

# **Science, Culture, and the Emergence of Language**

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**Running Head:** Language emergence

# **Science, Culture, and the Emergence of Language**

## **Abstract**

A major achievement in the sociology and philosophy of science over the past two decades has been the recognition that science is a form of culture with its own creeds, language, material practices, perceptions, theories, and beliefs. Learning science then amounts to participation (from more peripheral to central ways) in the particular practices of this culture. We argue here that there are some fundamental, heretofore neglected, ways in which newcomers come to perceive and talk about natural phenomena. Beginning with 'muddled' talk and supported by deictic and iconic gestures, learners isolate salient objects and events which are, in increasing ways, represented in linguistic forms. More abstract forms of communication (writing, abstract symbols) are competently used only later in the emerging communicative patterns. There is some evidence that these patterns of development transcend specific cultures. As such, there lies tremendous potential in science activities that focus on observational and theoretical language in the presence of the relevant phenomena.

Worldmaking as we know it always starts from worlds already on hand; the making is a remaking. (Goodman, 1978, p. 6)

## **Preface**

To many, our approach to developing an understanding of the relationship between science and cultural diversity in the classroom may appear radical. We start by twisting Goodman's statement to the point where much of the connotation is squeezed away leaving only the suggestion that making a world (in this case making a scientific community) begins with those things on hand. Worldmaking, as thinking (Heidegger, 1977), literally is handwork. More specifically, we explore the connection between worldmaking and our own bodies in attempt to open a discussion regarding how a hands-on approach to science education facilitates the emergence of scientific communication through gesture. Our intent here is to communicate in what sense gesturing and physical manipulation transcends cultural differences and provides a common doorway into the culture of science and hence towards a greater development of scientific understanding.

## **Science as Culture**

Mannheim's (1936/1966) sociology of knowledge is premised upon the idea that "there are modes of thought which cannot be adequately understood as long as their social origins are obscured" (p. 2). From this perspective the construction of knowledge can be seen as a social activity. In other words, it is constructed by "men [and women] in certain groups who have

developed a particular style of thought” (p. 3). As such, Mannheim emphasizes the role of the group in the construction and maintenance of knowledge and downplays the role of the isolated individual. It is not surprising, then, that science has come to be recognized as a form of culture with its own creeds, language, material practices, perceptions, theories, and beliefs (Fuller, 1997). This shift towards viewing science as culture has been facilitated by an increasing interest in scientific practice from disciplines traditionally concerned with cultures and subcultures. Researchers from these disciplines, including sociology, ethnography, and anthropology have applied the methodologies of inquiry honed in cross-cultural studies and applied them in the laboratories of science (e.g., Latour & Woolgar, 1986; Traweek, 1988).

In the wake of Kuhn’s (1970) seminal work, *The Structure of Scientific Revolutions*, researchers have come to associate scientific culture with specific social, material, linguistic, and rhetorical practices. Consequently, an increasing number of researchers have focused on the role of language in the construction of scientific cultures (e.g., Bazerman, 1987). However, along with linguistic conventions, there are other practices that contribute to the development of scientific cultures including visual, gestural, and manipulative activities (Lemke, in press). For example, a number of studies have marked the transformation of language as it moves from the uncertainty embedded in initial observation statements, to propositions constructed during laboratory conversations, to a statement of observation as an unassailable scientific fact (e.g., Amann & Knorr-Cetina, 1990; Latour & Woolgar, 1986; Roth & Bowen, 1999a).

Micro-analytic studies that document and theorize the emergence of new observational and theoretical descriptions are scarce. (The study of astronomers in the process of discovering a new celestial object is one exception [Garfinkel, Lynch, & Livingston, 1981].) There exist, however, several historical studies that have attempted to document and theorize the emergence of new

language from the moment to moment activities of past and present researchers (Gooding, 1990; Pickering, 1995). Furthermore, both Gooding and Pickering provide clear indications that language emergence is deeply caught up in material practice. That is, there is a co-dependent emergence of the nature of the objects scientists see (observational descriptions) and manipulate, their technical know-how, their descriptions of the apparatus, and their theoretical descriptions of the phenomena.

If there is such a deep link between scientists' observational and theoretical descriptions, on the one hand, and the material activities and manipulations of equipment, on the other, we may expect similar relationships among school-aged learners. However, only a few micro-analytic studies have explored how conceptual talk (at Piaget's "formal" level) is linked to students' interactions with the physical world (e.g., Roth & Duit, 1997). In this article, we argue that there are some fundamental processes in the emergence of observational and theoretical language involving manipulations that give rise to gestures, which themselves support the emergence of language. Several examples from a large database are used to make salient the transition from initially muddled talk to forms of language more consistent and viable with students' experience. We argue that these processes are fundamental and therefore transcend culture.

We begin our argument by describing the relationship between language, gestures, and the manipulation of equipment. Subsequently, we provide two detailed examples of language emergence in relation to gestures and manipulations of equipment. In our concluding section, we sketch the tremendous opportunities that lie in asking students to describe and explain phenomena in the presence of materials and equipment.

## Language, Gestures, and Manipulations

The role of gesture and manipulation in the initial emergence of language has long been recognized (Miller, 1981). That is, before children develop their first words they can spontaneously pick up objects and present them to adults. Thereupon, communication skills, through the manipulation of objects, begin to develop long before linguistic competence. Furthermore, as language begins to develop the process of manipulation plays an essential role. Consider, for example, that a child's earliest words typically fall into two major types: names for concrete objects and words used in social interaction. More interesting, however, is the fact that these concrete objects are characteristically things that can easily be manipulated. As Miller (1981) points out:

[C]hildren do not name things, however obvious or important, that just sit there: walls, tables, trees, grass. Children's first concepts develop from sensorimotor interactions, and those concepts are apparent in their first words. Children talk about what they know. (p. 114-115)

In this section, we sketch out our argument about the emergence of scientific language from the initial "(inconclusive) muddle" (Rorty, 1989, p. 6) that can be observed among scientists and students. In the process, hand movements play a crucial role. Initially concerned with manipulating and sensing objects in the world, these movements evolve into symbolic gestures and ultimately, viable descriptive and theoretical language.

## From Muddle to Mature Language

The creation of a new form of cultural life, a new vocabulary, will have its utility explained only retrospectively. (Rorty, 1989, p. 55)

Earlier studies in the history of science conceptualized theory evolution in terms of revolutions, connoting more or less sudden changes in the way phenomena are described in observational and theoretical terms (e.g., Kuhn, 1970). More recent treatments suggest much more subtle changes. For example, Rorty (1989) suggests that during the transition from the Ptolemaic to the Copernican worldview, the talk of scientists, church elders, and others was more like “inconclusive muddle.” (Here, muddle is a positive descriptive term.) Out of this muddle emerged the new, internally consistent Copernican language for talking about celestial phenomena. However, there are neither internal (to language) nor external criteria (nature) that can *explain* this new language; the new language is an emergent phenomenon. In recent years, two studies in particular highlighted the nature of new scientific observational and theoretical language as an emergent phenomenon (Gooding, 1990; Pickering, 1995). Both studies show, in pain-staking detail, how experimentation (as a situated form of learning) involves the manipulation of conceptual and material objects. Through mutual adjustment, processes of resistance and accommodation, conceptual and material objects co-evolve into new mutually constitutive entities. That is, new theoretical and observational languages co-emerge in a process mediated by the material agency of the experimenter. During this process, much of what is talked about is uncertain (does not have a definite status) so that the language is highly ambiguous when viewed from an a posteriori perspective. It is only after the fact, when scientists have come

to a new structure, that they reconstruct their narratives for demonstrative (e.g., publication) and pedagogical purposes (Gooding, 1992).

Quine (1995) sketched a possible trajectory for the emergence of scientific language from the physical stimuli of the body. Beginning with perceptual similarity of salient objects, which are first fixed by sweeping (iconic) or pointing (deictic) gestures in the vicinity or direction of the focal scene, the trajectory concludes in mature scientific language. In the evolution of scientific language, two or more simple observation sentences (e.g., “It’s raining” and “There is a cloud”) come to be correlated into observation categoricals (e.g., “When it’s raining, there is a cloud”). In the transition to more focused observational categoricals (e.g., “Whenever it’s raining there are clouds”) we have the foundation of a theoretical language. (In the Appendix, we provide a brief description of robotics research that synthetically modeled language emergence consistent with Quine, and point readers to two extensive reviews of the neurobiological and neuropsychological literature consistent with our thesis.)

#### From Manipulations to Gestures

Gooding (1990) and Pickering (1995) brought out the central role of human agency, particularly the manipulations of objects and equipment, to the structure of emergent observational and theoretical languages. At the same time, a different feature of communication, gestures, is an observable feature in scientific laboratory communication (Goodwin, 1995; Ochs, Gonzales, & Jacoby, 1996; Woolgar, 1990). Without recourse to deictic (pointing) and iconic (sweeping) gestures, scientists would find it difficult to communicate. Similar work among middle and high school students suggests that gestures are not only an integral part in students’ (proto-) scientific language, but that these gestures actually facilitate the emergence of scientific language (Roth, 1996a, 1996b).

Gestures, therefore, play an important role in scientific laboratory talk. Our review, then, shows that different classes of movements—manipulations (“ergotic movements” [Cadoz, 1994]), sensing (“epistemic movements” [Weissberg, 1999]), and gestures (“symbolic movements” [Roth, 1999c])—are related to scientific language.<sup>1</sup> Yet, we have not found one study concerning the relationship between the three different forms of movements in scientific discourse. But there is evidence from the brain sciences that neuronal assemblies responsible for language make in fact use of neuronal assemblies that previously developed first in response to human movements and later took gestural functions (Bates, in press). With respect to language in general (Goldin-Meadow, Alibali, & Church, 1993) and scientific language more specifically, there is evidence that gestures might perform a transitional function between the ergotic and epistemic movements, on the one hand, and mature scientific language on the other (Roth, 1999a, 1999b, in press).

Ergotic, epistemic, and symbolic movements are important aspects of cognition in all cultures (Cassell, in press). In fact, studies among Australian aborigines and African bushmen tribes documented a deep interdependence of body movement, gesture, language, and other aspects of cognition (Haviland, 1993; Levinson, 1997; Widlok, 1997). Thus, in order to account for the orientation feats accomplished by members of these cultures, gestures, narratives, and bodily action form an irreducible system of cognition. Furthermore, across cultures, the relation between gesture and language is so profound that even blind people will use gestures not only with seeing but also with blind interlocutors (Iverson & Goldin-Meadow, 1998). Our review brings us to an important point, which, if confirmed in further research, has tremendous implications for learning scientific language in culturally diverse classrooms. If gestures arise

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<sup>1</sup> Objects may be manipulated to facilitate perception, recognition, thinking, planning, and so forth. Such

from laboratory manipulations and if gestures have a function in the emergence of scientific language, then there are avenues for developing scientific discourse that transcend linguistic differences due to students' cultural backgrounds. In the following section, we provide two case studies that illustrate the emergence of language from, and supported by, manipulations of objects and subsequent gestures.

### **Case Studies of Language Emergence in Science Classrooms**

The case studies presented in this section derive from an extensive database that includes more than a dozen studies of learning in school science laboratories in four countries (Australia, Canada, Germany, and USA). In each study, 2 to 3 student groups were videotaped over an entire unit lasting from 3 to 16 weeks. The following cases exemplify patterns that hold across the different studies. The first case study comes from a grade 12 physics class in Canada in which 20% of the students came from various Asian countries to get their high school certificates, and the remainder of the students were of various European and Asian descent. The second case study was recorded in a German grade 10 physics class.

#### From Confused Muddle to Theory: In the Mother Tongue

The following episode features three students, Elizabeth, Glen, and Ryan working with a computer-based Newtonian microworld (Interactive Physics™) as part of their grade 12 physics course. They have already observed repeatedly the circular object and the two associated arrows.

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manipulations have also been termed “epistemic” (Kirsh & Maglio, 1994).

Their task is to determine the relationship of the arrows to the motion patterns displayed by the onscreen object.

[[[[[[[[[[Insert figure 1 about here]]]]]]]]]]

Glen proposes a description in which the “big arrow” and time are the same (lines 01-02); Ryan suggests that they should run another experiment in which this big arrow is shorter (line 03). Elizabeth (line 04) and Glen (lines 05-06) propose alternative referents for the two arrows (“time” and “direction”); Ryan attempts a synthesis, but his use of “though” (line 09) indicates potential trouble. Elizabeth tentatively formulates a referent for the “little arrow” (lines 10-11), but Ryan suggests that they do not know that referent. Glen then provides an observational description of the little arrow: “it always stays straight” (line 13). He simultaneously uses his pen in an iconic gesture that makes salient the direction of the arrow that stays straight.

Here, the language is best described by our concept of “muddle.” Students use the same terms (“big arrow” and “little arrow”), but, as it turns out later, the three students did not realize for some time that the referent of “little arrow” and “big arrow” were different. That is, because “big” also connotes long or tall, the adjective was used to denote both the «force» arrow and the «velocity» arrow.<sup>2</sup> In addition, students make reference to different observations by using the same word, “direction,” to index different observations. Thus, the trajectory is initially parallel to «velocity» but toward the end of the trajectory, it is parallel to «force». When Elizabeth talks about the little arrow representing direction (line 04), Glen, though he at first contradicts her, then proposes a label of “velocity” for the “big arrow.” As it turns out, throughout this lesson, the three students employ up to 10 different words to talk about the same object. For example, the

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<sup>2</sup> To avoid confusion in the changing referents and lexical items for the same things, we identify the object in terms of the standard definition within physics discourse. The outline arrow represents force and is identified here as «force» and the single line arrow which represents velocity is denoted by «velocity» in our text.

three students referred to «force» using any item from the set {little arrow, big arrow, time set, time, direction, time & direction, velocity, redirection, gravity, force} before they ultimately settle for “force.” They also used eleven different words to denote «velocity» until they settled for “velocity.” In other groups, we made the same observations (Roth, 1996a). Overall, this episode exemplifies the beginning of students’ communications when they are unfamiliar with a given domain; their language appears brief, incoherent, inconclusive, and (from an observer perspective) continuously changing in topic. Most novice researchers do not know where to begin an analysis of such episodes.

In this simple (micro) world, there are only a few objects. Yet in the conversations of this student group (as well as the other groups in the class), what is being talked about, as well as the words used to denote whatever is being denoted, differ—without the students’ awareness. As a result, many observers of these and similar episodes are taken aback and propose that these students have some cognitive deficit, misconceptions, do not show enough effort, and the like. Such explanations may be viable if it were not for the fact that we recorded structurally similar episodes in studies of physics learning in four different countries, including the best students (valedictorians and the like) in each case. Moreover, just as intriguing is the observation that we find the same type of “muddled” talk in studies of scientists when they work in domains with which they are not very familiar (Roth & Bowen, in press). At the same time, when individuals have considerable time to familiarize themselves with the domain at hand, we find them at some later point talking in coherent ways, with certainty, and consistent discourse about the objects and events in the focal phenomena.

To provide some evidence of such a shift, let us return to the same three students. About two weeks after the previous episode, and about two more hours of interaction with the Newtonian

microworld, the three are working on a task which asked them to hit a rectangle on a post, requiring the circular object to move through the hole in the wall (Figure 2). After having tinkered for a while with «force» and «velocity», the three observe the object moving through the hole as in Figure 2a. Glen then provides a description that mixes observational and theoretical terms in order to plan their next move. Thus, he first identifies «force» as force (line 01) and then likens the situation to a basketball throw where the ball, at the “top of the arc,” appears to “stop in the air.” In order to get a similar effect, he then proposes how to reorient «force» and «velocity» to get the object to move through the desired trajectory to hit the rectangle. He finishes his turn by suggesting how velocity can be changed by clicking the object (lines 05-06).

[[[[[[[[[[Insert figure 2 about here]]]]]]]]]]

Here, we see no more hesitation and the use of signifiers is consistent with standard physics. Glen still uses a considerable number of deictic (pointing) and iconic gestures, which can almost always be observed when the objects of the discussion are present in the situation. (We address the relation between verbal and written language in the next section.) Importantly, because students talked over and about the entities on the screen, they could employ deictic (for pointing) and iconic (for sweeping) gestures. As the video offprint in line 13 (Figure 1) shows, there is an interaction between the gesture (pen) and the image behind it. The utterance “the little arrow always stays straight” and the direction of the pen in fact tell the listeners to look for something that stays straight and its direction. In the present case, there are two arrows that are in approximately the same direction. However, the adverb “always” allows listeners to draw on the previous experiments in which one of the two arrows always remained in the same direction.

In contrasting these two episodes, we see that, beginning with initially almost incomprehensible talk students developed observational and theoretical language for the

phenomenon at hand. How students move from the initial “muddle” (which we use without negative connotations) to mature science talk is a question virtually not addressed in science education. Furthermore, by using the concept of “muddle,” we highlight the tremendous challenges faced by students during learning, when they have to move from where they are to where curriculum designers and teachers want them to go. As such, one of the central questions regarding the development of scientific concepts has to be how students get from muddle to scientific discourse. In the following section, we provide two analyses how language evolves when students engage in laboratory activities.

### From Moving Things to Talking (and Writing) Science

In our long-term studies, we are interested in following students from their initial encounter with new phenomena to the point where they had developed a viable discourse about them. Here, we are concerned with science laboratory activities that require students not only to conduct investigations but also to construct observational and theoretical descriptions. In this section, we use excerpts from one study to exemplify the data obtained in these studies and our more recent theoretical understandings of these data. (Additional development and application of these ideas can be found in Roth, 1999a, 1999b, in press.)

The following episodes exemplify the evolution of observational and theoretical talk as it becomes increasingly independent from the material aspects of the activities. The context for these episodes is a pith ball and rod experiment intended for students to develop observational and theoretical languages of electrostatic induction. (See Appendix B for a description and standard explanation of this typical high school physics investigation.) This evolution can be glossed in the following terms. Students begin their first explanations by reenacting parts (or all) of an investigation which serves as topic of and background to their utterances. In subsequent

attempts, the materials and equipment still function as ground but gestures begin to replace actual objects and events. In the next stage, students frequently employ a different object or gesture only to represent some relevant aspect of the event they talked about, and finally they represented all relevant aspects of objects and events in symbolic (abstract) form.

In the course of their activity, which extends over two 45-minute lessons, Matt and Phil make six clearly distinguishable attempts to construct an explanation. Excerpts from three of these explanations are featured in Figure 3. Initially, students rely almost exclusively on redoing the investigations as part of their attempts to provide a description of the phenomenon and as a context for constructing observational and theoretical descriptions (Figure 3a). At this point, they had repeated the investigation (as described in Appendix B) several times. Next, they decide to write down their observations and explain what they see. However, during this episode, they find themselves stymied and incapable of expressing themselves in writing. Rather than writing, they return to the equipment and Phil begins to build a description as he conducts the investigation again. He begins by discharging the pith ball (Figure 3a.i) uttering “discharging” and then brings a ruler, which he had charged by pulling it between his knees, close to the metal rod uttering “we now hold it here” (Figure 3a.ii). As the pith ball begins to bounce, he points toward the end of the rod while beginning a theoretical description on the basis of electron surplus (Figure 3a.iii). He then introduces a non-word “deficitary” (they use a neologism, “*unterschüßigen*,” that does not exist in German) electrons, which want to go “there” and then moves his left hand parallel to the direction of the pith ball/metal rod axis.

**[[[[[[[[[[Insert figure 3 about here]]]]]]]]]]**

In this episode, Phil repeats the investigation, including metaphorical-iconic gestures that enact the theoretical objects (electrons). The presence of the material and equipment allows a

description, as a naming of objects and actions. (In evolutionary [phylogenetic] and developmental [ontogenetic] terms, this comes prior to language that is independent of the objects.) That is, repeating the investigation so that it is there, in front of everybody's eyes, makes a detailed and explicit description unnecessary. It is a general phenomenon of everyday interaction that what goes without saying remains unexpressed (e.g., Clark, 1996).

Because the associated events are most often too fast (such as the bouncing pith ball in this investigation), students simulate the events by moving the objects through the different stages of the phenomenon. This allows students to describe the observed objects and unfolding (simulated) events in real time allowing for a copresence of expressive means (words, gestures) and the aspects of the world they perceive. This stage of learning is exemplified in Figure 3b. Here, Matt describes the events while his hand re-enacts the same movements that had earlier charged the ruler and brought it close to the metal rod (Figure 3b.i). But now, he no longer charges the object; the apparatus is simply the background against which his gestures are to be seen. His subsequent gesture and talk invoke electrons as the theoretical entities, which, in a metaphorical way, are said to move in parts of the equipment (Figure 3b.ii-iv). His right hand enacts the movement of the electrons in the rod which, because the electrons are presumed to be the charges in the charged ruler, are repelled and move to the opposing end in the metal rod.

In what becomes the next phase of constructing observational and theoretical descriptions, objects other than those involved in the investigation are used in a representational manner. A piece of paper comes to stand for a transparency film; two pens are used to represent two materials; and a third fountain pen with removable cap is used to model the separation of nucleus and electrons (see Roth [1999d] for further details). This was also the case in the work of Phil and Matt (Figure 3c). Phil had picked up a plastic rod, which, as the unfolding presentation

shows, stands for the metal rod in the earlier set up. This rod provides a representational ground against which other parts of the equipment and theoretical entities appear in the form of gestures. This allows listeners to understand Phil, although his talk is highly indexical as he describes the preparation of the phenomenon with the words “you hold the rod here” (Figure 3c.i). This utterance is accompanied by a gesture of the right hand close to the right end (from his perspective) of the plastic rod. From his perspective, this orientation is the same that he had earlier with respect to the apparatus, and the right hand took the same position in which both he and Matt had held the charged object. His right hand then moves toward the left end of the rod while uttering that the theoretical entities (“everything”) is going there (Figure 3c.ii). The subsequent frames (Figure 3c.iii, iv) show his description of how the pith ball (“the little animal”) approaches the end of the rod (“comes here”).

There are a number of typical dimensions for the early stages of communicative competence (cognitive complexity and temporal aspects are discussed in subsequent sections). First, students use equipment and materials, which they describe in observational terms. Second, their conceptual talk is often scientifically inappropriate. Third, in the early stages, students often speak from the point of view of the inanimate entities involved and thereby portray these entities as animate. Fourth, human agents draw heavily on verbal and gestural indexing (linguists refer to this as verbal and gestural “deixis”). In the early phases, the materials and equipment serve as ground and, in some cases, are replaced with arbitrary objects. For example, Matt replaced the original ruler with a pencil (Figure 3b.i), which subsequently served mainly as a pointer. The presence of these materials (or their substitutes) affords students to point to particular aspects without generating the corresponding words to signify them. Matt does not name the iron rod other than in Figure 3b, though he refers to it repeatedly as part of his presentation. Also, he does

not name the pith ball, but only refers to the object as “this” or “it” usually accompanied by pointing (gestural deixis). “Here” is relative to the position of the hand and where he is located as the observer positioning (linguistically, this is described in the term “origo”). The point of view is holistic in the sense that objects and subjects are not separate, but immersed together in a shared world. (Researchers have come to use anthropomorphism for descriptions of the world emerging from this immersion.)

In the subsequent phase, students used some of the materials from their investigations as ground against which they layered their theoretical descriptions. We can conceptualize the deictic and iconic gestures as participating in enacting a Gedanken (“thought”) experiment, but a Gedanken experiment enacted in concrete terms with worldly objects. Whereas students conducted the investigation or moved parts of the equipment literally around as part of describing what happens and constructing a theoretical description in the previous event, students now simply use talk and gestures in one communicative act.

When students become very familiar with the objects, equipment, and phenomena produced with them, their attempts to explain no longer require the presence of the materials. At this point, we see arbitrary objects as signs that stand for some object or entity. For example, in an explanation of how static electricity is produced, one student, Jessica, uses two pens to represent the two materials to be rubbed. A third, fountain pen stands for an atom, which, as part of the rubbing, is separated into a positively charged nucleus and negatively charged electrons. Her iconic gestures enact the separation by pulling the cap off the pen, while her verbal and gestural deixis associate each of the entities with the corresponding macroscopic materials. In a similar way, toward the end of the second lesson spent on the steel rod-pith ball investigation, another

student, Phil, produces an explanation in which he only uses an arbitrary PVC rod to stand for the steel rod.

As students become more familiar with the phenomenon and with talking about it, their language increasingly represents the entire phenomenon.

This is the stand. There is a little ball of elderberry mark, it is neutral, uncharged, and coated with graphite. Here, this one is an iron rod, a conductor. Now we thought about a trick. The task was posed in this way: construct the set up in this way, and then bring a charged plastic ruler close to the end. [Matt, JU6p.15]

Compared to the earlier episode, in this excerpt an increasing number of aspects relevant to the phenomenon are articulated. No longer do the materials only stand for themselves visual available to all (though this is still the case), but they are re-presented in the verbal description. Thus, in the case of the little ball that students had seen bouncing back and forth, its material (elderberry mark), coating, and electrical property are all articulated.

The sequence of episodes illustrates how students become increasingly independent of the actual objects and equipment in the production of their observational and theoretical descriptions. There is an abstraction from the actual phenomenon to the simulated phenomenon with the actual objects, to a simulation where the objects themselves are replaced by other, arbitrary objects (Figure 4). We observed a progression from iconic representations of phenomenal entities to more abstract representations of objects and events. (An analogous progression was observed in the notes, compositions and drawings of grade 4-5 students [Roth, in press].) Thus, these grade 10 students initially represented their investigations and explanations of phenomenon by depicting objects and events and subsequently used increasingly abstract signs to stand for the same entities. Here, the initial stages are exemplified in the depiction of rubbing materials and a little person holding a neon lamp to the charged film (Figure

4a). At later stages, the same phenomenon is represented by single charges (rather than films) and the icon- “hand” combination rather than the entire person (Figure 4b.left). Less graphic still is the subsequent sketch in which ground (“Erde”) and light bulb are depicted by symbols from the electrotechnical domain.

**[[[[[[[[[[Insert Figure 4 about here]]]]]]]]]]**

To summarize, in situations such as these, language emerges by taking on an increasing amount of representational function from other modalities. These other modalities include the world itself, gestures that both pick out objects and enact them, and objects standing in for other objects. Furthermore, although students’ ultimate task is to produce written (observational and theoretical) descriptions, these come only very late (literally at the last minute); gestural, verbal, and pictorial expressive modes precede written language. Simultaneously, we observe a shift from depiction and iconic representation to abstract sign and from descriptive expressive modes to theoretical (explaining) modes.

We assume that what students do in these episodes is, first and foremost, enacting a telling of world through the manipulation of both the material objects and language. In their absorbed activity, they are coping rather than theorizing. When students use gestures, for example, to point at an object, they articulate the world in two ways: (1) they indicate the joints where it is carved into wholes and parts; and (2) they “tell” these wholes and parts. Telling, as gesturing gestates or makes world. In this sense, these students’ gestures allow them to pick out the object in the way small children pick out the chair uttering /chair/ in the presence of the object «chair». In this sense, telling is equivalent to primary human observation sentences or bird calls and monkey cries that occur in the presence of a tiger. This way of regarding telling as primordial is equivalent to the view of the observer in cybernetics: telling is first-order observing (Lock,

1997). Theorizing, on the other hand, is second-order observing, as the subject begins to tell the similarities across observations not only of other observers but also his own; theorizing, as interpreting, requires hypothesis formulation and testing (e.g., Luhmann, 1995). It is, therefore, only after the fact (when they competently discourse in the language of science) that students can evaluate different ways of talking about a phenomenon.

### **Hands-On Activities: “From Stimulus to Science”**

In *From Stimulus to Science*, Quine (1995) outlined how conceptual languages could develop from raw stimuli at the human sensorimotor periphery. The itinerary outlined in this book was largely confirmed in synthetic modeling experiments with robots that had to learn not only language but also the nature of the world they inhabited. (See Appendix A.) Our micro-analytic studies of language development in school science laboratories suggest that similar processes may be in operation. In this section, we briefly discuss first the implications of our work to science education, particularly the role of hands-on activities that afford language development via manipulations and gestures.

In this article, we have suggested that science itself is a culture with its own particular narrative forms, material practices, beliefs, etc. Viewed in this way, learning science is equivalent to other forms of acculturation including participation (from more peripheral to central ways) in the particular practices of this culture. A number of cultural studies of science have documented the trajectories along which graduate students increase their participation in the core practices of science, particularly the representational (linguistic and otherwise) practices (e.g., Roth & Bowen, 1999b, 1999c; Traweek, 1988). One of the central aspects of culture,

however, is language. The relationship between science (as culture) and language was brought into focus particularly through the seminal *Talking Science*:

Learning science means learning to talk science... “Talking science” means observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, writing, lecturing, and teaching in and through the language of science.  
(Lemke, 1990, p. 1)

Here, Lemke suggests language not as a medium that stands between students’ minds but as a constitutive aspect of the activities of observing, describing, comparing, and so on. In addition to language, we made salient the role of manipulations and gestures in the development of scientific language. More specifically, we showed the mediational role gestures take between language and world in a double sense. First, gestures are an important component in the transition from manipulations to language; and second, gestures also ground (connect) verbal utterances to the objects that they are said to be about.

First, “hands-on learning” has been a slogan, but there exists a lack of research to show how conceptual (“abstract”) understandings arise from manipulating things in the physical world. Our own work, from which the present case studies are taken, shows how hands-on learning affords new forms of observational and theoretical talk. The data presented here exemplify how, in the beginning, students’ talk is muddled revealing little resemblance to subsequent ways of describing phenomena in observational and theoretical terms. However, students engage in the world to manipulate and sense objects. These manipulations are associated with object movements that themselves lead to salience of specific features. This salience is a crucial, operative factor in ostensive definition of objects and events (Quine, 1995) regardless of language or culture.

Second, gestures are not only about objects and events but also occur over these entities. Gestures serve to ground (link) particular expressions in particular material aspects (ostensive function). This ostensive function of gesture allows a spreading of communication across different modes of expression. Because of this connective function to language during the latter's initial emergence, it is crucial that students be given the opportunity to engage in attempts to describe and theorize phenomena in the presence of the original materials and equipment. As our examples from the German classroom illustrated, it is through a slow evolutionary process that students develop the competence to talk about the phenomena independently of their presence. In this respect, the patterns in the development of scientific language mimic those characteristic of early language development (Lock, 1997). That is, physical gestures become accompanied by vocal gestures (utterances) that, in the case of high school students, have conventional form through their prior experience. Furthermore, students' verbal and written expressions therefore become increasingly "abstract," that is, independent in their form from the original events that they describe. The transition moves from sensori-motor iconic to symbolic iconic, and from iconic to symbolic forms of signs.

The ostensive function of gestures, which links emerging words and objects in the students' world, is a cultural invariant. Therefore, it provides the basis for new language to emerge, thanks to the shared environment in which students work. That is, through their interactions, and drawing on deictic and iconic gestures, students can come to agreements about just what is perceptually similar. These perceptually similar entities become the basis on which language can emerge. (See also Appendix A.)

We argue—grounded both in studies of language emergence among scientists and students—that writing and other formal ways of representing observational and theoretical

descriptions should follow extensive opportunities for talking (and gesturing) science in the presence of the objects and events. In this, our work is consistent with the claims that individual development (ontogeny) repeats the development of humans as biological and cultural beings (phylogeny) (e.g., Piaget, 1970). Furthermore, our work is consistent with cultural invariants of language emergence, particularly the integration of bodily movements, gestures, language, and other aspects of cognition (Bourdieu, 1997).

As they enact their muddled talk and gestures, students make available to each other those entities that become salient to them, which, in turn, become the topic of their conversations. It is through their interaction that students can become aware of the extent to which their perceptions of the entities are shared. Sharing perceptions and the observational descriptions associated with them is not something that can be taken for granted; rather, there is evidence that students see phenomena in (sometimes radically) different ways (e.g., Roth, McRobbie, Lucas, & Boutonné, 1997). However, out of the interactions, students can come to reliably associate verbal expressions, gestures, and objects and events—which, thereby, make a transition from idiosyncratic personal experience to shared aspects of the world.

Gestures and language are also available to the teacher in the class. As such, she has many opportunities for identifying the entities that are salient to students, and how these are represented in talk. More so, Goldin-Meadows and her associates suggest that mismatches between gestures and talk can be used to make inferences about individuals current understandings (Goldin-Meadows, Wein, & Chang, 1992; Goldin-Meadows, Alibali, & Church, 1993). This research suggests that during transitions, gestures precede verbal means in communicating the new understandings. Thus, teachers who pay attention to and read students' gestures can help facilitate (i.e., scaffold) the emergence of appropriate language because its

precursors do already exist in sensorimotor representations. In this respect, the role of the teacher is of particular importance, for there are no criteria available for selecting one way of talking over another before these ways actually exist (Rorty, 1989). Thus, students (as scientists) have no way of judging the appropriateness of their ways of talking until some later point. Only from the vantage point of a consistently viable language is it possible to point out the problems arising from earlier forms of talk. Teachers, however, already know the observational and theoretical language that students are to learn. Through their interactions with students, and assisted by their reading of gestures, they can scaffold students in their development of new forms of (proto-scientific) language outlined in the curriculum.

We consider the work sketched here only as a beginning, raising many questions about the relationship between hands-on science activities and the emergence of language among students of different cultural origins. Because manipulating things in the world gives rise to salient objects and events, students, even though they may speak different languages, can come to agree on what they see; in this process they are supported by their deictic and iconic gestures. In turn, these gestures provide a base on which common forms of verbally referring to, describing, and explaining can emerge.

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## Appendix A

### Synthetic Models and Neurobiological Studies

Readers might ask themselves what makes us so confident that our model is viable? The most compelling models of language emergence, requiring a minimum of prerequisite knowledge (no inborn grammar, no inborn ontology) were developed in the robotics community (e.g., Steels 1997; Steels & Vogt, in press). Here, robots are equipped with a minimum of motion and communication primitives. They are then let loose in a (simple) environment where they learn, by moving about, to make their world. If they do not do this in a viable way (e.g., not find food by docking into a recharging device), they will die. In this way, each robot makes its own world. When there are two or more robots, observation makes evident that the robots (perceive and) react differently to what we detached human observers might call the same object. However, when these robots are allowed to interact, one can note that some “groups,” despite initial differences in the way they see and denote objects in their world, develop shared ways of seeing and denoting. It can also be observed that those “groups” of robots that develop shared ways of seeing and communicating have greater survival rates than groups that do not develop shared ways.

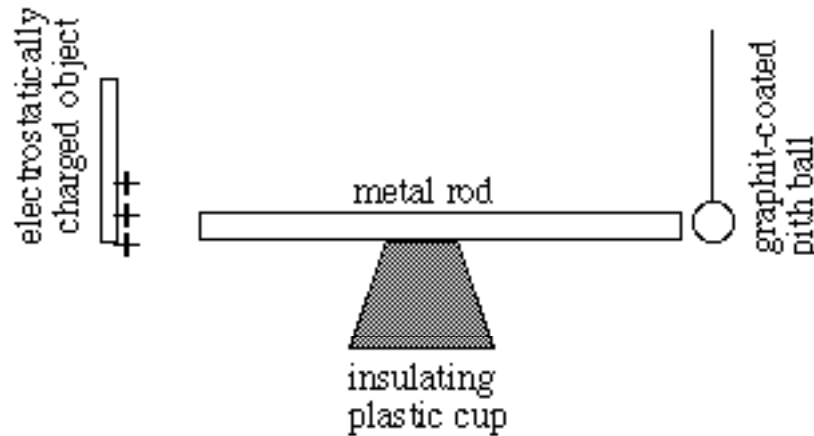
Recent research in various brain sciences is consistent with the view on language development outlined in this article. Two reviews of the neurobiological and neuropsychological literature on language competence and language acquisition note the tight connection between the meaning of content words and individual human activity (Bates, in press; Müller, 1996). Thus, the neuronal assemblies activated with a content word are widely distributed over auditory, motor, somatosensory, and visual cortices. This is, because these modalities are involved in the acquisition of the meaning of given content words.

## Appendix B

### Pith Ball and Metal Rod Investigation

#### Investigation and Observation

In this investigation, students first bring close and then remove a charged object to the metal rod. They can then observe the graphite coated pith ball move toward and touch the metal rod. The pith ball then continues on its own to move to, touch, and bounce back from the metal rod. The bounces decrease until the pith ball returns to the starting position.



#### Scientific Explanation

Scientists explain the phenomenon in the following way: (1) As the charged object is brought to the metal rod it produces a charge separation; (2) A similar process occurs between the metal rod and the pith ball, with opposite charges facing each other. Although the pith ball is neutral over all, it is seen as charged from the direction of the metal rod; (3) Because oppositely charged objects attract each other, the pith ball is attracted to the metal rod where it takes up charges and becomes effectively charged; (4) The removal of the charged object leaves the metal rod charged in one sense and the pith ball in the opposite sense, thereby attracting each other, which leads to

the movement of the pith ball; ( 5) Each time the pith ball touches the rod, some of the earlier “stolen” charges are given back until the electrostatic forces between the two objects are too small to allow the pith ball to touch the metal rod.

### **Captions**

Figure 1. Episode from a lesson in which students attempt to find out the relationship between the two arrows and the circular object by conducting experiments with different arrow sizes and directions.

Figure 2. Episode from a lesson in which one student uses a mature form of school science talk to describe and explain the on-screen events.

Figure 3. Three episodes from a classroom in which students are asked to conduct, then describe and explain the rod and pith ball investigation in order to evolve a language about electrostatics.

Figure 4. The evolution of increasingly abstract forms of representing scientific phenomena also occurs in the written modalities. a. Initially, students use more depictions and iconic representations. b. Later, they increasingly use representational forms that no longer have iconic relations with the objects and events they explain.

01 G: Oh yeah the big arrow 's time, 'K (1.2) the  
02 big arrow' s time.

03 R: OK, we'll make it shorter.

04 E: So then the little arrow is direction. (1.3)

05 G: Yeah the big arrow is direction. No I mean  
06 the big arrow is velocity=

07 E: =It's, time=

08 R: =No, it's

09 time but it also directs, though.

10 E: Yeah and then the little arrow, no the little,

11 isn't the little arrow. (2.1)

12 R: We don't know yet.

13 G: The little arrow always stays straight.

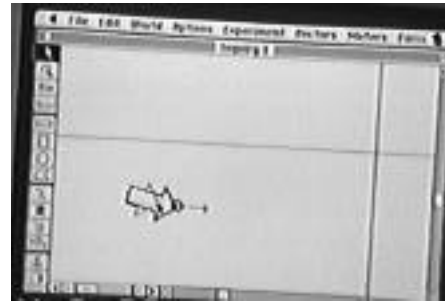
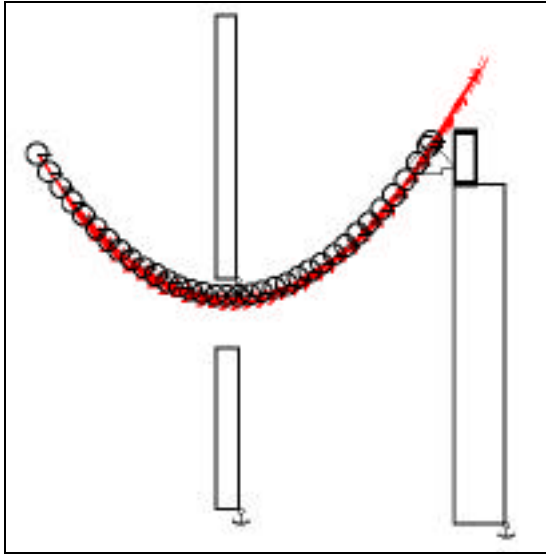
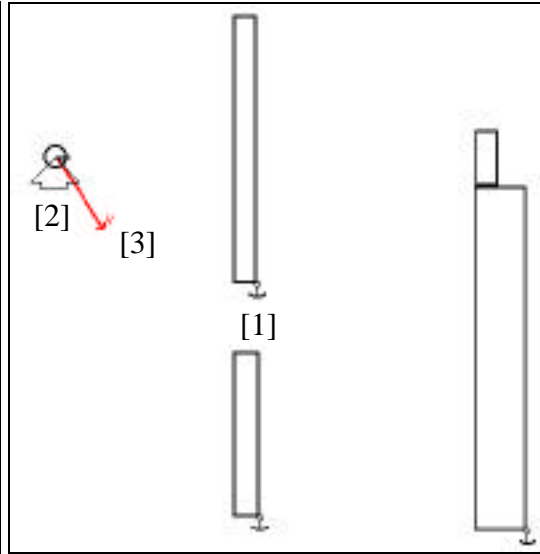


Figure 1

a.



b.



01 **Glen:** See cause you know how your force is going this way [UP], but  
02 once it hits that place [1], it stops in the air. And then you know, a  
03 basketball, once it hits the top of your arc, you want it to go down  
04 right? So you put the tip put the bottom over here [2], then you have to  
05 have this really long over up here [3]. You want the velocity like a lot  
06 longer. Go to... click the circle!

Figure 2

**a.**



**i. So, ↑ discharging**



**ii. We now hold it ↑ here. Then there is an electron**

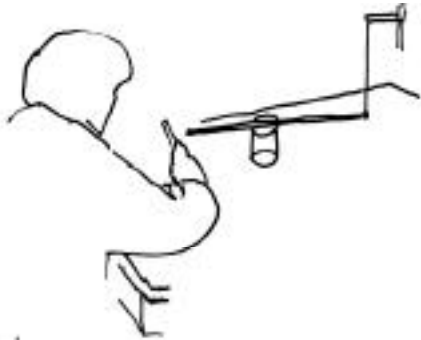


**iii. ↑ surplus. The deficient electrons want to go there**

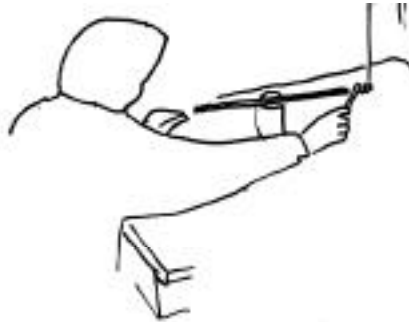


**iv. So ↑ it will be attracted.**

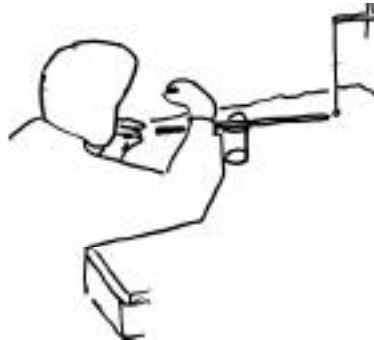
**b.**



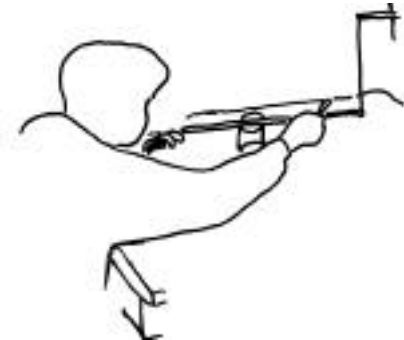
**b.i. ↑ He is holding it to here, all the electrons**



**a.ii. ↑ (0.61) disappear into this part**



**a.iii. because the electrons ↑ repel**



**a.iv. each other ↑**

**c.**



**i. ↑ You hold the rod here therefore**



**ii. ↑ everything is going here let's say, repels**



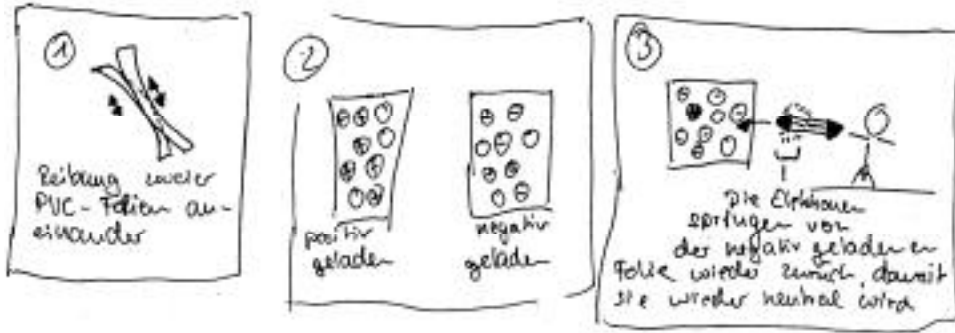
**iii. Now comes the little animal ↑ Comes here**



**iv. ↑ Goes**

Figure 3

a.



b.

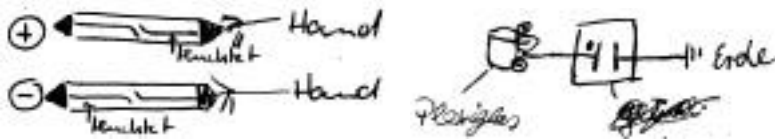


Figure 4