense making traditionally is studied only from the perspective of sense as a mental issue, when in fact, without the body, there would be no senses and therefore there would be no sense whatsoever (for example, computers cannot make sense but only transmit and process signals). Only a living body has senses and thereby has the means to make sense of the world. The four chapters in this section attend to the embodied and bodily nature of sense making at different settings of learning. Chapter 3 theorizes literacy as the performances of living bodies rather than being
the outflow of mental or purely linguistic capacities. The body is deeply involved in knowing a language—my sensuous, living body is the link between speaking/hearing, on the one hand, and knowing my way around the world, on the other hand. Literacy denotes the cultural nature of knowing to communicate. Most studies of (scientific) literacy tend to use the notion of “constructing meaning” to theorize the process by means of which students become literate. Yet, the conditions that make literacy practice possible and bring about the associated conceptual development are hardly made salient and theorized. Therefore, literacy is often attributed to categories (e.g., mental) independent of bodily experience. In this chapter, we develop the idea that literacy always expresses itself somehow, concretely, in the (discursive) actions that are bodily produced and performed. We exemplify the central role of the body in computer-mediated literacy practice and the associated development of conceptual understanding in physics laboratory to support two claims about learning physics in a thermodynamics laboratory. First, the body temporally engages with different laboratory artifacts and spatially realizes literacy. Second, the body spatiotemporally coordinates cultural artifacts, which constitutes a terrain from which a higher-order cognitive function arises. We conclude that the central aspect of literacy in students’ conceptual development consists in the performance of a world, which bridges interpretive resources and the experience of the world metonymically.

As part of chapter 4, we expand the relation between communication and the experience of the world and therefore theorize the role of living bodies in conceptual development. Existing pedagogical theories often posit the source of conceptual development in terms of the literacy of an individual child or teacher and therefore suggest instructional strategies or instructional models based on (frequently unquestioned) presuppositions about the learning process. These theories give little attention to the real conditions that make the (real-time) communication of an idea possible. In this chapter, we extend our approach to literacy and participative (unindifferent) understanding to give the body a central role in conceptual development. We exemplify the contentions that (a) the body constitutes the mediating hub that translates, in an ongoing manner, the experience of the world (objects) and the word in communication; and that (b) the body constitutes the mediating hub that generates a new ways of making sense of the word. We conclude that a body-centered framework helps understand the sensuous labor that increases the resources for translating participative (unindifferent) understanding.

In chapter 5, we focus on the learning paradox involved in knowing mathematical inscriptions (sign forms other than language used in [electronic, paper-and-pencil, or whiteboard] written communication) and study the role of the body. Science teachers frequently use mathematical inscriptions (representations) in their lessons. In classroom talk, different types of mathematical representations assist science teachers in explaining concepts. Yet, students often have difficulty reading (interpreting) mathematical inscriptions that they encounter in their science lessons and associated science conversations. In this study, we theorize the practice of reading mathematical representations from a holistic perspective and articulate pedagogical principles of concept development. We thematize the cultural dynam-
ics of reading mathematical representation and exemplify it by analyzing a case example in which children in and through communication first come to know some geometrical inscription. First, the body reproduces and transforms cultural resources for interpreting mathematical representations. Second, the increase of heterogeneous interpretive resources in communication increases possibilities for realizing a new way of talking. Third, knowing mathematical inscriptions emerges from the different, irreducible modes of communication as an integrated whole. We conclude that knowing mathematical inscriptions is equivalent to (bodily and embodied) reading between elements of mathematical inscriptions that constitute a series of references to bring about scientific conceptions in its totality.

In the course of chapter 6, we theorize the role of the body in making sense of lecture talk. In this chapter, we suggest an approach to conceptual development that does not start from the dichotomy of the formal and the informal. We propose an approach that points out the problem of theorizing cognition (conceptual understanding) by depending on specific forms of representation (e.g., scientific terms). As alternative, we envision a cultural-historical approach to language, which considers different, irreducible modes of communication as an integrated whole and therefore allows theorizing cognition without separating it from the concrete ways by means of which human beings communicate. We provide an exemplary analysis of a lecture talk in a university physics classroom and exemplify dialectic theories that explain the development of conceptual understanding. We suggest that this approach takes account of the fact that people communicate scientific concepts through hybridization, which does not reproduce a genre self-identically but through the proliferation of difference.

In Part C, we provide perspectives on mathematical and scientific learning in terms of living bodies that inhabit the world where they encounter science or mathematics as new linguistic and cultural forms. The two chapters in this section provide an analytic framework of communication that makes emotional-volitional valence and ethico-moral valence integral aspects of action and therefore of cognition as well. In chapter 7 we propose a set of concepts for conceptualizing issues of learning science from the perspective of the unknown, as an encounter of the learner with the (radically) foreign/strange. We draw on ethnographic work in one undergraduate physics course at a Canadian university, where we followed in particular one female Japanese student, who had come to this country for the purpose of getting a degree. As an entry point and as source of empirical materials, we draw on our auto/ethnographic experience as immigrants because doing so comes with particular advantages to ally pathos (the capacity to be affected) to the experience of the foreign/strange. We view this experience as something that is happening to (affecting) us; and this something is beyond all prior experience, understanding, and anticipation. We articulate three phenomenological dimensions that pathos (empathy) allows us to understand concerning the experience of the foreign/strange and then provide an exemplary and exemplifying analysis.

In chapter 8 we develop the notion of the body as the ground of solidarity and responsibility. Qualitative research designed to develop ways of understanding and explaining lived experience of human beings is a reflexive human endeavor. It is
reflexive in that researchers come to better understand themselves in the attempt to better understand their participants. Consequently, research ethics itself becomes an ethical project, for it pertains to participant and researcher at the same time: Both are subjects, knower and known. Particularly in case of research on learning, reflexivity arises from the fact that the research constitutes learning about learning. How is ethics in research on learning reflexive of ongoing events and changes of the human learning? In this chapter, from our experience of conducting a project designed to inquire into “learning in unfamiliar environments,” we develop pertinent ethical issues. First, ethics is an ongoing historical event; second, ethics is based on the communicative praxis of sensuous bodies; and third, ethics involves the creation of new communicative forms. We conclude that ethics is grounded in a fundamental answerability of human beings for their actions, which requires communicative action that itself is a dialectical process in opening up possibilities for acting in an answerable manner.

ISSUES OF METHOD

This book articulates the dynamics of how learners encounter and experience science and mathematics in everyday settings. Each chapter draws on case exemplars to exemplify theoretical claims on sense making, which we have extracted from a series of research projects. First, the examples of learning geometry presented in chapters 1, 4, and 5 are part of a mathematics education research project that studied children’s understanding of three-dimensional geometry concepts in the mathematics classroom of a Canadian elementary school. The curriculum consisted of 15 geometry lessons conducted by a university research team in collaboration with a schoolteacher over a period of three weeks. Second, the case examples in chapters 2, 3, 6, 7, and 8 are extracted from a research project on learning physics, which was conducted as part of a larger-scale project on crossing the boundaries between very different activity forms and the forms of cultural knowledgeability required in each. The purpose of the project was to study students’ learning and development of identity across different cultural settings, particularly in the areas of physics at the university level.

The data sources exist in the form of recorded Hi-8 digital videotapes, curriculum materials and students’ worksheets, teachers’ handouts, and researchers’ field notes. The video recording of the elementary mathematics consists of a series of geometry lessons conducted in the school classroom. The video recordings of university physics covered curricular classroom activities (lectures and lab experiments), consultation and problem solving sessions (assignments), and non-curricular university sessions (e.g., department seminars). We digitized the videotapes into QuickTime files. The digitized files were segmented and transcribed. Offprint images were created from the video files and imported to transcripts, which ultimately were replaced by hand-drawings. We saved sound tracks of the episodes as separate audio files. We used a freely available, multi-platform software package PRAAT (downloaded from http://www.praat.org) to analyze pro-
sodic properties of utterances such as pitch, pitch contours, speech intensity, and speech rate.

We maintained prolonged engagement, persistent observation, and peer debriefing with disinterested colleagues in the research laboratory to meet the trustworthiness criteria (Guba & Lincoln, 1993) throughout the research. For example, the participants in the research on learning physics were undergraduate physics students and lecturers. One of the research participants was an international female student (pseudonym Mariko) studying physics. To gain a better understanding of the learning environment in the way it is salient and relevant to learner’s everyday life, we conducted intensive ethnographic work involving our participation in various settings of learning physics and collecting a wide range of data sources. We conducted research observations and associated interviews about her physics study, which were followed by videotaping two undergraduate physics courses (thermodynamics and optics) and other school practice over a semester. Through our prolonged study of Mariko, we came to understand the gap between her efforts and positive comments on physics lessons on the one hand and her real performances on the other hand. Our analytic approach offered a possible explanation of the gap (chapters 2 and 6) and of participative (unindifferent) thinking (chapters 3, 7, and 8). This approach does not attribute characteristic phenomena to the capacity of an individual (student, teacher) or the nature of discipline (mathematics, physics) isolated from the concrete situations of teaching and learning but respects the aspects of the situation publicly made available to participants. This method increases the possibility to develop a theoretical framework that is transferrable and testable and also simultaneously deepens the understanding of the particularity of the lecture situation. The authenticity criteria have also been attended to. For example, we watched some of the videotaped lessons with the key research participant. In our collaborative session with Mariko, we observed that she developed a better understanding of physics concepts when she had an opportunity to watch a lecture-video and see/listen to sense making resources deployed in the lecture in the forms other than her own notes.

We also developed a reflexive form of research. The researcher and the research participant came to constitute the reflexive relation between the two and afforded two important aspects during the fieldwork: On the one hand, it provided discursive resources for establishing a rapport and facilitated discursive interaction between the two, and, on the other hand, it provided the researcher with a reflexive ground for taking a first-person perspective on the research participant’s experiences refracted through the lens of her learning experiences. In chapters 7 and 8, the reflexive relation between learning to do science and mathematics and learning to do research on it provided opportunities to experience moments of research activities explicitly through an ethical (rather than metaphysically cognitive) lens. It also allowed us to bring the emerging ethical issues to bear on the research. In this sense, these studies embodied a dialectical process in which our understanding of ethics evolved. Each step constituted research praxis producing a description of ethics as lived praxis and, by the very praxis, became a ground of reflexive step. In chapter 8, we see a moment that the researcher had experienced with the research
participant (episode), which brought forth an ethically critical question for the researcher herself (SWH). The moment became a constituting event in her learning to do research and in research on learning. This was a first reflexive step that transformed the lived experience into the description of the lifeworld. In the next step, we came to provide a description of the issue having changed as we discussed it in a reflexive fashion, that is, reflexive to the process of raising and phrasing the question. This is the phenomenological method Georg W. F. Hegel (1977) used in *Phenomenology of Spirit*, where the outcome of the study is an understanding of the process of arriving at the outcome. Consciousness comes to understand itself as an instance (concrete realization) of collective but contingent consciousness, which means that the process of arriving at this understanding is itself contingent.

In the course of this book, we employ the following transcription conventions:

- **[and]** Square brackets in consecutive lines with or without numbering show an overlap of speech with body movements, which extends for the duration of speaking the words underlined;
- **((draws))** Italicized words within double parentheses constitute transcribers’ comments on visible body movements;
- *** Asterisk mark denotes an instant that corresponds to a drawing of video-offprint of which the figure number is labeled at the end of the comments;
- **(2.0)** Number within parentheses indicates elapsed time of pause in tenth of a second;
- **NOW** Capitalization marks speech that is louder than the normal speech intensity;
- **<<p>well>** Words within angle brackets indicate lower speech volume (pianissimo) than normal;
- **(find out?)** Question mark in parentheses indicates inaudible utterance(s);
- **cu:be** Lengthening of a phoneme is indicated by colon;
- **?;:.** Punctuation marks are used to indicate characteristics of speech production rather than grammatical units;
- **it’s-** Equal sign at the end of one turn and at the beginning of the next indicates latching turns, that is, there is no gap between the two speakers;
- **↑↓** Arrows indicate a rise or fall in intonation sharper and more clearly noticeable than normally occurs.
PART A

FROM THE SENSE OF THE BODY
TO THE BODY OF SENSE
Generally speaking, the new psychology has revealed man to us not as an understanding that constructs the world but as a being thrown therein and attached to it by a natural bond. As a result it re-educates us in how to see this world that we are in contact with at every point of our being, whereas classical psychology abandoned the lived world for the one which scientific intelligence succeeded in constructing. (Merleau-Ponty, 1966/1996, p. 68)

This introductory quote derives from a text on cinema and the new psychology, which Merleau-Ponty found in Gestalt psychology. The author makes a point fundamental to the current book project. Human beings are not constructing the world but are thrown into it, being connected to it “by a natural bond.” We live in a real world, together with our thoughts, not in a netherworld that is the result of mental constructions. Despite the many problems others have shown with respect to the constructivist metaphor, many science and mathematics educators continue to hold on to it. In this section particularly and throughout this book generally, we mobilize evidence for the central role of the body in the way that Merleau-Ponty conceived it.

Learning science or mathematics involves students’ exposure to different sources of sense experience, some of which students have never come across before. For example, in science classrooms students come into contact with visual graphics like the double helix structure of the DNA molecule, sound-words like the names of chemical elements in the periodic table that are not part of everyday discourse (molybdenum, rubidium, or strontium), or equipment used in laboratories for the first time through the experience of seeing, hearing, and touching. Central to this occurrence is the double nature of sense experience. First, the contact with objects from the cultures of science and mathematics consists of bodily and sensuous (visual, aural, and tactile) experience. To perceive some new aspects of the world, students have to let their bodies affected by the different sources of sense (sensuous) experience. Second, at the same time, the sensuous experience of the world does not remain at the material level but provokes sense that constitutes a form of knowing the world. That is, students perceive the world by letting their sense experiences mark some sense on them, without which learning would not be possible. Coming to see the structure of the DNA molecule while seeing the complicated image of the double helix and hearing a teacher’s verbal explanation involves this double nature of sense experience. Phenomenological philosophers such as Maurice Merleau-Ponty have explained the double nature of sense experience in terms of the living body. This body is different from a machine that simply
PART A

collects information from outside. This is not the body studied by biologists, who do not focus on the living part but only on the way life manifests itself to the observing human being (Sheets-Johnstone, 2009). The observer’s body is not just a material entity but a form and instantiation of life that is capable of acting and at the same time being affected and self-affected by the act that it produces. Thus, the expertise in recognizing DNA patterns while gazing at complicated visuals in the film would not be possible without the living body that inscribes (structures) itself in and through tedious bodily work (e.g., eye movement) and learns how to see.

Therefore, the phenomenological notion of the living body provides a clue about the development of thinking. For example, when someone tries to talk about new ideas and do not find appropriate words, we may observe the person’s body engaged in looking for them such as with hands leafing through notes and eyes gazing at diagrams. The lived (bodily) experience of the world is not transparent but “thick” in the sense that the conscious mind cannot objectify the whole – if this were to be the case, the mind would no longer be engaged in learning something new. The living body constitutes the hub of sense experience, on the one hand, and the hub of scientific and mathematical sense making, on the other hand. This double nature of the sense experience constitutes the source of scientific and mathematical perception and learning in and through everyday occurrences of classroom communication. Vygotsky already acknowledged this double nature of sense making experience when he proposed that verbal thought (or verbal thinking) constitutes the whole unit to be investigated to study the child’s scientific concept development rather than language or thought alone. In Thought and Language (Vygotsky, 1934/1986), the author suggests that we ought to be studying “the development, the functioning, and the structure of this unit [i.e., verbal thought], which contains thought and speech interrelated” (p. 6) rather than “breaking it up to its component elements, thought and word, neither which, taken separately, possesses the properties of the whole” (p. 211).

In this first part of the book, we study the double role of the living body in knowing and show the great power of this idea to explain everyday practice of teaching and learning. We follow and expand the holistic framework Vygotsky presented along dialectic, phenomenological traditions. We show that perceptual experience and sensuous experience – two moments of sense – constitute one another in and through the living body. That is, we theorize that learning means coming under the influence of various forms of sense experience and perceiving them as totalities. The material bodies in the classroom become sense-making resources only within the living (sensuous) praxis of doing (talking) science or mathematics where the living body constitutes the organizing center. The living body with its senses comes to constitute the body of sense. We theorize and exemplify this general principle in two different contexts of teaching and learning concepts, which are often considered abstract and belonging to a realm separate (independent) from actual, sensuous praxis. In chapter 1, we study a mathematics lesson in which little children learn about three-dimensional geometrical objects and associated concepts. In chapter 2, we investigate a university physics lecture in which a professor talks about thermodynamics concepts to physics undergraduate students. In our analysis
of teaching and learning at the two different levels of teaching and learning, we exemplify the corporeal and incarnate nature of real-time thinking and conceptual understanding. In both cases, we show that the living body captures the very “more” of teaching and learning that (mechanical) information processing cannot capture; that is, the living body constitutes both the venue where the conceptual gain is achieved and the substance of conceptual gain itself.
CHAPTER 1

MATHEMATICS IN THE FLESH

This displacement of the memory from the domain of thought to that of the flesh, this corporeal memory of which Maine de Biran had the unheard-of intuition, doubles itself depending on whether it is considered at work in the delivery to the senses or in its immanence, before the intervention of any intentionality. (Henry, 2000, p. 207)

Biran did not reduce consciousness to motility but he identified motility and consciousness. . . . It is not a consciousness becoming movement, but a consciousness reverberating in movements. (Merleau-Ponty, 2001, p. 64)

Memory is probably the single-most important phenomenon to be attributed to the capacities of the mind. Yet as this introductory quote shows, there are forms of memory that are better thought of as corporeal rather than mental phenomena. Intentionality and our fundamental capacities related to agency are built on such capacities that predate mental representation. Although we have begun to develop a theoretical framework that takes serious the phenomenological critique of intentionality and agency (e.g., Roth, 2010a, 2011a), a lot of work remains until a more comprehensive theory is developed. The present chapter contributes to this work of a phenomenological account of mathematics (science) in the flesh.

In this chapter, our intention is to articulate a more comprehensive approach to development than exists in Vygotsky’s framework and its logocentric approach (he restricts himself to words and “word-meaning”). That is, this chapter takes Vygotsky’s theory of participative (unindifferent) understanding and develops it to include not only words but also the living body as a whole, which has many other means for articulating sense than the vocal cords alone, to constitute a more holistic approach. We draw on phenomenology to propose a different way of understanding the nature of mathematical concepts. We substantiate the theoretical issues by presenting exemplary case studies that exhibit children’s trajectory of learning geometry in a second-grade mathematics classroom. We exemplify an instance of verbal thinking in which a child engages in knowing the world (object) in and through the living body. We conclude that the extended framework of participative (unindifferent) understanding allows theorizing the role of emotion in knowing and learning mathematics without separating it from cognition.

INTRODUCTION

The “construction of meaning” tends to be the main pedagogical goal for the teaching of mathematics. Yet, the metaphor of construction, which is also used to theo-
rize conceptual development and conceptual change, describes learning by taking recourse to that which is unknown to students and therefore produces some irresolvable problem to explaining learning, as it is lively realized. For example, imagine a person who does not know (see) triangles. How can the person aim at (intend to) learning (about) triangles if they are both unknown and invisible to the person and from within the world of the person? Because the person is blind to this aspect of the world, and because there is no concept (however defined) of triangles, how can this person learn (communicate) about triangles? Some readers might too rapidly suggest, well the children can touch, or adults can lead the child. But the research in Russian institutes for deaf-blind children shows that much more is required for these children to learn, for when they arrived in these institutions, these children were in mere vegetative states (Meshcheryakov, 1979). They did not have “innate” exploratory instincts in the way that Jean Piaget or Ernst von Glasersfeld postulated. There is therefore a real learning paradox that I cannot intend what I do not know, and, as shown for the deaf-blind, particular conditions are required to get me of this double bind. This is the essential idea of the learning paradox that constructivist educators have not resolved. That is, because students do not know a concept, they cannot at the same time aim at (intend to) learning it; if they knew the concept, necessary for being able to make it the object of an intention, then they would no longer need to learn. Even social constructivism has not solved this problem, because if individuals cannot see and do not understand triangles, they cannot do so in the social interaction.

Lev Vygotsky is the key person in psychology who opened a new path to solving the problem by attending to the inter-functional relation between thought and speech in the child development. In his book Thought and Language, Vygotsky (1934/1986) studies the roots of thought and language and suggests that at some point of the child development the two lines of development encounter of which the central phenomenon is participative (unindifferent) understanding. The signification of the word is not a stable property belonging to the word (Bakhtine [Volochinov], 1977). Participative (unindifferent) understanding consists of an ongoing living process that develops as a thought is verbally articulated in speech and also affected by speaking simultaneously. In fact, speaking and thinking are not stable entities but processes, and the overarching phenomenon that gathers them into the same unit is itself a process. “Participative (unindifferent) understanding” is a process at three levels: it develops from moment to moment, in the course of a person’s change (ontogeny), and throughout cultural history. Thus, to study the child’s concept development, Vygotsky highlights the significance of considering “the full sense of the term” in the fullness of communication. The very possibility for the development of participative (unindifferent) understanding is involved in the whole unit of communication in which the sound-word is mobilized and marks sense in some way. Vygotsky’s holistic approach to the participative (unindifferent) understanding reveals some mechanism by which mathematical concepts first come to mark sense for the learning students. For example, if learning is an intentional (constructive) process, it has to be framed in such a way that it is entirely located in and contextualized by students’ everyday experiences and language. For students,
everyday experiences and concepts therefore constitute the very condition that students have to depend on when they learn about it. For students, the conceptual growth involved in mathematical conceptions pertains to the transformation of these mundane experiences and everyday (spontaneous) concepts as the material to be transformed. This material is given in its everydayness rather than by an act of the conscious mind that somehow constructs an object that it does not know. Philosophers have recognized this as the fundamental problem of all forms of constructivism: How can the mind know that what it does and thinks relates to anything outside the body. Even the radical constructivist “solution” that the matter is not one of truth but one of fit does not get us out of the problem, for the constructivist mind is so caught up with itself that it cannot go outside to check its “construction” for fit. The constructivist mind knows no outside (Henry, 2003).

Vygotsky’s holistic approach is in line with the phenomenological idea that the living body has the capacity to open itself up to be touched by the world, which deals with the learning paradox somewhat successfully. In the sociology of Pierre Bourdieu (1997), it is precisely this capacity of the body to be open to the world where it is affected that leads to the structural homology between the social and material world and the individual’s dispositions for seeing and acting. The holistic approach to sense experience follows a Marxist way of thinking, materialist dialectics (or dialectical materialism), which is a framework that integrates the material and the ideal (consciousness, thought) within a single unit of experience. Although the material and ideal are different, they are recognized as manifestations of a higher unit – as wave and particle are recognized today as different manifestations of light. Yet, there are limitations in Vygotsky’s logocentric approach to language and communication. Although Vygotsky points out the significance of analyzing “whole unit,” he analyzes participative (unindifferent) understanding only by leaving out the body, which is also the way Vygotsky’s work has been adopted in many educational studies after him. The purpose of this chapter is to bring together Vygotsky’s cultural-historical perspective on thinking and speaking with Merleau-Ponty’s analysis of the role of the body in communication. The living body solves the learning paradox because the corporeal engagement in/with the world not only transforms the world (objects) but also brings about changes in the living body, which is structured in/through the experience. The living body that senses and is affected by the world constitutes the integral aspect of learning in which the invisible/unknown becomes visible/known to the person. Therefore, we theorize the central aspect of the living body in learning mathematics (science) and propose a more comprehensive approach to concept development (formation). Our theoretical extension in this chapter bears two-fold significance. First, we extend Vygotsky’s framework of participative (unindifferent) understanding to include the living body that has become an important dimension in educational research in general and research on mathematics education in particular. Second, the extended Vygotskian framework contributes to resolving the learning paradox and the problem of constructivism.
CHAPTER 1

FROM WORDS TO THE LIVING BODY

Communication is central to the development of participative (unindifferent) understanding in learning mathematics. Listening to the other talking about and interpreting representations allows students to participate in the classroom communication and come to encounter conceptual resources new to them. For Vygotsky (1934/1986), the development of participative (unindifferent) understanding in communication constitutes a central phenomenon that explains the development of scientific concepts and the role of instruction. The significance of communication as linked to the conception development is that it allows us to attend to all the extra-linguistic capacities that are part of any practice. For example, gestures and the multimodality of communication have recently gained a lot of attention in mathematics education. That is, anything linguistic in language use therefore bottoms out in forms of experiences that are pre- and extra-linguistic. In this framework, learning mathematics is like learning a language that is part of a larger unit encompassing the fullness of life – all the bodily and corporeal resources that bring about the living/lived experience of the world are also related to conceptual development.

The Living Body as Expression

In his introduction to English version of Merleau-Ponty’s (1969) La prose du monde [The Prose of the World], the translator John O’Neill characterizes one of the fundamental messages of the book in this way: “we are the language we are talking about. That is, we are the ground of language through our body. It is through our body that we can speak of the world, because the world in turn speaks to us through the body” (Merleau-Ponty, 1973, p. xxxiii). That is, language, our living bodies, and the world are intertwined, flesh of the same flesh. Conceptions, always already expressed through my body and language in a familiar world, therefore have to be thought in this same manner.

Conceptions have origins and trajectories in child development. Mathematical conceptions in this chapter are related to the temporal development of participative (unindifferent) understanding in communication rather than “meaning” that is assumed to reside in specific forms of representation (e.g., words, mathematical representations, and other forms of scientific representations). Our approach to the development of participative (unindifferent) understanding follows dialectical theories of thinking and speaking and its extension to a body-centered comprehensive framework. First, we draw on theories of thought and language that is part of a larger unit encompassing the fullness of life (Bakhtine, 1993). Participative (unindifferent) understanding arises from the process that integrates thought and speech (gesture) dialectically – “continual movement back and forth from thought to word and from word to thought” (Vygotsky, 1934/1986, p. 218). Second, we follow other studies that have extended Bakhtin’s participative (unindifferent) understanding dialectic toward the point that thought is dynamically related to the whole unit of communication rather than to words alone. For example, in communication, words take forms of sounds (e.g., prosody) and constitute one part of the whole.
network that marks sense (i.e., living participative [unindifferent] understanding) together with other corporeal forms of experiences mobilized simultaneously (e.g., gestures [McNeill, 2002]).

The extension following the Vygotsky-McNeill approach makes two significant contributions that lead to a more comprehensive approach to conceptual development than exists in Vygotsky’s framework (i.e. participative [unindifferent] understanding). First, conceptions – the concrete ways in which concepts are realized in and by individuals – are distributed across many different forms of experiences, language, gesture, and body (the whole, including emotions). That is, rather than consisting of words alone, we understand “conceptions” to be grounded in the experience of dwelling in a world so that our entire body becomes a source of expression (Merleau-Ponty, 1945). In this move, we take into account my everyday ways of being, for example of talking to others, where I do not experience myself as a computer that mobilizes conceptual structures and concepts stored in my mind. I just talk in the same way that I move my legs and feet: I simply walk. Moreover, in communication I do so as an entire being, and anything I do may turn out to be a general expression that tells others more than what I intend. From my bodily turns or intonations, others take that I am disinterested or angry even though I might not have had such an experience or, I learn through these expressions that something does not interest me and that I am angry. Both Vygotsky and Merleau-Ponty point out that when I speak, I find out what I am thinking: There is not first thought, which is then emptied out into the public. Speakers find out about their thinking as much as listeners. This more holistic theory of conceptions considers different, irreducible modes of communication as a whole.

Second, in this framework of communication, conceptions then may express themselves concretely as part of an embodied life that is irreducibly interconnected with language; therefore, everyday lived experiences constitute the condition for conceptual development. This focuses our attention on the processes by means of which everyday non-scientific conceptions come to be transformed into scientific conceptions. Rather than being eliminated and eradicated, everyday conceptions are the ground, material, and even tools in a transformative process that leads to scientific conceptions. To understand learning, we need to understand is this transformation. We must not theorize learning in terms of the abandonment (“eradication”) of old conceptions, because this would also mean that we have to think of abandoning (eradicating) all the tools we have available, in fact, abandoning the very ground in which any thinking occurs.

In this way proposed, the theory of participative (unindifferent) understanding includes the dynamic role of the living body, which allows, for example, emotion to become an inner part of thinking in the way Vygotsky asked for. The following four points summarize the dynamic of development in communication from an extended Vygotskian, body-centered perspective. First, the living body constitutes the mediating hub in experiencing the world (objects). Second, the living body constitutes the mediating hub in communication; my body is my expression rather than merely a tool for expressing what is in my mind. Third, the real-time articulation of thinking with and for the other is distributed within the unit produced by the
bodily action in itself and with respect to them (e.g., speech, gestures, eye gaze, body orientation and movement, etc). Fourth, eye gaze, gestures, body orientation and movement, which are involved in experiencing the world (objects), are also involved in communication. The four principles explain the integral role of the living body in the translation of the whole unit of participative (unindifferent) understanding in which the living body mediates the unity of different forms of experience: “The unity and identity of the tactile phenomenon do not realize themselves through any synthesis of recognition in the concept, they are founded upon the unity and identity of the body as a synergic ensemble” (Merleau-Ponty, 1945, p. 366). The role of the living/lived body guides the analysis of development without having to mystify it or begin from the dichotomy between spontaneous and scientific concepts.

**Concept Development at Three Levels**

The proposed comprehensive model considers the development (translation) of mathematical concepts (participative [unindifferent] understanding) at three levels: the cultural-historical level (e.g., geometry as a field of study), the ontogenetic level (e.g., the child development), and the situational level (i.e., concrete events in a mathematics lesson). The trajectory of a child’s conceptual development involves dialectically related temporal scales. First, conceptual development involves an individual’s participation in the reproduction of participative (unindifferent) understanding that has been established and develops at the cultural-historical level. For example, children in the mathematics classroom listen to a teacher explaining geometrical shapes of three-dimensional objects using different sound-words (e.g., cube, sphere, cylinder, prisms, and pyramids). For children, those sound-words may be terms that are not used in their everyday talk and therefore constitute foreign sounds that they are confronted with in the mathematics class. However, words used in geometry have a long history traced back to the ancient Greek in which people at that time used terms that emerged and grew out of their everyday life and experience and have been transformed over a long history, of which the trajectories are left in etymology. Here, the cultural-historical development is tied to the ontogenesis of individuals who became the names associated with particular concepts. Culture developed as, for example, Euclid, Pythagoras, and Thales worked on the statements that we know today under their names. But the same process occurs today, for observed changes in the culture of science and mathematics occur only when the “driver” of change is in the performance of culture itself. Culture is performed precisely when children engage in relations with their teachers and the cultural artifacts in their classrooms. Because conceptions and (mathematical) literacy require the mobilization of a network in which sound-words make links to other forms of experience, including those that make our everyday life (Roth & Thom, 2009a), we have to conduct our analyses simultaneously at the individual developmental (“Where is the student in her development?”) and cultural-historical levels (“Where is the [pedagogical] culture at this point in time?”).
Second, the development of participative (unindifferent) understanding at the ontogenetic individual level occurs as the individual actively engages in the salient aspects of the world (objects). Here we have to be cautious, for what is salient to an adult teacher is likely not the same than what is salient to a child, who is only in the process of learning geometry. These different ways of seeing and experiences come together in the classroom, where all participants take for granted that they are in the same world, even though closer analysis shows that they are acting in the different worlds given to their perceptions. The here-and-now of the situation constitutes the setting in which corporeal forms of experience are mobilized and where links are made in appropriate ways. Children learn geometrical concepts by participating in concrete situations in which they have to point out specific objects or speak this or that—which we show in the next section. That is, the ontogenesis of scientific concepts is tied to the microgenesis of children’s talk as it unfolds in real time. Therefore, the consideration of the development of participative (unindifferent) understanding at the three levels—cultural, individual, microgenetic—and their intertwined relations allows us (a) to integrate embodied and bodily forms of knowing into the unit of participative (unindifferent) understanding and (b) to analyze a child’s conceptual development from a holistic perspective.

SENSE EXPERIENCE AND MATHEMATICAL CONCEPTIONS

Conceptual development occurs over time. In fact, from a phenomenological perspective, we ought to say that developing, as process, means producing time and space. Because this idea is difficult to comprehend, writing (Fr. écriture) has been proposed as a metaphor (Derrida, 1967), for in writing, as the pen moves across the page, both space and time are produced, and, with it, words and ideas unfold and develop. The child in a geometry classroom participates in talking about three-dimensional objects and temporally develops its understanding of concepts. In a way very similar to writing, the moving body expresses by creating space and time of communication. The act of speaking or listening to others’ talk unfolds in time as much as it is making time. That is, time is generated as the conceptual possibilities that classroom objects make available are realized into different forms of experience. Certain ways of being-in-the-world emerge as the living body temporally engages in objects and therefore spatially realizes different forms of experiencing the world. Those (temporally emergent) different forms of experience are all potential forms of knowing the world that have a significant role in the child’s conceptual development. They involve the potential to affect the real-time translation of the whole participative (unindifferent) understanding unit and therefore they are simultaneously unique and partial representations of a higher communicative unit. For example, speech and gestures are two irreducible components both of which dynamically incorporate the context of communication in an integral way and therefore affect the development of the contents of communication. Each constitutes a potential opportunity from which a new way of knowing the world (as a result of the translation of the previous) emerges and begins to grow. Therefore, the child’s conceptual development pertains to the dynamic coordination of differ-
ent forms of experience. Any one form of experience belonging to the emerging concept can activate any other form. Any one form of experience therefore can stand for the totality of experiences that makes the concept. Such a relation, where a part comes to signify the whole of which it is a part, is known as a metonym (Roth, 2011a). In this way of thinking about concepts, therefore, every experience is part of the concept. That is, whereas in other theoretical approaches children’s interaction with concrete materials is merely a stepping-stone, kicked away once the abstract concept is attained, in our approach a concept implies all the practical experiences a person has had and that leave traces in the living body. In this manner knowing a concept never is severed from “applying” a concept such that one cannot know a concept without also knowing how to apply it.

The living body is central to this spatiotemporal coordination because it mobilizes different forms and more so makes links between them. The unity that the living body makes available allows the constitution of a participative (unindifferent) understanding unit from which a higher-order cognitive function arises. In this section, we conduct a case analysis and exemplify the role of body in the spatiotemporal translation of a participative (unindifferent) understanding unit. We show how a child bodily engages in the world and thereby develops an understanding of three-dimensional geometry concepts. In the following excerpt from a geometry lesson, second-grade children participate in identifying a mystery object placed on the glass panel of an overhead projector. The object, which is surrounded by a wall from paper, is itself invisible. All that the students see is a shadow projected on a screen and different three-dimensional objects on a shelf below a chalkboard. Therefore, students are given opportunities to talk about the geometrical shapes of unknown three-dimensional objects and their relation to their observed two-dimensional projections. We exemplify a comprehensive approach to conceptual development by substantiating the three-level analysis of the development of participative (unindifferent) understanding.

*Episode 1.1*

01 Teacher: Clara

02 Clara: "[um]" (((Clara puts her hand down and stands up)))

03 "[(1.8)] (((Clara walks to the front)))

04 [I don’t think it can be a circle] (((Clara grabs a yellow sphere on the shelf and turns toward the teacher and other students. *She holds the sphere with her fingertips propping around the round surface/edge)) (Figure 1.1a)

05 (1.4)

06 Teacher: "[¿? ¿] circle?" [circles are flat] (((Teacher points at Clara))) (((Teacher holds the palms of her hands facing one another and *moves them closer))) (Figure 1.1b)
Clara raises her hand and the teacher calls her name (line 01). Clara says “um” and walks to the front side of the classroom (line 02). She picks up a yellow sphere, one of the objects placed on the shelf underneath the chalkboard (line 04). She grabs it by using her fingertips and turns to face the teacher and other students (line 04). She holds the yellow sphere as high as her chest and gazes at it. Simultane-
ously she articulates for the audience that she does not think “it can be a circle” (line 04). A pause comes about (line 05). The teacher points her right hand at Clara and articulates that circles are flat (line 06). Simultaneously, the teacher puts the two palms of her hands together, which constitutes a gesture of narrowing (line 06). Clara gazes at the yellow sphere in her hands (line 07). One of the students sitting in the classroom utters “sphere” (line 08). Clara puts the palm of her right hand attached to the surface of the sphere and grabs it by using the whole hand instead of fingertips (line 09). Another student utters “sphere” (line 10). Clara repeats the word “sphere” and rubs the right surface of the sphere using the palm of her right (line 11). The teacher repeats the word (“sphere? yes, that’s right”) and utters “why don’t you think it could be the sphere” (line 12).

**Analysis**

In this episode, we see a child participating in a conversation about a mystery object and verbally thinking by talking to a teacher and other students in this second-grade geometry class. (The episode exemplifies a beginning [formation] of mathematical thinking realized in communication.) Clara proceeds with picking up a sphere and shows it to others. She holds a round surface and edge of the sphere using her fingertips and suggests that she does not think “it can be a circle” (line 04). After a 1.4-second pause, the teacher points at Clara and says that circles are flat. The teacher’s action provides concrete form of knowing “circle.” The utterance “flat” and her gestures of narrowing the space between her facing palms connects the word “circle” to flatness, which contrasts to the spatial shape of the sphere that Clara holds. Clara’s utterance juxtaposes two words, “it” and “circle,” neither of which directly refers to the object that she holds up (i.e., a sphere). Therefore, the teacher’s action makes Clara’s coordination of the utterance and the act of picking up the object problematic: It is not clear why she picks up a sphere among others and what she means by “it” or “circle.” Clara gazes at the object in her hands. While participating in the talk about the mystery object, Clara encounters something foreign/strange: it makes an appeal and demands a response.

One of her classmates utters “sphere,” and thereby makes a sound-word available in the classroom. The articulation of the sound-word “sphere” opens an opportunity for the emergence of a different form of experiencing the object. Clara puts her palms to the surface of the sphere, and thereby changes her way of holding the object from using her fingertips to using the whole hands. This allows her to touch the round surface of the sphere rather than the circular edge of the surface. This new form of experience is linked to speech when Clara repeats the sound-word “sphere” following another student’s uttering “sphere” in the next. Clara’s speech translates the experience of the object into the sound-word, “sphere,” which also affects the experience of the object into her rubbing movement over the surface of the sphere using the palm of her right hand. Clara’s body mediates the translation between the physical experience of the object and the hearing of the sound-word. Both experiences are corporeal, which means, it is precisely the living body that constitutes the translation. The two experiences are the experiences of the same “I
can.” Clara’s change of her way of bodily holding (experiencing) the object constitutes a point at which she explicitly changes the contents of her speech but also lets a new participative (unindifferent) understanding unit emerge. It makes for an opportunity through which everyday forms of knowing the world (e.g., round surface of a sphere) are mobilized in such a way as to link to the sound-word and other forms of experience (e.g., teacher’s gesture). This therefore expands a network of experiences that have left their mark in and on the living, lived body that we identify with the name Clara. From this holistic perspective, conceptions, “emerging in and from experience, exist in and as of experience” (Roth & Thom, 2009a, p. 186). Any single experience serves as an entry point into this network, because it is not only an integral part of the conception but, as a signifier, also stands for the network as a whole (the signified). The relation of any experience to the whole therefore is of metonymic nature.

The episode exemplifies the beginning of mathematical thinking to which the child’s basic experiences in her everyday life are integral. For Clara – or anyone else in this second grade mathematics classroom – the round surface of a sphere may not be an experience unique to mathematics (geometry) but common to her everyday life. For example, when children play with a ball, they have opportunities to touch the round surface of a ball. Thus, etymology shows that the Greeks words pertaining to “circle” (kúklos) and “sphere” (sfaîra) originate from the sound-words referring to “ring” (kúklos) and “ball” (sfaîra), respectively. That is, for Greek people, speaking the word sfaîra immediately mobilized an everyday experience of using a ball and therefore constituted a metonymic relation to a network of corporeal experiences related to this toy. Yet, children today have no clue as to the relation between the geometry words “circle” or “sphere” and their everyday experience. These words initially are foreign. They are associated with geometry classes but not with the general experience outside of school. In fact, the “reading circle” or “story circle” do not involve the kinds of ideal objects that geometry is about. In a way, these words are dead metaphors whereas they have been very much alive for the ancient Greek, for whom they denoted everyday experiences. Today, English-speaking children have to learn to make explicit links between these new and foreign sound-words to their everyday experience (e.g., playing with a ball) in the mathematical classroom. These experiences therefore become constitutive of new ways of knowing, as familiar ways of experiencing kinds of objects come to be associated corporeally: feeling the sphere and hearing the sound-word both happen in and to the same “I can” that characterizes the living/lived body to which we refer by saying and writing “Clara.”

In this way, the episode exemplifies the beginning of conceptual development in which Clara learns to differentiate “circle” and “sphere” by actively participating in making a network of everyday experiences. Yet, again, it cannot be the result of her intention to differentiate them. For example, Clara simply says “circle” because it makes sense to her – she raised her hand and volunteered to speak. Articulating the word “circle” brings her to a situation in which she encounters different forms of knowing “circle” and the object (i.e., sphere) that she holds in her hands (e.g., “flat,” narrowing gestures, and “sphere”). In this instant, there is no evidence that
Clara knows what or whether she needs to differentiate. She just engages in touching the object that she already holds in her hands (i.e., the palm curved along the round surface of the sphere) and utters the sound-word (“sphere”) that her classmate has suggested. These simple actions bring into alignment the resources that make up the participative (unindifferent) understanding unit. Thus, the teacher utters “why don’t you think it could be the sphere,” which thereby translates Clara’s initial claim (i.e. “don’t think it can be a circle” [line 04]) into another (i.e. “don’t think it could be the sphere [line 12]). The episode exemplifies the central role of the living body in the child’s conceptual development: it provides opportunities for metonymically bridging interpretive resources and the everyday experience of the world in two ways. First, the living body mobilizes different forms of experiencing and increases interpretive resources for knowing the world. Second, the living body coordinates different forms of experience and increases conceptual possibilities (e.g., the emergence of higher-order cognitive functions).

TOWARD A HOLISTIC APPROACH TO VERBAL THINKING

In this chapter we exemplify a comprehensive approach to conceptual development (concept formation) that does not presuppose participative (unindifferent) understanding separated from the everyday conditions that make the communication of concepts possible in the first place. We take Bakhtin’s theory of participative (unindifferent) understanding and combine it with Vygotsky’s approach to the development of thought and language. This leads us to a holistic approach in which bodily forms of knowing and learning constitute the irreducible condition for conceptions – an idea that Vygotsky, because of his exclusive concern for the word, has not articulated in his writing. We exemplify the ways in which a child’s body temporally engages with objects located in local spaces and makes links between different forms of experiences. The living body is central to learning geometry because of the capacity to realize everyday forms knowing the world in a specific setting and to translate them into spatiotemporally coordinated mathematical forms. Because of the unity of the corporeal “I can,” the different experiences that come from the hands, body, ears, or eyes are already integrated rather than demanding for a (constructivist, computer-like) mind to coordinate them. We suggest that conceptions involve the development of my familiarity with my lifeworld, that is, of my knowing my way of around the world. This development coincides with the development of communication (expression) in situ. In a nutshell, therefore, we can say that as the child’s talk unfolds (level 1), the child moves a little bit along its developmental trajectory (level 2), and a bit of mathematical cultural history is produced (level 3). It is precisely such a conception that allowed Bakhtin (1981) to explain the development of the novel (level 2) in the history of Greco-Roman culture (level 3) as people used language in conducting their everyday affairs (level 1).

Sense making is a core aspect of science and mathematics education and generally discussed in terms of language. This chapter informs us precisely about the source of the possibility of making sense: the living body. It is the living body that bridges and translates between interpretive resources and the experience of the
world and thereby contributes to the development of higher-order cognitive func-
tions. The child in our example participates in a cultural activity (i.e., geometry 
curriculum enacted in the elementary mathematics classroom) and simply works 
with objects (including words) given to her. The alignment of actions spread across 
her living body emerges as she encounters the words and other forms of objects 
rather than through the intentional act toward an outcome that would have to be 
known to her already. The living body draws on and mobilizes again the totality of 
resources that have a long cultural history. In the children’s actions, “the sensual 
illustration of the concepts” “is surreptitiously substituted” by means of the con-
crete figures and bodies that stand in school lessons for the idealities of geometry 
(Husserl, 1939, p. 217).

By extension of this chapter, we direct our attention to emotions that constitute 
an integral part of verbal thinking when the living body is thought as part of scien-
tific and mathematical conceptual development. Language-centric traditions of 
psychological thinking have treated emotions additional to thinking and therefore 
belonging to a separate domain of learning (e.g., motivation, attitudes). Our case 
analysis in this chapter implies the inseparability of emotions from thinking and 
speaking as a whole and therefore from sense making in the following two ways. 
First, the living body produces and reproduces emotional valence toward the object 
in/of communication. Clara volunteers to speak and to express herself to others 
teachers, classmates) in the classroom. Simultaneously this opening of herself to 
the world in and through her actions also gives her an opportunity to listen to oth-
ers. Clara’s series of action involving facing others and attending to the shape of 
the object in the next shows the continuous production and reproduction of her 
openness to others. Clara articulates her proposal to others in a public forum and 
attends to the teacher’s talk and gesture. Then, this communication leads Clara to 
experience the object in her hands, and thereby realizes the teacher’s talk as the 
request to attend to the shape of the object. Although Clara does not initially pro-
duce a hypothesis that a mathematician would consider sound, she neither gives up 
nor loses her orientation (openness) to the object. The living body continuously 
engages in knowing the object and makes possible the reproduction and transforma-
tion of the emotional valence (i.e., her attraction toward the object). Second, 
sense making emerges from and develops on the empathetic terrain of communica-
tion. This is clear from our analysis that the attention to the object is maintained 
and develops by communication with others. The living body reproduces and 
transforms the empathetic terrain of communication where Clara touches the object 
and articulates for others her sense experience. Emotions are an irremediable part 
of the terrain of learning and this terrain is generated and maintained by the living 
body. This explains why students come to develop a good sense of topics (i.e., lit-
eracy) when they have opportunities for dealing with scientific and mathematical 
objects within the very setting where they have opportunities for talking about 
these same objects.
LECTURES AS CORPOREAL PERFORMANCES

Lectures are often conceptualized in terms of information transfer. Science and mathematics professors tend to talk about using lectures to “get information across” and about how much their students do or do not “get” the main points of a lecture. Other scholars, though they come with very different presuppositions, do not abandon the transfer metaphor but focus on the “construct meaning of” what physics professors (lecturers) say and the notes they put on the chalkboard (overhead). In this situation, the conceptualization still occurs in terms of some stuff that goes from lecturer to audience, but whereas in the first case it is a simple transfer, the interpretation and making of participative (unindifferent) understanding are highlighted in the second approach. In either case, the view does not explain, for example, why students indicate to have a clear sense of understanding while they sit in a lecture whereas they subsequently experience failure to understand their own lecture notes or textbooks while preparing for an exam. Based on more than a decade of studies on the corporeal nature of science lectures (e.g., Pozzer-Ardenghi & Roth, 2010), the purpose of this chapter is to articulate and exemplify a different way of understanding physics lectures. We show that there is more to lectures than the teacher/professor talk plus notes. This informational “more” may explain (part of) the gap between students’ participative understanding that exists in the situation where they sit in the lecture, on the one hand, and the one where they study for an exam from their lecture notes, on the other hand. Our results suggest that in lectures, concepts are better thought of as heterogeneous performances in which sense arises from the synergistic and irreducible interrelations of different communicative modalities, including gestures, body movements, body positions, and prosody. Each of these modalities is but a one-sided (and therefore partial) manifestation of the communicative whole. These one-sided manifestations cannot be simply added up to yield the whole, because their characteristic particulars only appear in relation to all other one-sided manifestations. There is therefore a part–whole relation such that taking out or adding any single manifestation changes the communicative whole and therefore all other parts. For example, without intonation across a word sequence, we do not know what is meant by “This is a chair.” It might be a question, an assertion, or an affirmation. The nature of what is meant also changes according to the particular word or words emphasized. Thus, the sequence “THIS is a chair” is heard differently than the sequence “This IS a chair” or “This is a CHAIR.” Such changes generally are not recorded in the notes that the students take while attending a lecture, and yet play a crucial role in understanding what is communicated.
INTRODUCTION

Science lectures are about concepts and how to employ them in thinking about physical problems. Science lectures present concepts to students in real-time and therefore constitute a unique conceptual event that is irreducible to textual forms. That is, in science lectures, professors not only produce sounds that are heard as words but also perform other communicative actions: they gesture, draw diagrams, write equations on the chalkboard, or move around different parts of the classroom. In fact, the inner contradiction of the natural sciences is the disjunction between language, on which participative (unindifferent) understanding is based, and their non-linguistic representations that constitute the antithesis of sense (Heidegger, 1954). Sometimes lecturers show demonstrations, and thereby juxtapose yet another set of performances to the other parts of the ongoing lecture. All of these can be understood as resources for making sense. Yet, in the culture of high school and university schooling, there is a tendency among students and even professors to approach physics concepts only in terms of the verbal texts produced (e.g., textbooks, lectures, and lecture notes) – we do note that there are some science (physics) educators concerned with conceptual understanding, but in the bigger picture, most physics teachers and professors do not adhere and teach to conceptual understanding. Underlying this tendency is the assumption that the performative dimension of physics lectures can be reduced to the (disembodied) reproduction of texts and equations and therefore that embodied aspects of communication other than words (e.g., gestures, body orientation) are supplementary such that their sense can be articulated by means of words. In this quite common approach, complex bodily performances are reduced to language and linguistic signs. But that which can be written down is only one (necessary) part of the objectivity of science; the other necessary part is the actual work of producing and working with language and signs (Husserl, 1939; Garfinkel & Sacks, 1986). Whereas this (generally invisible) work is mobilized on the part of the lecturer, it is not likely produced by the students once they study from their lecture notes.

Viewing language as a carrier of participative (unindifferent) understanding and everything as a supplement runs counter to sociocultural theories of communication, according to which language and all other semiotic (sense making) resources such as gestures are subordinate to a higher order communicative unit, of which language and other resources are but one-sided, incomplete expressions. The adjective “one-sided” means that speech and the gestures that are co-produced cannot be reduced to one another: They are unique and partial dimensions of a higher communicative unit that seems to exist in the lecture as a whole. This position is consistent with recent linguistically oriented studies that show that visual representations – which in the social studies of science are denoted by the term “inscriptions” – come to constitute a communicative unit only in relation to the corporeal actions of the lecturer. Our research team conducted a considerable number of studies over the past decade attending to the deployment of scientific concepts in and through communicative performances (e.g., Pozzer-Ardenghi & Roth, 2010). These studies suggest that communication constitutes a core phenomenon of knowing and learn-
ing physics and that concepts, if there are such, can only be “transmitted” from one person to another by different communicative means all of which require bodily performances. Therefore, a study of different modes of communication in physics lectures has the potential not only for articulating the dynamic dimension of language and literacy but also for responding to pedagogical issues such as the role of lectures in students’ development of scientific concepts. For example, gestures that seem to provide contradictory information from a visual representation at hand are neither redundant nor independent. Rather, they constitute resources that push the development of the ongoing talk. While lecturing, in and through the bodily performances that somehow translate between what students know and the professor’s understanding of the field, a physics professor – in addition to teaching the concepts – also comes to develop knowledgeable ways of talking physics for students who do not yet know the physics concepts.

In this chapter we articulate and exemplify a different way of understanding physics lectures: from a body-centered perspective. We summarize in the upcoming two assertions (captured in the section subtitles) what we have learned over a decade of studying gestures and other bodily expressions in science lectures generally and in physics lectures specifically. In so doing, we also introduce science educators at the secondary and post-secondary level to the cultural-linguistic analysis of the performative dimension in physics lectures. We conceive physics concepts as *performances*, and thereby articulate a cultural-historical and body-centered approach to lectures. In using the notion of *performance*, we appropriate the linguistic approach claiming that teaching constitutes a communicative activity and therefore that capturing the concepts made available in physics lectures requires the consideration of all the resources mobilized simultaneously and in the course of time. We explicitly acknowledge the heterogeneity of communicative performances since it addresses the nature of the social world that students experience when they participate in lectures. That is, students do not perceive what might be in the head of the lecturer – what they concretely perceive is his vocal, gestural, and positioned bodily performance of concepts in the here and now of the classroom. As if they were sitting in a lecture held in the language that the lecture is to teach, students, in attending physics lectures, are confronted with the unknown. They do not yet know what they come to encounter in the next instant and what they will know only as a result of their participation. Therefore, the heterogeneity of communicative performances constitutes the structural possibility for conceptual development by which the audience can come to know some concepts. The lecture, even though it uses concept words to talk about concepts unknown to students also has to provide those resources that students already find intelligible. It is out of the double heterogeneity – across the unknown/known language and multiple modalities – that students are enabled to appropriate from a lecture that which is absolutely and unforeseeable to them.

In what follows, we provide our assertions together with the highlights that summarize the current state of the art. We draw on previous studies of lecturing particularly on the topics of gestures, the use of visual representations in scientific communication, and the role of the body in the constitution of communication
space. Simultaneously we engage in an extensive data analysis, which means we closely look at the claims reported in the previous studies and draw on them as the lenses for understanding case materials that we have in our data sources. We use examples from an undergraduate physics course in which the professor talks about the laws of thermodynamics and associated concepts (e.g., adiabatic demagnetization). We analyze the professor’s communicative actions and the communicative spaces (fields) that the body physically configures in the course of interacting with artifacts and other structures of the setting. We exemplify how different kinds of performances constitute sense-making resources for communicating concepts and that significance arises from the synergistic, irreducible unit of different communicative modalities, including speech, gesture, body position, body orientation, and prosody (e.g., pitch, speech volume, speech rate).

We build up our assertions on lectures by analyzing the (bodily) performances that are publicly made available in and through communication rather than depending on psychological categories or the bodily correspondences we cannot access (e.g., invisible and hypothesized structures of the mind). Therefore, our exemplary case analyses are relevant to studying the cultural (sense-making) structure of communication and the lived work of physics lectures. As part of implications for improving teaching and learning physics, we propose translation as a concept for theorizing teaching and learning physics in and through lectures. Our assertions may well explain the lived experience of participating in lectures to teach or learn physics concepts: that is, some answers for questions such as “Why do students have a sense that they understand while they sit in a lecture and find themselves failing to understand while they prepare for an exam with their class notes or textbooks?” or “Why do teachers (lecturers) in the classroom often ask their students to look at them talking rather than copying texts from the chalkboard into their notebooks?”

CONCEPTS – PERFORMANCES IN AND ACROSS FIELDS

Here we articulate and exemplify a different way of understanding physics lectures. In physics lectures, it is common to use inscriptions, that is, external visual representations that appear on paper, computer monitors, and chalkboards including equations, photographs, graphs, and diagrams. Inscriptions constitute important resources for articulating and communicating concepts. Inscriptions ought not to be taken as inherently communicating something but as requiring tremendous effort on the part of lecturers to make their sense salient for students. For example, previous studies show that lecturers spend a substantial amount time of their lecture talk near inscriptions and produce various communicative resources in association with inscriptions such as graphs, photographs, tables of numbers, or maps. Importantly, these studies show, for example, how lecturers change their body position and orientation in predictable ways when their narration changes: A physics professor moves back and forth between two chalkboards where the Aristotelian and Galilean positions on motion are articulated respectively (Roth & Tobin, 1996) or a biologist reorients when her talk changes from being about an inscription (map,
The coordination of gestures and speech is so important that in cases of non-alignment, even scientifically trained audiences have difficulties understanding the lecture. Even more interesting, perhaps, is the fact that when two or more science teachers work together for a significant amount of time – e.g., exceeding two or three months – then their gestures, body positions and orientations, and prosody displayed in lectures tend to become alike (Roth et al., 2005). These studies therefore suggest that the proper unit for analyzing concepts comprises not only language and inscriptions but also the movements of lecturers (e.g., gestures) with respect to the geography of the classroom and the relationships between different modes of communication.

The concern of physics lectures in this chapter is related to the development of participative (unindifferent) understanding. For example, speech unfolds in and through time, thereby also producing the temporality of the lecture. A physics professor in a lecture hall temporally develops the concept and, together with it, thought. Lecture time is generated as the pedagogical possibilities that sense-making resources make available are realized in and through concrete (lived) work. In the presence of inscriptions, the lecturer’s body moves not only in and for itself but also with respect to things in the settings (inscriptions and other structural resources); and it is in this relation to other things that the sense of any individual expression becomes salient and thereby marks a feature as remarkable. For example, the relative position of the body with respect to visually available representations parses and mediates the space that is associated with an orientation to the inscriptions, on the one hand, and the space in which narratives unfold about the world that the inscriptions denote, on the other hand. The spatial configurations that the body produces by moving about in the classroom are important sense making resources – even in the case that these are not consciously attended to as in the case of prosody – for students attempting to understand physics concepts. Consider the following examples of a university physics lecture in which a 30-plus-year veteran professor draws a graph on the chalkboard and talks about the third law of thermodynamics. This law can be formulated in this way: As a system approaches absolute zero temperature (0 K), its entropy tends to a minimum while remaining greater than 0 (i.e., $S > 0$). The episodes exemplify that physics lectures are corporeal performances, of which a central aspect is found in the different arrangements of communicative modalities that the body performs or deploys in and across physical spaces.

*Physics Concepts Take Place in Different Fields of Communication*

Physical arrangements in lectures constitute communicative resources: Speakers’ distances from and relative body orientations to inscriptions are integral to the sense of what is being communicated – spatial sense making resources help understand physics teaching in a theater-like context. This is so because both lecturers and inscriptions not only occupy physical spaces but also – because they break the spatial symmetry – mark out preferential spaces in the lecture hall associated with
the sense of what he communicates. The body moves about the hall in lectures, and thereby opens different local fields for the performance of concepts. In fact, the field itself is a contextual constituent of the sense of the concept. In the following episode, the professor is in the process of drawing a temperature–entropy graph of adiabatic demagnetization on which he builds a narrative concerning the third law of thermodynamics. The episode shows that the articulation of the concept in different communicative modes is related to the change of their physical arrangements. Communicative productions take place in different spaces and, therefore, the physics concepts consist of spatially unfolding corporeal performances.

Transcript 2.1

01 [and another one] [and another one]
   ([draws the fifth horizontal line]) ([draws the sixth vertical line]) (Figure 2.1a)
02 [we NOW WE GET VERY VERY CLOSE get]
   ([moves the chalk toward the origin])
03 [EXTREMELY close to zero]
   ([turns his body to the right and begins to walk])
04 [but I think this we see from there]
   ([turns his face to the students in walking to the right])
05 [you will never actually come to get to absolute zero]
   ([*shakes his right arm rhythmically beside his body and moves toward the students]) (Figure 2.1b)
06 in a finite number of operations ([2.0])
   ([*moves to the students and stops]) (Figure 2.1c)
07 and that’s going to um find an

In this situation, the professor stands oriented toward the chalkboard and draws a graph (Figure 2.1a). He draws a horizontal line (the fifth from the right) while uttering “and another one” (line 01). He continues by drawing a vertical line (the sixth from the top) and repeats “and another one” (line 01). The professor’s utterance increases in pitch (base speech frequency), becomes louder (higher in intensity), and becomes faster (higher speech rate). He suggests that the stepwise line approaches the origin of the graph and comes “very, very close to” it (line 02). The
professor turns to the right and begins to walk. He continues to talk with high speech intensity, suggesting that they get “extremely close to zero” (line 03). The professor walks and turns his face to the students. He makes available to his audience some hesitation (“but I think” [line 04]) and then continues, “we see from there you will never actually get to absolute zero” (lines 04–05) “in a finite number of operations” (line 06, Figure 2.1b). In uttering, he rhythmically moves his right arm (these movements technically are called “beats”) in synchrony with the ups and downs in the pitch of his voice; and he turns his step toward the students (line 06). He finishes speaking and moves closer to the students (line 05). The professor stops moving and stands still at one end of the chalkboard (line 06, Figure 2.1c). After a two-second pause (line 06), he continues by uttering: “and that’s going to um find” (line 07).

In this episode, we see that the professor’s communicative performance take place in terms of different positions and placements in the classroom. Initially, he stands close to the board at the center of the front classroom. He draws straight lines between the two curves on the graph and thereby performs a process of lowering the temperature by means of “adiabatic demagnetization.” Here, the movement of the chalk and hand constitute a gesture that metaphorically denotes the physical process. The professor engages with the inscription, and thereby enters what other researchers of gestures in physics have called the “domain space” (Ochs, Gonzales, & Jacoby, 1996). The professor leaves this local space as he finishes drawing. His body turns away from the board and he begins to move to the right, in which he ultimately turns toward the students. Here the professor begins to produce talk of a different genre (line 07). Following previous studies, the former domain space and the new domain space that emerges from the professor’s orientation toward the students can be conceptualized respectively as an inscription space and a narrative space. Very different gestures and narratives are produced when lecturers (professors, teachers, presenters) face the audience (e.g., “you will never actually come to get to absolute zero” and the gestures of shaking his arms besides his body [line 05]) than when they are oriented to the chalkboard (e.g., “we get very, very close” and the movement of the hand and piece of chalk toward the origin of the graph [line 02]).

The differentiation of the narrative space from the inscription space is significant, for the inscription and the physics concepts that it refers to are extended to another local field in the lecture hall but in a different form. Because the two fields are associated with the relative position of the body with respect to the inscription (the visually available graph), on the one hand, and to the audience, on the other hand, the movement of the body constitutes a central aspect of the differentiation and the transition. For example, after finishing the stepwise drawing of lines on the board, the professor turns his body away from the board. More so, there is a rapid increase of the pitch and speech intensity in his utterance around at the instant of turning the body (line 02): Whereas he has been speaking with a pitch in the range from 120–130 Hz, his pitch now moves up to between 282 and 364 Hz; and his speech intensity moves from a mean of 54 dB to a mean of 63 dB, which corresponds to an increase of speech volume by a factor of 8 (each 3 dB interval consti-
tutes a doubling). That is, at this point the speech intensity is eight times of that what it normally is; as the perceptual correlate of intensity is loudness, what the audience members actually hear is indeed a significant increase. (We report intensity, which can be easily mathematized, measured, and quantified, whereas loudness is a perceptual quality that depends on subjective judgments.)

With these substantial increases in pitch level and speech intensity, the professor makes especially salient the point that adiabatic demagnetization never fully reaches absolute zero temperature – the prosodic properties constitute a component that clarifies the concept of the third law of thermodynamics. Whereas one might have been able to see the chalk and hand get to zero, the sudden change in the voice parameters signal attention to what is currently being said, that is, the possibility to get very close to without actually reaching absolute zero temperature (0 K). Here, prosody constitutes a change in sound that the body, through the vocal cords, makes available for marking out the salience and sense. But the body produces these changes without conscious attention so that the difference between the thought expressed in them and the thought itself becomes undecidable, an issue that already Immanuel Kant noted toward the end of his life but could never develop in his articulation of the nature of thought (Nancy, 2008). All of these material resources, together with his walking to the right and the gesture of shaking his right arm, can be seen to constitute a unit that allows getting out of one domain space and into another, which thereby articulates the physics concept, the third law of thermodynamics.

Physics Concepts are Marked by the Heterogeneous Organization of Different Communicative Fields

Inscription space and narrative space are two salient domain spaces (or fields) found in physics lectures. The lecturer’s body not only opens up these different spaces but also materially interconnects them, and thereby structures different communicative performances in and across spaces. This is exemplified in the following episode (immediately following the previous episode) where the professor performs an aspect of a concept – the stepwise decrease of entropy – in the form of an analogy. He moves back and forth between the two local fields. From this back and forth movement arises an analogy between forms of performance. That is, the analogy arises from two similar but different performances that are held together by the movement from one to the other space. Because these performances are for the benefit of the audience, the conceptual structures are brought to the surface rather than leaving them – as in other teaching approaches that use analogies – in the depth where they are often inaccessible to the learner.

Transcript 2.2

08 other way to [adiabatic magnetization]

09 [it’s going to (0.9)]
The professor continues to talk and thereby engages in the (embodied) performance of concepts in the narrative space. As he utters “adiabatic magnetization” (line 08), the professor’s body turns toward the graph (line 08, Figure 2.2a). He takes a few steps toward the board and stops (line 08). He quickly turns toward the students and approaches them with his arms stretched (Figure 2.2b, line 09). He faces the students and utters “it’s going to be” (line 09). The utterance stops, and a pause unfolds (line 09). The professor takes a big breath, which is followed by another pause (line 10). He produces words in a mumbling manner (line 10). The professor bends his fingers with the two arms still stretched (line 10). He moves his right arm to his left (line 11). He thereby generates a gesture of “isothermal compression” that he also names (line 11). The right hand stops at the left point (Figure 2.2c) in which he utters “followed by” (line 11). The professor moves the
right arm back to the right side of his body saying “adiabatic” (line 12, Figure 2.2d). He utters “decompression” and moves his right arm back to the center (line 13).

In this situation, we see and hear how the communicative resources that are produced while squarely facing the audience in the narrative space (lines 11–13), constitute an analogous structure to those that were produced in the inscription space. The gestures of pushing and pulling together with the utterances of “isothermal compression” and “decompression” (Figures 2.2c, d) can (and have to) be seen as iterations of the stepwise shape of the graph on the board (Figure 2.1a) both physically and metaphorically. The performances in the two local spaces constitute one structural unit for articulating the concepts of “isothermal magnetization” and “adiabatic demagnetization.” This is consistent with other observations in physics lectures, which suggests the inference that it is common to present concepts by translating inscriptions to analogous but distinct representations. This episode exemplifies how the body takes a central role in producing those analogous structures by mediating the undecidable relation between communication and engaging in the world.

The preceding paragraphs underscore how physics concepts are constituted in and by means of the heterogeneous organization of different communication fields. On the one hand, the body makes transitional movements and therefore differentiates spaces. At the same time the body produces communicative resources that coordinate those differentiated spaces. For example, in the previous episode the professor stops moving and stands close to the students (line 06). He finishes his transition and, being there, opens up a narrative space (line 07). However, when he begins the narration, he can no longer engage directly with the inscriptions (e.g., visible lines and curves in the graph) that were once available to him. Thus, in the course of saying “adiabatic magnetization,” the body turns to the graph, takes a few steps, and comes back quickly (lines 08–09, Figures 2.2a, b). This series of body movement physically connects the narrative space to the graph on the board, and thereby constitutes a growth point (McNeill, 2005), that is, the undeveloped and therefore general seed of an idea from which the compression–decompression narrative emerges and develops. The professor orients toward the graph, of which the performance takes place between the inscription space and the narrative space, and therefore mobilizes the graph as an agential component that affects the performance in the narrative space. Conceptual explanation about the dynamic process of lowering the temperature is constituted by the performances distributed over the spatial structure of the classroom.

TEACHING AND LEARNING CONCEPTS IN PHYSICS LECTURES

Lectures are pervasive in high school and university science and mathematics courses. In this chapter we exemplify the embodied performances of concepts in physics lectures and propose a novel approach to understanding lectures as they are heterogeneously realized in the university lecture hall. Many studies on teaching physics (e.g., models of instruction) count on textual (written or verbal) informa-
tion to analyze what has been taught, and thereby re-present the realities of teaching into disembodied forms. For example, the real classroom events are often attributed to specific teaching/learning models or some descriptions of teachers’ intentions and beliefs (i.e., what has been intended or planned to teach). Throughout this chapter, we take an approach that considers the physics professor’s labor in the lecture as a singular plural whole. We do not reduce the heterogeneous whole to the part – this is at the heart of a cultural-historical, Vygotskian approach to human knowing and learning. In *Thought and Language* (Vygotsky, 1934/1986) the problem of the reductionist approach to psychology has been highlighted. Our analysis of lectures in this chapter indicates that the communicative value involved in the professor’s practical engagement in the world (e.g., inscriptions) exhibits the power of the communication of concepts in physics lectures. The difference in physics lectures from reading a physics book lies in the communicative capacities involved in the professor’s lecturing act, that is, in his performative work that his audience comes to witness if not directly but at least in terms of its effects. Therefore, communication constitutes a good paradigm for theorizing science lectures. This allows us to distinguish between students’ experiences of participating in the lesson, on the one hand, from their reading the lecture notes, on the other hand.

Multimodality, in the sense that we use the term here, does not mean many modalities that add up to the complete message. Nor does it mean that the same message is produced across multiple modalities. Multimodality, as we use it here, means heterogeneity because different modalities of communication cannot be reduced to each other – for example, the essence of the continuity of a pictorial graph is not rendered by the words “continuity of a graph” or, for these matters, by any other combination of words. We may have the same words – e.g., “isothermal compression” – but very different informational content when the professor emphasizes one rather than another part of the adjective. Thus, saying “ISOthermal compression” draws attention to the “iso,” the staying constant, whereas “iso-THERMal compression” draws attention to temperature in a possible contrast to another variable (“isentropic”). Some studies do in fact attend to the multimodal nature of communication in the science classroom (e.g., Kress et al., 2001) – and this may address the social realities of knowing and learning concepts in lectures (particularly the role of students). In these studies, the multiplicity of communication is used to support a new pedagogy to literacy – but the aspects of heterogeneity involved in the notion of multimodality and its implications for teaching and learning concepts have yet to be articulated. Each modality can be understood as part of a whole, the concept (Figure 2.3). Each contributes to the constitution of other modalities, its identity, and, in turn, is constituted by others as well as by itself. The part (e.g., temperature-entropy curve) contributes to constituting the whole and therefore denotes this whole only metonymically, because, as part, its communicative quality depends on the relations within the whole. But, characteristic for metonymy, one part does not capture the essence of other constitutive parts. If we pull only one part or add one new part, then the whole changes and no longer is the same so that, because of the whole–part relation, all the other parts change together with their mutual relations. We could also say that we are dealing with a
singular plural phenomenon, where the singular whole really is a plurality of moments, but the nature of each moment depends on the plurality. As a result, in each conceptual unit, the singular is plural and the plural is singular.

Lecture performances exist in time and space. They realize physics concepts by temporally deploying different modalities of communication in and across different domain fields (i.e., inscription, narrative). From a holistic perspective, a central issue related to the two modes is that they are closely intertwined in the course of conceptual development: a movement from concrete to abstract (e.g., mathematical analysis) requires a movement from abstract to concrete (e.g., knowing details of materials at hand). For example, coming to a better understanding of the thermodynamic cycle (i.e., the graph on the chalkboard) goes together with coming to a better understanding of the motion of a bouncing ball (i.e., details of analogy introduced by the professor’s narrative) – see chapter 6. Psycholinguistic studies show that heterogeneous communicative productions (e.g., gestures and speech) constitute a dynamic process in which thinking develops all the while being connected to the context of communication – “the intra- and interpersonal planes are inseparable in all acts of speaking” (e.g., Levy, Duncan, & Cassell, 2008, p. 6). The bodily performance that produces the mundane features of a lecture grounds the communication between presenter and audience. The observed heterogeneity (multimodality) of communication in a lecture is characteristic of human interactions generally. In what follows we highlight and discuss the significance of the results in the previous analyses. We articulate scholarly insights into the knowledgeability and improvement of teaching and learning concepts in lectures. We suggest that the heterogeneity of bodily performances is not a redundancy but constitutes the very terrain of communication that makes the development of concepts possible – i.e., teaching and learning as hybridization.
Teaching in Lectures as Hybridization

The presence of artifacts and their multiply layered relations to the human body constitute a distinctive aspect of scientific communication in lectures. Inscriptions (e.g., graphs) constitute prevalent resources that mediate talking concepts in physics lectures. From a perspective of the lecturing physics professor, his talk and physics inscriptions that he presents may all make clear sense and refer to a set of clear ideas (i.e., physics concepts). Yet, from a students’ perspective, the use of inscriptions raises a (pedagogical) problem: Students depend on a professor’s talk to know inscriptions presented at hand, but the professor’s talk with/about those inscriptions is known to students only when they already know the inscriptions. In fact, we can hear – and therefore speak – only because we always already understand (Heidegger, 1927/1977), and, because understanding is associated with language, inscriptions presuppose but are irreducible to language. Coming to understand physics inscriptions and associated physics talk mutually presuppose one another.

Our analysis of the lecture performances shows that the body has a significant role in this pedagogical practice. Thus, the professor’s iconic gestures of pushing and pulling in the second episode and associated utterances “compression” and “decompression” are constitutive for the sense of the associated physics concepts (adiabatic demagnetization and the third law of thermodynamics) by their analogous relation to the graph – they constitute a form of translation of non-identical expressions into one another. As translations go, they inherently capture only some but not other aspects of the original expression even in the special case where both expressions are within the same modality or language (Derrida, 1996). The lecturer’s body orientation and eye gaze toward the graph realize this structural (cultural) relation and drive the analogy or metaphoric thinking. These heterogeneous body movements between spaces (i.e., between the graph and the narrative/gesture) not only open one additional space by differentiating the latter (narrative space) from the former (inscription space) but also explicate the conceptual presuppositions that make this translation possible. Therefore, we conclude that the professor’s competence lies in the knowledgeable bodywork that translates between different communicative content. Teaching physics concepts means translating and hybridizing the ongoing lecture talk. The capacity to increase the heterogeneity of communicative resources (i.e., hybridization) constitutes the central aspect of knowing concepts. Physics instructors successfully assist their students to understand physics concepts by producing different communicative performances.

The role of the body in teaching physics concepts is related to the dialogic (social) nature of communicative practice. In lectures, the mobilization of cultural artifacts (e.g., pointing to a graph) presupposes the understanding of the other (i.e., audience). A physics professor may do this performance rather than something else because he is located in a specific condition of talking physics. For example, the mobilization of the compression-decompression analogy for adiabatic demagnetization makes sense on the assumption that students are familiar with the physical relation between volume-pressure-temperature while a gas undergoes an isother-
mal compression and an adiabatic decompression. The physical presence of students in the lecture hall provides a set of possibilities, some of which are concretely realized in the lecture performances. Listening to lectures is different from reading books alone because the lectures produce in heterogeneous communication a hybridized form of knowing that is not equivalent to any other. In this sense, the metaphor of the “construction of meaning,” which is often used to theorize classroom communication, pertains only to the conscious parts of knowledge and not to all forms of knowing that make explicit forms of knowing possible in the first place.

Learning in and through Lectures: a Chain of Translation

The tenor of our chapter is that concepts are not ephemeral entities, metaphysically existing somewhere in the rarified spaces of another world, but constitute real, corporeal performances and living labor. This labor is observable in the performative productions of lectures. Physics concepts (heterogeneously) performed in lectures have the potential to be transferred and therefore translated into different sense-making units under the condition that the students perform similar work. Translation involves performances of mapping one domain onto another. Transformation means that dissimilar entities are made to correspond to one another, such as a line graph, on the one hand, and a mathematical equation, on the other (Janvier, 1987). Translation also occurs even within one and the same communicative mode, such as when the word “dog” is mapped onto the words “Hund” (German) or “chien” (French). Translation occurs even within one and the same language (Ricœur, 2004). Such translation is commonly observed when a listener requests a speaker what he means leading to the speaker to use different words “to say the same.” That is, translation requires an assumption that two different expressions are the same although they are very different on the surface. To what extent this assumption is fulfilled is an issue that interaction participants tend to solve in a pragmatic manner and as a matter of course. The process of learning physics concepts in and through lectures therefore can be seen as a chain of translations that involve the migration of lecture performances from the initial forms in which they are produced (e.g., university lectures) into those which students/professors produce (e.g., lecture notes) and also into other (sub-) cultural settings (e.g., individual study at home, and problem-solving with peers). Our examples show that some performances of physics concepts not only comprise verbalizations but also gestures, body orientations, and gazes.

Students, however, only record in their notebooks what is written on the chalkboard and some of what the lecturer says (Figures 2.4a, b). Students’ notes generally lack all the other communicative resources that a lecturer makes available in modes other than talk, including gestures, body orientation, body position, and prosody. There exists a tension between the physics concept as it presents itself, performed by the professor, on the one hand, and the reduced way in which the lecture is recorded in the students’ notebooks, on the other hand, where all the resources that the professor’s body has made available in the talk no longer exist. We
(the authors) are not astonished to find that students often do not make sense of their lecture notes, which capture only some aspects of lecture performances.

Lecture notes – and, for the same reason textbooks – do not replace lectures (Figures 2.5a, b). This, too, may explain why experienced professors often ask their students to look at them talking in lectures instead of being occupied with making notes or reading textbooks. Gazing at and listening to the professor places students in a strange position: They are familiar with the world and yet contribute to producing growth points in the lecture performance. Therefore, we suggest that students take different communicative performances as their resources for understanding concepts and also attempt to increase the possibility to mobilize them for their individual studies. Moreover, teachers and educators need to recognize that transferring some communicative productions to another setting brings about the reduction of the whole unit of information that was available in the previous setting and at the same time the amplification in the course of enacting those productions as part of another communication unit. Learning physics concepts means to become able to navigate the world in communication rather than “constructing” something independent of the concrete condition (e.g., abstract disembodied metaphysical concepts).
CHAPTER 2

16.2 The Third law of Thermodynamics

Nernst’s heat theorem and Planck’s extension of it, while originally derived from observing the behaviour of chemical reactions in solids and liquids, is now believed to apply quite generally to any processes, and, in view of that, it is time to reconsider our description of adiabatic demagnetization. We see immediately that figure XV.1 needs to be redrawn to reflect the fact that the entropy of the substance approaches zero whether or not it is situated in a magnetic field. The revised drawing is shown in figure XVI.1, in which I have drawn three consecutive magnetization-demagnetization operations, and it will be readily seen that we shall never reach a temperature of exactly zero in a finite number of operations.

The same applies to any operation in which we attempt to lower the temperature by a series of isothermal constraints that decrease the entropy followed by adiabatic relaxations — whether we are compressing a gas isothermally and then decompressing it adiabatically, or stretching a rubber band isothermally and loosening it adiabatically. In all cases, owing to the convergence of the two entropy curves at zero temperature, we are led to conclude:

*It is impossible to reduce the temperature of a material body to the absolute zero of temperature in a finite number of operations.*

This is the Third Law of Thermodynamics, and is an inevitable consequence of Planck’s extension of Nernst’s heat theorem.

![Graph](image)

**FIGURE XVI.1**

**Figure 2.5.** Lecture notes that the professor handed out to students provide textual information of the Third law of thermodynamics driven from Nernst’s heat theorem (a) and a graph that refers to magnetization-demagnetization operations (b). These lecture notes do not replace the lecture because they do not comprise all the performances that are made available in the real talk (e.g., the compression-decompression analogy).
In this chapter we articulate and exemplify a different way of understanding physics lectures. We specifically show how physics lectures constitute embodied performances, that is, work producing concepts. This work exists in and as of the lecturer’s bodily engagement with things and in itself. We propose that the different communicative productions in and across different physical spaces of the lecture hall constitute the sense of physics concepts because the body renders them structured in the movement. Yet, the structure of those communicative performances does not pre-determine lectures because the movement of the body takes place in real-time within a situation as a whole. Thus, in our examples, the professor does not mechanically reproduce a planned talk but actually articulates concepts in real time for, and in the presence of, the audience. Inscriptions, such as graphs, constitute resources toward which the body orients itself; therefore they become an agent that participates in the ongoing articulation of physics concepts – some science studies theorize the role of materials and inscriptions in scientific work from the perspective of agency – the powers that reside in the sense of the phenomenological “I can” – and performativity. Inscriptions, textbooks, and words are constitutive parts of higher order communicative units rather than re-presenting concepts in themselves. Therefore, in science lectures, concepts are heterogeneous because they are distributed over the physical arrangements of different communicative performances that the body produces in relation to and with other things in the setting. The dynamic transactions between different modes of communication allow those resources to constitute a participative (unindifferent) understanding unit.

Given that there are many good physics books on the market and an increasing number of Internet resources, it is a legitimate question why universities offer lectures as part of their curriculum. What is it that lectures offer over and above verbal content and visual representations? Whereas quite a number of science education studies propose alternative forms of teaching other than lectures and report their effectiveness, it is rare to find communicatively oriented studies that explicate what makes lectures successful or unsuccessful. In this chapter, we provide an account of the value-addition when students attend lectures as compared to reading a textbook or an online resource, and thereby informs physics educators of the probable directions toward which research on physics lectures could be configured and evaluated – for example, the spatial arrangement and coordination of communicative fields have the power to explain the sense-making capacity of the resources provided in lecture talk other than the main, conceptual storyline. Our perspective also provides an explanation for the gap between understanding that occurs in a physics lecture and that which occurs during preparing or taking an examination. In the performances of physics professors, there is much more than words and images that assist students to make sense of physics concepts. Because of the many resources made available, lectures offer opportunities to participative (unindifferent) thinking (Bakhtin, 1993) on the part of the students. In this chapter we provide a first proposal for the “more” that lecturers make available over other forms of presentations such as textbooks or lecture notes. In fact, in a strong sense, any con-
cept only exists in and as of its performance (Husserl, 1939); that is, concepts do not exist independently of the work that concretely realizes them in communicative acts. Just like a language that nobody speaks, mathematical and scientific inscriptions constitute only virtual possibilities of cultural knowledge, which always requires a performance to be kept alive. Books only provide resources but not the subjective work that actually constitutes the objectivity of the sciences. It is only because they are concrete-in-use that audiences can perceive concepts. By opening up, the different senses (eyes, ears) of listeners are affected; and this opening up to being affected through the senses is a basic requirement for the constitution of sense. The development of educational technology adopted in science (physics) lectures and talks increases the heterogeneity of communicative productions and therefore highlights the significance of cultural approach to communication adopted in this chapter. We now need to research ways in which students – and lecturers – can be assisted to be more aware of these additional sense making resources so that they can really capitalize on the value-addition that the lectures they attend offer to them.