This is an earlier version of the paper. The final one was published as:
Jornet, A., & Roth, W.-M. (2015). The joint work of connecting multiple (re)presentations in science classrooms. *Science Education, 99*, 378–403.

The Joint Work of Connecting Multiple Presentational Forms in Science Classrooms

Abstract

The aim of this study is to advance current understanding about the transactional processes that characterize students' sense-making practices when they are confronted with multiple presentations of what instruction considers instantiations of a common scientific phenomenon. Data for the study derives from a design experiment that involves a technology-rich, inquiry-based sequence of activities. We draw on *Interaction Analysis* to examine the work by means of which a group of upper secondary school students make sense of a number of different ways in which a physical phenomenon—a phase transition—is presented to them. Our analytical perspective, grounded in a cultural-historical framework, involves scrutinizing how the different materials emerge and evolve as signifiers for something other than themselves during student-student transactions. This approach allows us to trace the emergence of students' interpretations of the relations between phenomena and their diverse presentations without committing to any preconceived notion of what these presentations stand for. We describe how students' bodily and pragmatic actions become reified in conceptual terms, and how these index to lived-in experiences rather than to formal underlying concepts. Findings are discussed with regard to the central role of body and praxis in research on learning science with multiple presentational forms.

Keywords Multiple representations, Sign, Cultural-historical theory, Interaction Analysis, Body

Introduction

The competence of relating and coordinating multiple forms of presentation with each other and with the phenomena they stand for is a central aspect of science learning and practice, and an important concern in research in science education (Klein & Kirkpatrick, 2010). Traditional approaches situate the work necessary to establish such relations—the relations between the original phenomenon and the ways it is made present again – in psychological, private processes of information processing that mediate between *external* and *internal representations* (Mayer, 2003; Schnotz & Bannert, 2003). Whereas research informed by these frameworks has provided taxonomies and guidelines for the design of multi-media instructional materials (e.g. Mayer & Moreno 2002; van der Meij & de Jong 2011), a difficulty in the literature is that the analytical and theoretical attention is often withdrawn from the situated, material and public operations by means of which students relate phenomena with the signs and symbols that come to stand in for them. For example, students may do an investigation to find the relation between temperature and volume of a gas, are confronted with a diagram depicting the phenomenon, or use or interpret a p-V graph for constant temperature (Han & Roth, 2006). Students encounter the same phenomenon in different presentational formats. How do they come to relate these to constitute a holistic understanding of science? In this regard, emerging *situative* approaches argue that a focus on internal, individual processes of comprehension does not adequately address how the formal, intellectual aspects of *re*presentational practices emerge from competences that cannot be grounded in those very formal aspects, given that learners are not yet fully literate in the notational systems to which they are introduced during science instruction (Kaput, 1998; Klein, 2006; Roth, 2004).

To address these limitations, research has turned attention towards the analysis of *referential practices,* "the ways in which reference can be seen to be thoroughly embedded in, and inexorably intertwined with, the interactional activities in which they emerge and are constituted" (Hindmarsh & Heath 2000, p. 1856). From this perspective, the work involved in relating and coordinating multiple forms of presentation of a scientific phenomenon does not

only have a private and individual component, but also takes place *in* and *as* a irreducibly joint, public achievement. Research within this view has started to investigate how scientific literacies such as interpreting graphs, digital simulations and other forms of presentation, emerge from bodily, practical actions that do not presuppose a substantive referential function, but which acquire their intellectual character in the course of joint activities (Roth, 2004; Roth & Lawless, 2002).

The aim of this paper is to advance current understanding about the transactional nature of students' sense-making practices when they are confronted with multiple ways in which scientific phenomena are presented to them in educational settings. We first review mainstream research on learning with "multiple representations," and contrast it with studies that focus on the transactional work that takes for the learners to make sense of instructional materials. We then describe a semiotic analytical lens for the study of learning in instructional contexts with multiple presentational forms that draws on cultural-historical theory (Vygotsky, 1978, 2005) and builds upon previous research on scientific graphs' reading and the layering of presentations in science students' experience (Han & Roth, 2006; Roth & Bowen, 2001). We use this approach to examine the sense-making practices in which a group of upper secondary school students engage during a sequence of inquiry-based activities in which a scientific phenomenon—a phase transition—is presented first as part of a hands-on activity in which a spray can of compressed air is manipulated, and later as part of a set of linked digital models of the phenomenon. Throughout our analysis, body and material praxis emerge as fundamental dimensions (moments) in and of students' sense-making practices. The findings are discussed with regard to literature on science learning in multiple presentational settings.

Background

Research on Learning with Multiple "Representations"

Research generally reports that environments where the "same" or related scientific phenomena are presented by multiple means—such as physical experiments, graphs, and digital simulations—support students' development of scientific understanding (Adadan, 2013; Tsui &

Treagust, 2003; van der Meij & de Jong, 2006). However, these studies also show that learning in these environments is not straightforward. Research often finds that students tend to focus on surface features of the experimental materials and visuals rather than on the conceptual aspects related to them (Krange & Ludvigsen, 2008), fail to draw relations between otherwise linked presentational forms (Chittleborough & Treagust, 2008; Kozma, 2003), and do not necessarily make sense of the presented phenomena in the same terms that experts (designers, scientists, educators) do (Kozma, 2003; Roth et al., 1997).

A widely held—though often tacit—assumption in the literature is that the different instructional materials presented "encode" or "represent" information that the students are to grasp to learn. Accordingly, learning in this kind of settings involves grasping the syntax and semantics of the presentations. Thus, for students to learn, they first "must understand how a representation encodes and presents information" (Ainsworth 2008, p. 200). Even when learners understand this, "they still need to understand how this representation relates to the specific topic it is representing" (p. 201). In addition, learners need to be able to *relate* and *translate* across multiple presentations (van der Meij & de Jong, 2006). Learning in this kind of environments is then often described as consisting of a process of "mental integration." Thus, "only when learners identify these references within and between the external representations they can construct a coherent mental representation and come to a deeper understanding of the subject matter" (Seufert & Brunken, 2007, p. 321). Accordingly, much research within the field has been concerned with investigating the (cognitive) effects that different instructional interventions have in supporting the students' academic performance in multiple presentational forms learning environments (e.g. Bartholomé & Bromme, 2009; Seufert, 2003; van der Meij & de Jong, 2006). However, findings often suggest that the complex nature of these learning environments does not lend itself to factorial descriptions, and that it is difficult to specify key features for an effective design (Waldrip et al., 2010). In this regard, a review of research in the field points that "little is currently known about how learners achieve . . . integration . . . and attempts to help learners do

so by providing instructional support or software tools are far from proving invariably successful" (Ainsworth, 2008, p. 204).

At least two critiques to the view sketched above have been raised in the recent literature. First, approaches that view learning as a matter of "decoding" information from instructional materials tend to focus on correlations between pre-specified design features and measured learning outcomes, thus treating as epiphenomenal the social, bodily and material actions that take place during episodes of learning with multiple presentations (Furberg, Kluge & Ludvigsen, 2013). Second, the features of the different instructional materials and their relations of reference—what these stand for—are often considered with regard to normative models of expert knowledge. However, these may not be seen as such by those not yet enculturated in the literacy practices within which those relations are of currency: the students. This problem has been extensively critiqued by approaches that argue for the need of taking more learner-oriented approaches in the study of science and mathematics education (Lave, 1988; Lobato, 2012; Roth, 2012a).

From Multiple Representations to Multiple Presentations

The object of study of this paper is not whether and under what conditions students come to perceive the instructional materials in the form that instruction expects them to be perceived, but rather the actual, public processes by which students come to perceive any aspect of the material continuum as related to something else. Thus, although the literature generally refers to multiple "*external representations,*" throughout this paper we use instead the term *presentations* to emphasize the first-time-through nature of the phenomenon under study: Something first comes to be present, as form, before it comes to be present again, as representation. The term representation (re-presentation) suggests that what is presented exists twice. However, this is true only for those who already know what such presentations stand for. In the case of students' lived world, what is being re-presented is most likely unknown because it usually constitutes the very object they are yet to learn. We therefore take the processes by means of which students make

sense of and relate different presentations, and the resulting relations of reference to be empirical matters.

Studies concerned with the question of how relations of reference emerge in and through social relations have increased in the last years (Waldrip et al., 2010). Here, the particular materials in a situation are often described as *semiotic resources* to highlight that there is no "information" substantively ascribed to them, but that these acquire their sense in and through being recruited in the course of social praxis. Presentations are shown to become *deictic resources* (they can be pointed to by means of the hand or "indexical" terms such as "this") by means of which attention to particular features of the local environment is coordinated, making those features salient with regard to practical demands of an ongoing activity (Furberg, Kluge, & Ludvigsen, 2013; Nivala et al., 2012). Importantly, these practical activities do not presuppose an intellectual understanding of the curricular contents to which experts may associate the different presentations, but first *emerge* as *bodily* understandings (Roth & Bowen, 2001). Signs stand in metonymic relation to the situations in which these are produced, that is, the signs are parts of the situation that come to stand for the situation as a whole (as "the ham sandwich" can come to stand for a person eating a ham sandwich). Thus, even expert scientists need to "undo decontextualization" to understand their own graphs, and they do so by interpreting these in terms of their familiarity with precisely the local contexts from which, and the methods by means of which, the graphs were first derived (Roth, 2013).

The present study aims to contribute to this growing body of literature by (a) articulating an analytical framework for the study of the bodily and social aspects of learning in multiple presentational settings and (b) providing empirical ground to the framework by means of a case study of a technology-enhanced learning environment. In the following, we describe a cultural-historical, semiotic framework that will serve us to lay out an analytical approach for analyzing the emergence of sign (presentation) relations in educational settings with multiple instructional materials that are aimed at presenting "the same" scientific phenomenon.

Theoretical/Analytical Framework

In the remainder of this paper, we present a case study where a group of students discuss and connect multiple presentational forms and investigate the coordination work that it takes to establish such connections. Here we lay out the principles of a cultural-historical approach to the emergence of signs, and describe an analytical framework that in accordance with such principles.

The Sign—a Social and Material Relation

The relations that link one segment of the material continuum (e.g., a sound, a written word or line, a picture) to another segment of the material continuum are referred to as signs (Eco, 1984). In this article, we take a cultural-historical perspective on the sign (Vygotskij, 2005). Accordingly, the primary function of signs is to act on other persons; they are primarily a means of social contact. From this function is derived yet another function: signs as a means available to persons for acting on themselves. Signs, exemplified in Vygotskij's (2005) discussion of the changes in the signification of a word (*značenie slova* or *slovesnoe značenie*), are not stable but undergo cultural-historical, individual ontogenetic, and situational changes. Any sign is inherently a cultural phenomenon and constitutes a *social* means for acting upon others (Wittgenstein, 1953/1997). When signs become incorporated into practical action, the action itself is transformed just as it would be when a (new) tool is introduced. Although Vygotsky (1978) makes a categorical distinction between signs and tools, more recent work has shown that in learning processes, tools and material artifacts have signifying functions because they stand in for themselves (Roth & Lawless, 2002). This is an important aspect when signs emerge from transactional work with others, such as when intentional pointing gestures (i.e., deictic signs) emerge in and as relation between an infant and its parents (Vygotskij, 2005).

A number of implications with regard to learning environments with multiple presentational forms follow. First, the significations that curriculum designers intend to emerge for students should not be taken for granted but, rather, must be seen as *potential* inscribed in the experimental settings; whether students actually *realize* this potential is an empirical matter.

Second, presentational forms are understood as *occasions* for realizing (often unknown) potential learning trajectories and outcomes. Following Vygotskij (2005) and Wittgenstein (1953/1997), the analytical focus, therefore, is on the observable social transactions rather than on inaccessible mental models of individual social actors. Analyses include how teacher interventions and the larger social context shape, and are shaped by, the sense-making processes. In sum, a cultural-historical, pragmatic framework suggests that the relation between signs and signification is not straightforward but involves transactional *coordination work,* which produces the social relation between actors and, simultaneously, the sign relation between multiple forms of presentation.

Structural and Relational Work

In our approach we draw, as others do (Kaput, 1988; Latour, 1993; Roth, Pozzer-Ardenghi, & Han, 2005), a clear distinction between the material continuum from which objects, artifacts, phenomena, inscriptions, or sound (voice) are made and the structural aspects that characterize their use. The relations between any two presentations are based on structural and not on purely material or ideal properties. For example, the letters "E" and "M" consist of the same material but are structurally distinct and associated with different phonetic articulations; although a photograph of a flower and a graph of its growth rate may appear on the same book page or computer monitor, consisting of the same material basis, the significance of their relation is based on structural properties (Figure 1). There is therefore no "natural relation" between two presentations: there is an *ontological* gap between any two of them (Latour, 1993).

Previous research has shown that it is possible to describe the process of interpreting graphs and texts in terms of two activities, *structuring* – the activities that differentiate sign from ground – and *grounding* – the activities by which any structure is related to a familiar context of signification (Roth & Bowen, 2001). Building on this research, we assume here that any two presentations come to be linked as the result of two types of work: *structuring* and *relating*. First, the material continuum—e.g., the display of three arrows (Figure 3) or the spray can that appear in the study below (Figure 2)—has to be structured; it requires transactional structuring work (e.g., Roth, 2008). What structure related to an object, artifact, or phenomenon is relevant to any

given situation is not self-evident, even for experienced scientists. For example, in the present study, students have available a spray can. What is it about the spray can that is relevant to understanding a heat pump, the topic of the curriculum? Because students are to learn about the heat pump, the function of which they do not yet know, *it* cannot serve as a referent for structuring the spray can or an aspect that turns up in inquiry (e.g., the slightly cool gas emerging from it, the lower temperature of the can itself, which appears to move downward in the can, the structure of the can, or its capacity to push gas through the nozzle). Similarly, the material object or phenomenon has to be structured.

[[INSERT FIGURE 1 ABOUT HERE]]

The second type is *relating* work; it is by means of this work that a relation is established between the different presentations (Figure 1). In the work of biologists, for example, soil samples are entered into a two-dimensional array that corresponds to location along a transect and depth at which the sample was collected; this arrangement subsequently comes to be related to a graph that is said to feature horizontal and vertical distribution of different kinds of soil (Latour, 1993). In this way, a feature in the natural world, soil found in different places, comes to be related to specific features of a graph on paper *in and through the scientific practices*. The relations between two very distinct material features—graphite lines on paper and soil samples—are established in and through work. These relations, rather than being "natural," exist only in and because of this practical work.

With this background, our empirical analyses attempt to describe how the practical work involved in structuring and relating unfolds in the context of an inquiry based learning unit on science where a series of hands-on activities have (curricular) connections with a later set of digital models.

Research Design

Setting and Participants

This study is part of a larger project (MIRACLE), the purpose of which is to design science-learning environments that bridge activities across settings, including the school and the museum (Jornet & Jahreie 2013). The project employs the design experiment approach (Brown, 1992; Krange & Ludvigsen, 2009), where pedagogical interventions are conducted to systematically observe and analyze the resulting learning practices to further inform restructuring of instructional designs and theoretical conceptualizations about learning.

The data featured below derive from a study conducted during early phase of the project. An experimental setting featuring two different learning scenarios, a classroom and a museum space, was set up in a studio at the University of Oslo (Norway). Here we focus on the activities taking place in the school space. One group of three students from a Norwegian upper secondary school, together with their teacher of natural sciences, participated in the study. The students were one girl (pseudonym Kaamini) and two boys (pseudonyms Melka and Ishan). As part of a curriculum on energy, the students engage in a set of activities that, from the designers' perspective, are related to the topic of "heat pumps." Heat pumps are devices that transport (heat) energy from a colder source (external environment) to a warmer location (the interior of a house, for example) by means of mechanical work (pump). Understanding how heat pumps function involves understanding basic principles of thermodynamics. The unit also includes socio-economical issues related to energy consumption and the environment.

The experimental sequence occurred over a 6-hour period conducted on the same day. As part of the unit, students are asked to investigate material artifacts, observe what happens, discuss with each other, and record a small video with their iPods in which they illustrate and explain what they have observed. They later solve tasks involving digital models. Experimental activities in which the students act with relatively little guidance are combined with teacher-led interventions in which prior experiences are summed up and discussed with regard to curricular

issues. The analyses presented focus on episodes where the students are exploring the different learning materials on their own.

Data and Analytical Procedure

Events were video- and audio-recorded using two cameras and several microphones distributed in the experimental space. One camera followed them in close-up to obtain a complete record of their talking and pointing. The other camera was static and aimed at capturing contextual aspects that could not be captured by the first one, such as what was being displayed on the white board. Video-recordings were analyzed building on Interaction Analysis (Jordan & Henderson, 1995). Interaction Analysis draws on, among others, ethnography and conversation analysis, techniques that involve detailed observation of human transactions and communication within contexts of social practice, such as educational settings. It is a method for investigating "human activities, such as talk, nonverbal transaction, and the use of artifacts and technologies, identifying routine practices and problems and the resources for their solutions" (Jordan & Henderson, 1995, p. 42). The analytical process involved several rounds of jointly analyzing the data material, and of refined identification of relevant episodes. In the process, we arranged collective data session were our research community was invited to participate for input. Both verbal and non-verbal transactions were transcribed in Norwegian for the whole set of video-material using a software package for qualitative analysis (Nvivo 9).

In preliminary analyses, we identified those instances in which topical connections between the different materials presented to the students emerged in transaction. We were not only interested in graphical materials, as is common in the literature, but also in material phenomena that are often used in the classroom for *presenting* something other than itself, such as a physical law. These preliminary analyses led to an increasingly refined selection of clips for closer analysis of general patterns. A more detailed transcription including gestural and prosodic aspects of communication was performed, together with a translation to English, was conducted for the selected excerpts. The excerpts here reported represent particular instances of transactional work involved in the constitution of continuity across multiple presentations during

inquiry-based activities. (Transcription uses Jeffersonian conventions, as detailed in Appendix 1.)

Analytical Policies

Following a cultural-historical approach (Vygotsky, 1978), our minimal unit of analysis extends beyond any participant's private thinking, and captures individuals and materials in their relations with others. For this reason, we refer to the work as *transactional*, as it cannot be reduced to the work of individuals that is added up to make the joint work. Rather, joint action and work, though it requires the participation of multiple individuals, is taken as an (iurreducible) social phenomenon sui generis (Durkheim, 1919; Vygotskij, 2005). We attend to the *emergence* of signs with regard to the what-for and in-order-to of the actions taking place in, and as part of, *situations,* which constitute larger structures of signification that are experienced in a unitary sense (Dewey, 1938; Vygotsky, 1994). Thus, for example, in the current study, a stream of air resulting from pressing on the valve of a spray can is not experienced as it stands for itself, in isolation of anything else surrounding it, but takes place as part of an ongoing, purposeful action within a (science learning) situation. The phenomenon involves not only the stream of air, but also the background against which this stream is visible and takes its particular shape.

To understand how signs emerge from the point of view of the participants, without ascribing our own frames of reference to the semiotic process, we adopt disciplined ways to approach the recorded materials. We analyze participants' individual actions and utterances from a dialogical perspective, for which any contribution in transaction must be understood as responding to, and directed towards, other participants as well as to the actor herself (Bakhtin, 1986; Linell, 2009). Coherence and consistence are not assessed against external standards, but are regarded an internal (i.e., endogenous) achievement of the situated sequential organization of turn taking in the relation. Any turn is considered as part of the stretch of talk that precedes it, and its import to the constitution of ongoing action is examined with regard to the turn that follows it (Schegloff, 1968). Situational practices of social order provide participants with methods for holding each

other accountable and make talk coherent despite the un-predictable nature of any stretch of talk because engaging in conversation already presupposes mutual understandings over matters such as, for example, that questions imply conditional terms upon the kind of next turns that are expected (Roth, Lee, & Hwang, 2008). In this way, the context in relation to which sense is constituted is not given by frames of reference defined a priori by the analysts, but are understood from what the participants make available to each other in conversation. This, however, does not preclude us from aiming to add to a more general understanding of particular *institutional practices,* here science learning in an (experimental) inquiry-based setting (Heritage, 1998; Mäkitalo & Säljö, 2002).

The Emergence of Sign-relations in an Inquiry-based Multiple Presentational Setting

This study was designed to investigate how the different instructional materials presented as part of an inquiry-based sequence of learning activities emerge as salient aspects of participants' relations, and whether and how (if any) relations are established across them. In our analyses, we follow the students from (a) their first inquiries with a spray can of compressed air and a bicycle pump (Figure 2) to a later set of tasks involving (b) an interactive graph that displays a heat pump's coefficient of performance (Figure 3) and (c) a digital model of a heat pump (Figure 4). We analyze the work from which any relations between these different presentations emerge and study how the different instructional materials acquire their semiotic function in the course of the students' unfolding engagement with each other and with their teacher.

In the following, we present four excerpts from the curricular sequence in chronological order, and complement their analysis with descriptions of the events that precede or follow them to provide a thick description (Geertz, 1973) of the sequence of events. Throughout the analyses, we first describe how, during students' bodily relations with the spray can, the first accounts of the observed phenomena emerge as intimately related to the students' experienced world (Excerpt 1). We then describe how these initial accounts become reified in more disciplinary terms as students orient towards particular features of the setting that seem to make it *an* instructional setting (Excerpt 2). In the context of a task involving the linked digital models, we

finally discuss how and the extent to which connections across the different models and with the accounts achieved throughout the trajectory, are drawn in and through the participants' transactions (Excerpts 3 and 4).

Structuring an Unfamiliar Phenomenon

Experimenting with material artifacts provides students with a bodily sense and practical understanding of how the world works. Such experiences constitute the basis upon which the use of culturally specific language and visual presentations are grounded (Roth, 2004). Here we investigate this in the context of a hands-on activity. The experimental tasks follow a teacher-led introductory lecture on basic socio-scientific aspects of energy use. These tasks, which involve manipulating a spray-can of compressed air and a bicycle pump, are intended (by the curriculum designers) to illustrate the physical principles deemed relevant for understanding how heat pumps work. In this analysis, we take the two artifacts as constituting occasions where students *may* discover relations between pressure, phase transition, and temperature.

[[INSERT FIGURE 2 ABOUT HERE]]

The experimental task is introduced by the teacher and, in addition, formulated on the electronic board. Students are instructed to (a) hold a spray can of compressed air with one hand and spray towards the other hand, (b) observe and discuss what happens, and (c) record a video explaining their observations. The episode begins when the teacher is about to leave the room. A few seconds prior to Excerpt 1, Melka holds the spray-can and is about to spray. The students appear excited, as if expecting something special, laughter and silence following each other. Finally, Melka sprays.

Excerpt 1

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01 Melka:    AGH:, ((shakes left hand))
02   ((students laugh. Melka sprays again, this time longer))
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03 Melka: look at my skin. (.) agh. *((staring at spray can))* it gets cold. it gets freaking cold. *((shakes left hand))*.
04 Ishan: (let me see) if I feel it.= ((*extends arm and touches base of the can*))
05 Melka: =it becomes freaking cold. just feel it. (.) feel up there; ((*touches upper part*)) it becomes cold on the top, or something.
06 ((*Kaamini also extends her hands to touch the surface of the can*))
07 Ishan: yes. ic(h)e cold. ((*laughs*))
08 Kaamini: not on the bottom, but on the top. *((touching bottom and top of the can))*

Excerpt 1 illustrates students' first contact with some of the phenomena their learning unit *is about*. After the first spray, Melka shakes his left hand that received the air from the spray can, produces an interjection, and then all the students burst out laughing (turn 2). Melka sprays again, this time longer (turn 2). Immediately after, Melka articulates his impression (turn 3), drawing attention first to his left hand: "look at my skin" (turn 3). He then orients to the spray can surface, as he moves his right hand away from it and shakes it while uttering "it becomes freaking cold" (turn 3). Ishan extends his arm towards the spray can (turn 4) while Melka is extending the can towards the center of the table (turn 5). While Ishan is touching the surface of the can, Melka invites him to feel the upper part and offers a description that it becomes cold there (turn 5). Kaamini extends her hand, and both Ishan and Kaamini touch the surface of the spray can (turn 6). Ishan, opening with an affirmative "yes," confirms the offered description that the spray can gets "ice-cold" and laughs. Kaamini further confirms the impression that it becomes cold "not down, but up" (turn 8).

Our main interest here lies in the question of how the spray can and the phenomena surrounding it emerge as accountable objects in and through the students' transactions; that is, how an unfamiliar, unknown, and uncertain "it" *presents itself* and, in so doing, turns into a more definite thing. It is true that the spray can is a familiar object, but how this object relates to *this*

task is part of what students have to discover. At first, Melka, by means of verbal and non-verbal expressions, invites others to attend to observable aspects. These invitations are taken up by the others and, therefore, move the event along and give it shape. This allows certain aspects to emerge as salient, including the temperature at the surface of the spray can and that it does so in its upper but not in its lower part. It is in and through the transaction that this set of observations *comes* to exist, *emerging* from a more or less undifferentiated material plenum (lower part, Figure 1). Everyday phenomena (the feeling of cold, the sensation of the air blowing on the hand), made salient in and through verbal and gestural deictic actions (pointing, referring to), emerge as an *transactively* achieved (inherently shared) empirical ground that is closely related to immediate sense experiences. That is, a structure (the phenomenon) is emerging in and through the transactional work accomplished in the students' social relation. These deictic actions refer to the objects being pointed to and to the subjective impressions associated to them in the same move. In this sense, there is interdependence between the deictic gesture and the spray can, as an object of inquiry much in the same way as there is an interdependence of word and thing in children's early form of communication. The artifact, present in the situation, does not need to be made present again (i.e., *re*presented); it stands for itself and in relation to the students. At the same time, however, it is through the students' manipulations and talk that the artifact becomes objective, that is, an object to talk about and reflect upon in a joint, unified ground of experience.

What Happened? From Presentation to Re-presentation

As soon as students begin to talk about what happened, there is a shift from the immediacy of the initial experience associated with the objectifying nature of language. This shift is apparent in Excerpt 2, which immediately follows Excerpt 1 and where turns are therefore numbered accordingly. Ishan looks and points to the board while reading the instructions "feel, observe, and discuss" (turn 8); he later asks, "what happened?" (turn 10). Melka invites Ishan to test for himself (turn 11). While Ishan sprays, Melka holds his hands in front of the spray-can. All burst out laughing once more (turns 11–13). Melka invites attention to his hand (turn 14) and there is

more laughter (turns 15–17). Ishan, gazing towards the board, once again utters, "what happened"? (turn 17). This turn is not immediately taken up as the other two continue to laugh (turns 18–19). Ishan then orients his body towards the board while uttering "yes, bu::t-" (turn 20), and then loses his turn at talk when Kaamini and Melka begin to offer what can be heard as reply turns to Ishan's question (turn 21). Melka offers up an observational statement about the differences where ("down there," "up there") something ("it") happened (line 22). Beginning with a negation, Kaamini articulates a contrastive statement about "pressured air inside" the can (line 23) and continues with a causal consequent: "which makes it to come out at once" (turn 23). A tentative ("perhaps," "I don't know") offer of another cause follows: "pressure makes it to become cold" (turn 24). The drawn out "yes" appears to accept, affirm, and confirm this statement.

Excerpt 2

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08 Ishan:     ((looks and points to the board)) feel, observe and
              discuss.
09            (1.8) ((Kaamini laughs))
10 Ishan:     what happened?
11 Melka:     just try and press yourself. ((offers the spray can to
              Ishan))
12 Ishan:     right.
13            (3.8) ((Ishan sprays, Melka keeps one hand in front of
              spray. all laugh))
14 Melka:     look at the skin- ((laughing)) look at my hand, it
                  [feels like-
15 Ishan:         [((??, laughing))
16 Kaamini: so funny. ((laughing))
17 Ishan:     you are quick, well ok ((looks at board)) [what happened?
18 Kaamini:   [((??))
19 Melka:     don't point it at me. ((oriented towards Ishan. laughing))
20 Ishan:     yes, bu::t- ((orienting towards the board))
21 Kaamini:   [there is much air-
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22 Melka: [I don't know] what happened. I think it happened down there and suddenly it happened something cold up there= *((touches top of can))*

23 Kaamini: =no, there is much pressured air inside, *((points to spray can))* which makes it to come out at once. *((pushes arms out))*

24 Ishan: pressure makes it to become cold, perhaps, I don't know.=

25 Kaamini: =yes:::.

In this sequence, an interesting shift in students' transactions takes place. First, the locution "What happened?" is followed by an invitation to "try and press." That is, rather than a reply to a question, we notice an accepted invitation to make the material phenomenon *itself* present. This is precisely what has been reported in other inquiry settings, where students re-enact and present an investigation (or part thereof) again rather than making it present again by some other communicative means (Roth & Lawless, 2002). Work-related, that is, *ergotic* movements in praxis are the first and fundamental forms of presentations in which a phenomenon comes to exist (Roth, 2003). Communicative forms over and about the materials, such as gestures and talk, tend to follow before a full scientific discourse emerges that makes the phenomenon present *when it is actually absent* (not present). But in this episode, following the invitation to orient to the task requirements ("feel, observe, and discuss") a shift occurs. It is now that different verbal descriptions are offered for "what happened" and "why."

In response to the invitation to attend to the task's instructions, Melka articulates what has been a *shared* sense experience. The reception begins with a negation followed by an assertion about pressured air inside the can. This assertion becomes the premise of an observational statement about "it" "coming out at once." Although we have no means of knowing why and how she picks up the term "pressured air", the spray can, an office supply for cleaning desktops, is labeled in Norwegian as "pressured air" (*trykkluft*) and the term is used in everyday settings. Now, by means of a different grammatical structure, the physical artifact is referred to in a more decontextualized manner, incorporating a structure and terminology resembling scientific

discourse. Pressure is the subject also in the next turn and, by means of a new predicate, adds a novel dimension to the explanation in the process of emerging: whereas Kaamini articulates pressure as a modality of air, Ishan articulates it as an independent concept. This later articulation comes thus closer to a scientific formulation: an entity (pressure) is isolated from contextual, bodily experience. A transition becomes observable between deictic and iconic means of presenting a phenomenon again and phenomenon-unrelated means of presentation in language. A gap opens between language indistinguishable from practical understanding of navigating *in* the material world and language *about* the (functioning of the) material world.

Connections to and across Different Presentations

The instructional sequence is based on the assumptions that (a) the materials presented, including the "linked" digital models, bear structural similarities that can be recognized by the students, and that (b) earlier experiences with material artifacts later become resources for transacting with and integrating visual models that make present one or the other aspects related to heat pumps. However, whether students *actually* take up on what designers believe to be an affordance is an empirical matter. Here we investigate this matter in the context of a task involving three digital models of a heat pump. As our analyses show, the connections drawn with and across presentations do not appear to draw upon formal descriptions of the materials encountered, but rather are always indexed to a shared history of particular events (e.g., Roth & Duit, 2003). The presentations, thus, rather than conveying "meaning," become material resources for coordinating an orientation to solving the task that is *coherent* with this history.

Before we present the analyses, some specifications of the materials are required. Model 1 (Fig. 3) is intended to be a conceptual model of the efficiency ratio of heat pumps. From the curriculum designers' perspective, the upper (blue) arrow represents the input of electrical energy into a heat pump. Students can modify the value displayed on this arrow. The lower (green) arrow represents the energy that the heat pump obtains from the environment. The value on the green arrow and the outcome value change as the input value is modified. Values are given kWh.

[[INSERT FIGURE 3 ABOUT HERE]]

Digital model 2 (Figure 4) is intended to illustrate part of the inner mechanisms of a heat pump. It depicts a system of four connected elements. Heat pumps are a closed system of coils through which a refrigerant fluid is pumped. In one part of the system, the refrigerant is decompressed and takes in heat as it boils at low temperatures; in another the refrigerant is compressed and thereby condensates easily and releases the heat. This is so because phase transitions involve/require transfer of energy, which is transferred from the environment. It is according to this principle that a conceptual relation can be drawn between the hands-on activities and the digital models.

To facilitate students' connections across the visual models, digital model 1 is inscribed in the background. As students move the cursor over the figure, dialogue windows require the students to write down the functions of the different parts. To this end, the students can drag and drop digital post-it notes over the figure. A third digital model, in turn, was identical to digital model 2, but included an animation of the boiling and evaporation processes taking place within elements A and B of the model (Figure 4). In this third model, students also could modify pressure, which led to changes in those elements according to the designers' notion of evaporation/condensation. The students can move across the three models at any time. The designs' objective is that, drawing on their experiences along the trajectory and the materials' affordances, the connections between evaporation and heat pump's efficiency come to be understood by the students.

[[INSERT FIGURE 4 ABOUT HERE]]

The episode presented here reproduces students' transactions with and around digital model 2 (Figure 4). Previously, the students have solved a task related to digital model 1, where they had

to calculate the efficiency ratio. During that activity and the teacher-led sum-up session that followed it, the students have referred to the lower (green) arrow in digital model 1 as the "extra" energy, as it has been clarified that such energy does not come from the electric current but from the environment. In the current situation, linkages between that arrow and digital model 2 are the topic of discussion when reference to this previous activity is made.

Excerpt 3

01 Ishan: ((pointing over element A in model 2)) since this one is blue; ((shifts to model 1 and points over the upper arrow)) and this also is blue, so it has to be normal energy here. ((shifts back to model 2))
02 Kaamini: ye:::s::
03 (2.7) ((stare at the screen silent))
04 Melka: *((pointing over element B in model 2))* HERE Is the energy we get. Here is the small.
05 Kaamini: that's EXtra,
06 Melka: no, because here is one point eh=
07 Ishan: It's EXtra; It's EXtra;
08 Melka: =and here *((pointing over element A in model 2))* it's two point five.
09 Ishan: no
10 Kaamini: no, it's extra. Remember, that one was green and blue. Check the colors
11 Ishan: do we have to check the colors?

The excerpt begins in the middle of an exchange over one aspect of the interface. Ishan offers an explanation that relates two aspects of the material continuum—element A in model 2 and the upper arrow in model 1, to a third aspect—"normal energy"—by virtue of their color (turn 01). Kaamini acknowledges with an emphatic "yes" (turn 02), and the students stare at the screen in silence during some seconds (turn 03). Melka then offers an observational sentence, pointing emphatically over element A in model 2, and states "here is the energy we get", adding then "here is the small." Kaamini then specifies—indeed objects—"that's extra" (turn 05) and Melka

objects as he makes reference to a number (turn 06). Ishan repeats "it's extra" twice, interrupting thus Melka (turn 07), who however continues by identifying the element A in model 2 with another number, "two point five" (turn 08). Both Ishan and Kaamini reject this latter observation, and kaamini suggests her peer to "remember" that "that one was green and blue," and adds the imperative "check the colors" (turn 10). Melka, however, does not directly accept the latter command, as he questions whether they have to check the colors (turn 11).

Several aspects in this sequence provide evidence that a structuring activity is going on. The figure being discussed is obviously not self-explanatory. We can hear Ishan offering an explanation sentence that connects two elements of the models 1 and 2 to a third one, on the basis of a similitude in the (blue) color. This third element—normal energy—is made present in and through Ishan's deictic expression "it must be normal energy here" (turn 01). But this presence does not seem evident to all the participants. Whereas Kaamini seems to agree, Melka provides with a different account, which relates the specific material aspect being indexed—element A in model 2—with another term, "the energy we get." In contrast to Kaamini, Melka justifies this latter assertion by making salient the size of the element, not its color (turn 04). That is, there is not only disagreement on what the elements in the figure stand for (in particular, what the elements A and B in the model 2 are a sign of), but there is disagreement also with regard to which material aspects of the figure are signals and which others are just noise. Even here, where there is an explicit link and mapping between two presentations from a design perspective—the shape in the background of model 2 is identical to that of model 1—this link does not exist in and for the transaction in the intended terms. The material aspects of the figure do not present themselves as already structured, but the students must achieve such structure throughout transactional work.

The ways in which prior activities in the curricular sequence come to be part of students' structuring and relating work becomes evident as phenomena cease to be the object of such work and seem to become ready-to-hand, already presumed in the course of further joint inquiry (Roth & Hoffman, 2009). In the sequence here analyzed, the students use words such as "normal

energy," "extra," or "two point five" (turns 06, 08) without the emergence of repairs after next turns, such as requests for clarification of what is "meant" with such words (Schegloff, 1992). Whereas agreement regarding what model 2 is to stand for is not achieved, observational sentences generated to structure the current situation are made not in terms of immediate experiences—as was observed in the first turns of the experimental activities with the spray can—but refer to aspects of familiar, prior shared experiences, that are here treated as the *substrate* (Goodwin, 2013) upon which the students' ongoing referential practices are grounded. In this work of making co-occurrent two situations—the deictic references to the immediate environment, and the talk that indexes to immediately prior shared experiences in the curricular trajectory—we observe what is needed to establish a sign relation between two segments of the material continuum (Figure 1).

Importantly, the words used have currency both in students' biographies—they have emerged in and are indexes to previous activities in the curricular sequence—and in the teacher's and designers' discourse about energy, with which the students have engaged in prior teacher-led discussion during solving the digital model 1 task. However, the double nature of those signs, biographical and formal or disciplinary, is not necessarily evident to the students. In the transcript, the use of these terms appears to be indexing to the particulars of the students' biography. In the explanation sentences, there is no justification based on a particular body of knowledge that can be spelled out apart from the local contingencies of the situation. There is no articulated "meaning" of "extra energy" or of how this is re-presented in the figure, but prior bodily experiences are indexed. Thus, an element stands for extra energy or not with regard to colors or size, but on the premise of specific prior experiences, which students request to be recalled (e.g. turn 10).

The data also include instances where materials that where presented previously in the trajectory were indexed as part of the ongoing relational work. This aspect is illustrated in the following excerpt, which occurs few minutes after excerpt 5, where reference to the term "extra energy" is made again.

Excerpt 4

01 Kaamini: *((pointing over the screen))* It's there where we get extra.

02 Ishan: no, *((pointing over the elements A and C in model 2 respectively))* it must be cold and warm, because when you compress it like this one here *((takes the spray can and gestures on it))*, it was compressed air. And then it was cold inside. And then when it was released out, it became warm air again.

03 Melka: it wasn't cold inside.

04 Ishan: yes, it became cold?

05 Melka: it became cold because *((mumbles))((takes the spray can))*. this one needs heat to come out. That's why it takes heat from here *((moves hands in the air))*.

In turn 01, Kaamini is responding to a previous account of what may be happening in models 2 and 3 offered by Ishan. Kaamini responds by remarking that it is "there" where they "get extra," without specifying an object for the modifier "extra," as she points over the screen (turn 01). Ishan objects and elaborates another explanation sentence in which the assertion that element A "must be cold" and element C "must be warm," is connected by the conjunction "beacause" to a description and demonstration of the spray can that remarks that "it was cold inside" (turn 02). Melka in turn objects to this latter aspect (turn 03) and Ishan re-asserts that "it became cold," but raises his intonation towards the end of his utterance, as it occurs when someone poses a question (turn 04). Melka then initiates an explanation where it is articulated that the spray can takes in heat to "come out."

In this short excerpt, one observes three different accounts and three respective objections. The objections concern first whether it actually is "there" where "we get extra," whether the elements in the model are "cold" and "warm" respectively, and whether the spray can was "cold inside" or not. From the view of the designers, this is a wonderful opportunity for the intended connections to emerge. Indeed, an analogy between the spray can and the heat pump underlies

the design of the model: as it occurs in the spray can, heat pumps get their "extra" energy from the environment through evaporation. The account articulated by Melka seems to come very close to this canonical characterization. However, the links between the different elements laid out in conversation does not realize in the intended terms. Indeed, few moments later during this activity, Ishan will ask Melka "what should I write then?" as he is about to type on a digital post-it, to which Melka will answer: "but I don't understand that figure." There does not seem to be a relation of the kind that Figure 1 displays. At best, we can speak of a co-presence of these presentational forms and possible associations without an articulation of how formal aspects of one are related to formal aspects of another.

During the discussion, reference on the materials "at-hand," such as the spray can, seems central. First Ishan gestures on the spray can to articulate an observation regarding temperature differences between the components of the model, and their relation with compression (note that a dialogue window that labels element B as "compressor" emerges when the cursor is moved over). Melka gestures again on and around the spray can to provide an account of how temperature and energy phenomena play out in the artifact. Interestingly, in both Ishan's and Melka's articulations, the past tense is used, thus indexing a past event. In this way, the spray can becomes an occasion for collective remembering work (e.g., Middleton & Brown, 2005) concerning a previous event: what has happened and what has been observed. Contrary to the assumption that learning involves abstracting knowledge from experiences, "knowledge" about any salient (material) aspects in the current situation appears to be tacitly indexed to aspects of prior experience that become reified in yet another material aspect—signs. Thus, the crucial aspect here does not lie in an iconic relation (perceptual similarity) between the two corresponding presentations (artifact and associated phenomenon and digital interface) but in a third presentational form, discourse, that can be used in the talk about both during joint, sequentially organized inquiry. Overall, our analyses in this latter section support evidence that shows how our incarnate experiences in the world constitute the practical understanding, where any understanding of sign-mediated communication—vernacular or scientific—bottoms out

(Roth, 2012b). In the present study, this is shown to be the case also in the relational work that students perform to make sense of a multiple presentational setting.

Discussion

The purpose of this study was to investigate how the structure and relations (if any) between different presentational materials (related from a curriculum design perspective) emerged in the course of sympractical student inquiry. Although there are claims that one requisite for learners to take advantage of multiple presentational environments is to *first* understand the presentation's syntax and semantics (Ainsworth, 2008; van der Meij & de Jong, 2006), few studies actually investigate *how* such understanding emerges in the first place. In this study, we provide an account of such emergence from a socio-cultural, transactional perspective.

The analyses are conducted without presupposing any particular nature of the artifacts and visualizations that the students encountered and worked with. Artifacts and visualization are taken as part of the material continuum, but how they would appear to transaction participants and how they would function (i.e., the structure of the segments and their relation to other segments) is taken to be an empirical problem. The analyses are grounded in the data to see what students make of and with these segments of the material continuum, what structural properties emerge from students' transactional work, and how different structures come to be related to each other. Whether something *comes to be* a *re*presentation (model, analogy, metaphor) of something else is a question of the transactive, structuring, and relational work students accomplish.

In this section, we summarize our findings with regard to the observed structural and relational work. Two dimensions of learning that are often taken for granted or not attended to, the body and the praxis, appear to be *fundamental* to the emergence of signs, and, by the same token, to the development of new literacies. We conclude by articulating some implications with regard to research on learning in multiple presentational environments, and point out some limitations of the study and further research directions.

Multiple Presentations Require Coordination Work

In general, this study supports evidence that suggests that learning environments where multiple presentations are available can facilitate students' development of "conceptual understanding" of scientific topics (e.g., Adadan, 2013). As most studies do, it also shows that drawing canonical connections in and across different presentations is a challenging task (e.g., Kozma, 2003). However, this study departs from much of the literature in that it provides a description of the actual, bodily and practical work by means of which different presentations become structured and related from, in and through the learners' first-time-through perspective. The study shows that there was a good deal of sympractical, transactively accomplished structuring work by means of which segments of the material continuum come to be isolated. This work, as apparent in Figure 1, is a prerequisite for the work in which multiple presentations come to be related; signs, the relations between segments of the material continuum, are emerging. In structuring the material continuum, students made extensive use of deictic and iconic gestures and expressions that made salient certain aspects of the setting, providing structure to a unified field of experience and, therefore, to the phenomena they could account for. Thus, phenomena were structured (emerged) as the material elements in the situation (e.g., spray can) were acted upon, and not before.

The means by which such phenomena were structured and accounted for appeared inseparable from the bodies acting on them. This observation is not limited to the materials in the hands-on activity. Despite the intended pictorial and symbolic nature of their design, there was also bodily structuring work accomplished in the discussion over the digital models. Aspects of the digital visualizations were made salient as gazes, gestures, and talk were directed to them in the context of specific, object-oriented actions. The models were not self-explanative, and particular materials needed to be structured as students negotiated different approaches to the figures.

Deictic gestures and expressions have been recognized to play a crucial role in the development of disciplinary competences in science learning (Roth & Lawless, 2002). Studies

investigating learners' conversations across different media (face-to-face, online) have shown that when face-to-face transaction is restricted, gestures referencing the immediate context are partly replaced by verbal deictic expressions, suggesting thus the context-bound nature of communication in learning environments (Suthers, Girardeau & Hundhausen, 2003). In this study, deictic gestures do not only appear to bear a referential function, but become *fundamental* to the emergence of structure of the different presentations in the sequence. Thus, the body, as an integral aspect of deixis and transactional coordination (Hindmarsh & Heath, 2000), is shown here to be a fundamental moment in the constitution of sense with regard to and across presentations. More crucially, because structures were made present by means of body movements that were part of an ongoing transaction, structure changed with action, even when presentations remained constant in the material continuum. This further points to the pragmatic rather than substantive character of the emerging significations that we elaborate further below.

The present analyses support the socio-cultural premise that the introduction of signs fundamentally transforms activity (Vygotsky, 1978). As signs transformed activity, the nature of the presentations was transformed too. Thus, aspects of situations that had been structured and stabilized in transaction became uncertain and required of further inquiry as different ways of accounting them unfolded in transaction. In this progressive inquiry, signs that emerged in previous episodes of the curricular sequence became means for accomplishing new structuring work in further transactions, even when no articulated formal description of the significance of such signs seemed to be available. Interestingly, these signs appeared to be grounded on bodily experiences and a pragmatic sense of the current situation, rather than on formal descriptions, or "information," that these signs were taken to stand for. This account of as inherently developmental and ever changing phenomena sharply contrast with conventional characterizations of presentations as re-presenting information that can be then "searched," "recognized," and "processed" by learners (e.g., Bodemer et al., 2004; Larking & Simon, 1987).

Students made phenomena present in response to task demand, language appearing as yet another fundamental aspect of the coordination work. Orientation towards particular structures of

relevance to the "doing" of science learning, such as checking the tasks' formulation, resulted in a shift of the conversational premises of relevance in sequential transaction. In our study, we showed how, on the face of more or less implicit disciplinary demands, observational sentences indexing to immediate sense experiences no longer were accepted as sufficient, and accounts adopted grammatical structures that more closely resembled scientific discourse. These demands, in turn, facilitated a *contextual* re-*configuration* in which participants "demonstrably" orient bodily and conversationally to "a particular, locally relevant array of semiotic fields" (Goodwin, 2000, p. 1490). In this new configuration, certain features of situations appeared to be immediately and immanently seen as moments of a particular practice – learning in the science classroom. These findings are consistent with other studies highlighting the importance of considering the "institutional" practices embedded in the use of technology in educational contexts (Furberg et al., 2013; Krange & Ludvigsen, 2008).

Despite the clear orientation towards disciplinary (conceptual) talk observed in determinate sequences, relational work remained clearly grounded in bodily, material and pragmatic aspects of transaction. In linking across aspects of the different presentations, the students offered explanation sentences to argue for particular observations. Such arguments indexed to situational aspects of prior shared experiences rather than to formal principles or bodies of curricular knowledge. Even when using the conceptual aspects of talk, these appeared inherently in bodily form and indexed to the students' particular history of transactions. In this regard, the co-presence of material artifacts was fundamental for serving as occasions for collective remembering work (Middleton & Brown, 2005). Yet, no material aspect was determining with regard to the structures and relations that emerged. Indeed, these were often different from the ones intended by the designers. Thus, it is not that the students *misinterpreted* something, as it is often held in the literature (e.g., Chittleborough & Treagust, 2008); rather, the emerging relations between diverse segments of the material continuum (i.e., Figures 3 and 4) differed from the intended one.

Body and Praxis in Learning with Multiple Presentations

Throughout this paper, we emphasize the importance of attending to the transactional, pragmatic aspects of learning in environments where multiple presentational forms are available. In the preceding review of the literature, we note that research in the field has often relied on cognitive models of information processing, and that it has focused mostly on determining the relations between presentational features that were defined in advance on the one hand, and learning outcomes on the other. Whereas the merits and advantages of these approaches were acknowledged, it was argued that these approaches had difficulties in accounting for how, from the view of the learner who does not yet master an underlying disciplinary description, material presentations made sense. An alternative framework based on a cultural-historical approach was introduced in which the semiotic processes involved were theorized to consist of two types of sympractical (i.e. joint, fused practical) work: structural and relational. Through structural work, events and artifacts in the material continuum acquire objective form in, through, and for students' actions and transactions. Through relational work, any two events or artifacts in the material continuum are linked to each other.

The empirical analyses presented above provide detailed descriptions of the transactional work that takes to isolate and relate segments of the material continuum in transaction. Two aspects that tend to be taken for granted and which therefore are rarely theorized or empirically scrutinized—the body, and the context of praxis within which the body finds itself—have been shown to be central for understanding how structures emerge in transaction. In this sense, we here summarize two inter-locked competences that become of interest when research shifts from focusing on re-presentations, to focusing on the first-time-through presentational aspects of learning environments. The first one concerns the role of the body in the constitution of sense. It is through body movements that aspects of the environment first emerge as signs. That is, pointing, gazing and other deictic gestures are the first materiality by means of which the materials of the situation acquire structure. The body is not just re-acting to those structures; structures are not yet constituted as objective. There appears to be a knowing that is more

fundamental than the (conceptual) understanding of substantive matters—such as what the "meaning" is of this or that segment in a digital visualization—upon which events in the world bring about the possibility of being further objectified by means of communication. The body then may be seen as a moment of a larger unit of movement, where unexpected sense phenomena—the sudden feeling of cold when acting on the spray can, the contour of a shape when gazing towards a digital model—become present in an immediate and irreducibly particular, once-ever-occurring manner. It is only when this immediacy becomes part of an ongoing activity—the unit we have in mind here—that it can possibly acquire sense (Roth & Jornet, 2013).

Because bodily action always presupposes knowledge of the praxis in which body engages, it is not surprising to find in our study that students' experimentation with material artifacts served as a productive entry point to develop vernacular language towards other forms of discourse or *re*presentation such that these would be useful to the task. Hence, this primacy of the body aspect brings attention to a second competence: meaningfully relating to others in ongoing praxis. Body movements do not happen in isolation, but are always part of sequentially ordered social transactions. In this sense, movement is always motivated by and designed for others, addressing others (Bakhtin, 1986). Body movement, therefore, already assumes a mutual understanding among the participants (Roth, 2012b), even when different views of what the segments of the material continuum stand for are held in conversation. The sign primarily emerges as a social function when it changes the behavior of others (Vygotsky, 1978). Only later does it become a means for mastering one's own behavior. Any sign, therefore, first appears in the context of particular collective activity. Therefore, throughout this study, we insist on the dual relational nature of the sign: a relation between segments of the continuum and a relation between people. Accordingly, the function of language, here understood to comprise both talk and body movements, is not substantive. Language becomes a means for coordinating activity. Analytical description may therefore concern itself with describing how new segments of the material

continuum are accounted for by means of a language that, while may not be aligned with canonical descriptions, is nevertheless put into work to get things done.

The present findings show that the material aspects of multiple presentational environments, when drawn in transaction, become part of a larger unit of praxis, where their sense does not become substantive, but has a pragmatic character through and through. Studies on learning with multiple presentations already suggest the importance of grammar as an important moment in students' structuring work (Karlsson, 2010) and show how premises in transaction respond to particular institutional concerns associated to academic performance (Furberg et al., 2013). These studies show that "students' scientific accounts are produced in the intersection between a formalized scientific language and the *logic* of everyday language" (p. 59, emphasis added). Our study adds to this literature by arguing that the characterization of the "logic" of everyday language requires of an account that does not presume formal structures as the ground for understanding. Instead, characterizations of how new intellectual competences ("conceptual understandings") emerge out of relations between the body and situated praxis are required.

Concluding Remarks

We began this study by articulating a critique to the view of learning with multiple "representations" that assumes that a pre-requisite for learning "from" these sort of environments involves *first* that the students understand the syntax and semantics of the different presentations involved. Throughout our theoretical and empirical analyses, we argue that, when approached from a non-normative perspective, the processes by means of which any syntax emerges, it does so in and through the students' bodily transactions, which *are* the very flesh of learning with multiple presentations and not just a pre-requisite. Thus, we argue, understanding learning with multiple presentations requires an understanding of the pragmatics of joint action, of how the body and the materials become the ensembles that constitute a unified *situation* (Dewey, 1938; Roth & Jornet, 2014). This requires of detailed analytical accounts of the bodily and situated transactions that make up such unfolding situations. However, such analytical approach does not come without some limitations: these analyses are space and time consuming, and require of

thorough processes of synthesis and selection for results to be presented in the format of journal articles. In concluding this article, we would like to address one such limitation.

In the current study, we focus on analyzing episodes in which students were working mostly on their own. However, an integral aspect of the learning setting in which these transactions took place was the design of teacher-led interventions to sum up and guide the students' activities. Whereas we show how such episodes became integral to the semiotic *substrate* upon which students were further laying out their accounts, for the sake of focus, we do not include analyses of those teacher interventions. The role of the teacher in contributing to the ongoing structuring and relating work, however, is very salient in the data sources. Research often points out that, for students to learn from the different forms of presentations, it is important that teachers make them aware of those features that the teacher considers critical for the understanding of the process or concept that is the object of the curriculum (Bivall, Ainsorth, & Tibell, 2011; Lee, 2010). There is evidence that teacher-led sequences are a crucial resource in students' work of developing appropriate re-presentational resources to account for scientific phenomena (Furberg et al, 2013; Tytler, Prain & Peterson, 2007). Understanding how teacher interventions take part as yet another material, bodily aspect of the structuring and relating work that characterizes learning with multiple presentations is an important field for future research.

Acknowledgements

The research reported in this paper was supported by The Research Council of Norway as part of the Core Competence and Value Creation in ICT (VERDKIT) funding program. We would like to thank our research community at Intermedia (University of Oslo) for input to previous versions of this paper. A special thank you to Ingeborg Krange for her support and detailed comments throughout the development of this work.

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Appendix 1: Transcription conventions

,?;.	Punctuation marks are used to indicate pitch toward end of an audible unit: slightly rising, strongly rising, slightly falling, and strongly falling
[ ]	Square brackets indicate beginning and end, respectively, of overlapping speech
(.)	Clearly audible pause of unmeasured length, evt. time in seconds (e.g., (2.0))

(())	Our own comments and observations
(??)	Words missing. As many "?" as words missing
-	dash marks unfinished or interrupted utterance
(h)	laughing inserted in talk
word	an underlined word signal stress in the spoken utterance
wo:rd	colon indicates the prolonging of the prior letter or syllable
<word>	brackets pointing outward indicate word or phrase spoken more slowly than the surrounding discourse
>word<	brackets pointing inward indicate word or phrase spoken more quickly than the surrounding discourse

List of Figures

[1] The units of energy were incorrect at the time of the pilot study; this presentation no longer is part of the curriculum in its current form.

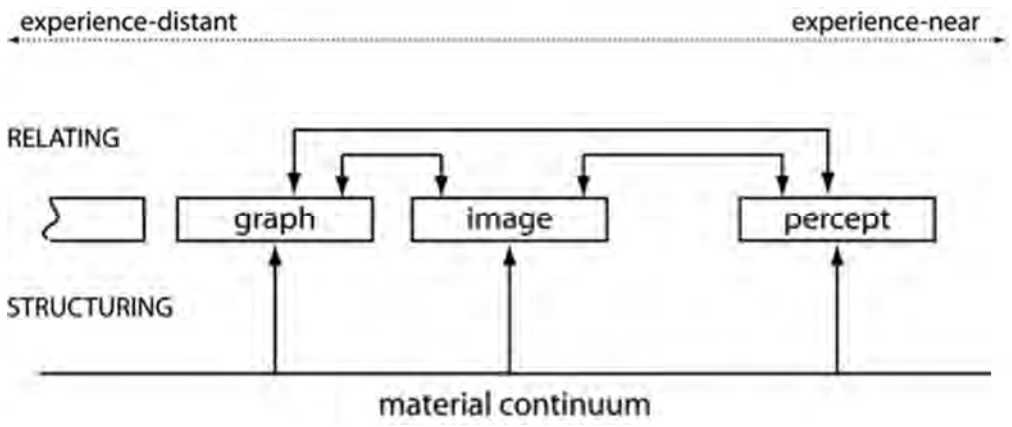

Figure 1. The relation between things in the world (objects, artifacts), as these are perceived, and different presentations (i.e., structured segmentations) thereof.
53x22mm (300 x 300 DPI)

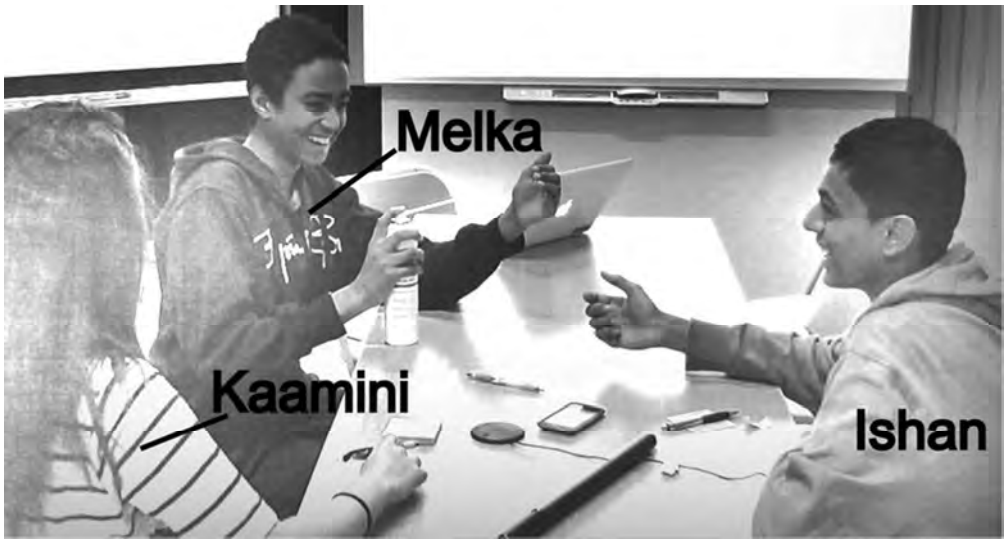

Figure 2. The experimental setting. Students experiment with artifacts and computers in a staged classroom environment.
71x37mm (300 x 300 DPI)

Figure 3. Digital model 1
131x59mm (300 x 300 DPI)

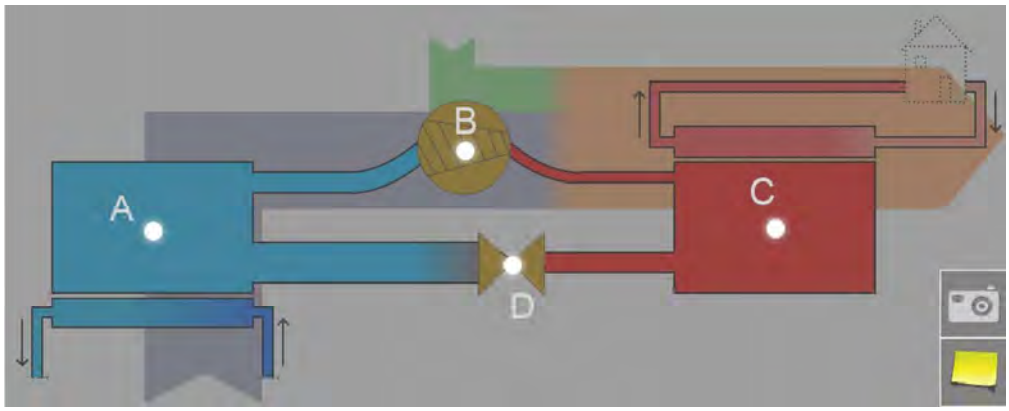

Figure 4. Digital model 2. Letters have been included for orienting the reader, but were not in the original model. Elements A to D stand for an outer heat exchanger, a compressor, an inner heat exchanger, and a valve, respectively.
116x46mm (300 x 300 DPI)