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How does the Body get into the Mind?

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How does the Body get into the Mind?

Abstract

In this article, we propose that gestures play an important role in the connection between sensorimotor experience and language. Gestures may be the link between bodily experience and verbal expression that advocates of 'embodied cognition' have postulated. In a developmental sequence of communicative action, gestures, which are initially similar to action sequences, substantially shorten and represent actions in metonymic form. In another process, action sequences are based on kinesthetic schemata that themselves find their metaphoric expression in language. Again, gestures enact kinesthetic schemata that are correlated with verbal expressions. Examples from a large database are used to illustrate the various processes by means of which language arises when students conduct school science investigations.

> Our consciousness and rationality are tied to our bodily orientations and interactions in and with our environment. Our embodiment is essential to who we are, to what meaning is, and to our ability to draw rational inferences and to be creative. (Johnson, 1987: xxxviii)

The way humans know and learn is central to the pursuits in many disciplines including psychology, neurobiology, sociology, and cognitive science. While researchers in each of these domains focus on different dimensions, many remain either silent about or disregard altogether the role of the body in cognition. In contrast, Johnson (1987) holds bodily experience as central to the way we know, think, and make sense of the world; in particular, there is some evidence that object manipulations lead to symbolizing gestures (Streeck, 1996a). Consequently, cognitive structure is a function of physical human experience in a thoroughly practical world. Working from (although not limiting ourselves to) this theoretical approach, we attempt to address how the practical world impinges on discourse, particularly discourses about 'abstract' objects and theories.

It has been argued that psychology 'has assumed all too eagerly *the split between the mind and the world*' (Ibáñez, 1994: 375, emphasis in the original). And despite efforts to mend the great schism of body and mind (e.g. Johnson 1987; Lakoff & Johnson, 1999; Varela et al., 1993) there has been little work to show how the human body figures in school learning. How does the body get into the mind (if at all), for example, when students begin to learn about and discuss abstract entities such as atoms, electrons or forces (e.g., as part of their school science experiences)?

In this article, we are centrally concerned with the relationship between body and mind. More specifically, we provide a theoretical model and examples for a developmental pathway in which doing and thinking (discoursing) are intimately linked. We suggest that gestures help to link human activity involving objects in the world and language that describes these objects and activities. Our argument is consistent with a strong biologism (Turkheimer, 1998): bodily experience is a central aspect of (psychological) meaning. That is, sensorimotor activation contributes to meaning and sensorimotor experience is a precursor of more abstract forms of representation (gesture, word).

From Cognition without Bodies to Embodied Cognition

During the cognitive revolution in the 1960s to 1980s, knowing and learning were modeled by physical symbol systems (e.g., Anderson, 1985; Simon, 1981), which were independent of the particular 'machine' that implemented them. The cognitive revolution by and large reified the Cartesian split between body and mind, for the latter was modeled independent not only of the body but also independent of the particulars of the computing device. Physical symbol systems could be made to work in a variety of computers that had little in common with biological beings—despite the claim to model intelligence. The result was a set of expert systems, computer tutors, and decision-support systems that were very good at modeling intelligent knowing and learning in highly constrained contexts but that were brittle with respect to the minor variations that occur in everyday practice (Dreyfus, 1992). This shivery nature has been ascribed to the fact that all these systems did not have the kind of *background understanding* of the world that characterizes human beings and other biological organisms (Reeke & Edelman, 1988). Thus, ('artificial') minds void of bodies lacked common sense, which allowed them to behave without having a theory of the world (Dreyfus & Dreyfus, 1988).

During the latter half of the 1980s, two related frameworks for thinking about knowing emerged. The first framework developed out of anthropological studies of everyday activities and came to be known as ‘situated cognition’ (e.g., Lave, 1988). This framework articulated knowing in terms of social and material practices enacted in highly contingent ways to suit the particulars of the moment and setting. Rules and procedures do not ‘cause’ situated actions, as in the traditional cognitivist formulation, but are descriptions of posteriori assessments of whether or not actions followed a general/normal pattern (Suchman, 1987). The second framework, ‘embodied cognition,’ arose largely from philosophical concerns (e.g. Lakoff & Johnson, 1999), though there exists considerable research in the natural sciences to support it (e.g., Decety & Grèzes, 1999; Rizzolatti et al., 1997). Embodied cognition, more so than situated cognition, emphasizes that knowing arises from physical interactions of the organism with its world. That is, bodily experiences are said to lead to sensorimotor schemata that are extended, by metaphor and metonymy, to domains that are not necessarily physical or material (e.g., Lakoff, 1987).

Basic principles of this second approach have been demonstrated in research on artificial intelligence where robots, which construct worlds and negotiate languages to represent these worlds, develop very robust knowledge and behavioral skills (e.g., Brooks & Stein, 1994; Steels, 1997). But how does this happen? Freedman (1977: 100) proposed that ‘[b]odily action evokes kinesic experience which serves to confirm existing schemata, and may even help to ‘bind’ image to word.’ During communication, image and experience are represented in symbolic form. It would therefore not be surprising to observe ‘remnants’ of experience and image during the communication. These remnants do in fact exist in the form of gesticulation observable when people use their hands, arms, and other body parts to render experience in global-synthetic form (McNeill, 1985, 1992). Gestures allow the speaker to re-experience private schemata through kinesthetic experiences (e.g. Ochs et al., 1994). In this way, words are not independent of the experience because ‘the motor act not only buttresses the image, but acts to cement its connection to the symbol, and it is this connecting process which seems to be the central psychological function of this activity’ (Freedman, 1977: 113).

More recently, an increasing number of scholars (e.g., Agre, 1997; Varela et al., 1993) have developed an argument framed early in the century in a variety of domains including biology (e.g., Uexküll, 1972), epistemology (Piaget 1970), and phenomenology (Merleau-Ponty, 1945). Accordingly, both structure and content of cognition arises from our sensorimotor interactions with the world. This body of research has attempted to grapple with the relationship between experiences in the world and abstract concepts. For example, it has been suggested that image schemata are at the basis of human categorization and cognition (e.g., diSessa, 1993; Lakoff, 1987). Following Kant, Johnson (1987) defines image schemata as structures that involve perceptual patterns in our bodily experience thereby connecting concepts with percepts; they have gestalt structure and constitute organized unified wholes in our experience. These image schemata include, for example, ‘containers,’ ‘balance,’ ‘forces’ (including ‘compulsion,’ ‘blockage-friction,’ ‘attraction’), ‘paths,’ ‘links,’ ‘scales,’ ‘cycles,’ and ‘center-periphery.’ Ultimately, such schemata are rooted in and arise from the human experience of having a physical body in a physical world (e.g., Merleau-Ponty, 1945). We find them again not only used in words and sentences (as analyzed by Lakoff [1987] and Johnson [1987]) but, interestingly enough, in the gesticulation that people use during speech. As such, although there is much debate as to the function of certain types of gestures (i.e. iconic gestures), spatial-dynamic features of concepts are a prominent characteristic in models of gesture-speech production (e.g. Hadar & Butterworth, 1997; Krauss & Hadar, 1999; McNeill, 1999).

Based on our extensive analyses of videotapes collected in naturalistic (school) settings, we believe that the study of gestures, their origins and evolution in individual development, provides insights to the role of the body in knowing and learning abstract concepts. There exist interesting relationships between the gestures students enact simultaneously with their talk about investigations that they conducted in school science laboratories. Hand-arm movements initially used for manipulating and sensing objects reappear in symbolic form as gestures as students describe and explain the phenomena they constructed and investigated (Roth, in press-a). There is further evidence from experimental (e.g., Church & Goldin-Meadow, 1986; Goldin-Meadow et al., 1993) and naturalistic studies (Crowder & Newman, 1993; Roth in press-b) that during transitional periods gestures express complex meanings that individuals do not (cannot) yet express in words.

DATA SOURCES

The excerpts presented here derive from a large database of videotapes accumulated over a 10-year period in physics and biology classrooms from Grade 4 through college level and in four countries. In all of these studies, we documented the interdependence of language, context, and cognition (e.g., Roth, 1996a; Roth et al., 1997) but the gestures that students deployed simultaneously with their talk were not salient to us. Only recently did we begin to note that gestures might play important roles in the genesis of scientific understanding (e.g., Roth, 1996b, 1999). Consequently, to understand and theorize the role of gestures in learning from experience, we began to re-analyze data from different classrooms with students at different age levels studying a variety of scientific phenomena. The examples presented here illustrate consistent patterns of gestures within and across these diverse settings.

In all studies, two or three cameras were used to follow as many individual groups during student-centered activities. During whole-class discussions and lectures, two cameras were used to triangulate the speakers to record all utterances with maximum reliability. Details of each episode are described as they are presented. The videotapes were transcribed within hours to a few days on a word by word basis, but without pause length or overlaps. The transcriptions of episodes with apparent theoretical appeal were then enhanced to include those features common to conversational analysis—the enhanced transcriptions included the extent of pauses, overlaps, stresses, and so forth. In addition, representations of the focal situations (e.g., artifacts, drawings, etc.) over and about which conversations took place were included in the transcripts. Here, these representations are video stills from the actual presentation. Because the videotapes were recorded at a rate of either 25 or 30 frames per second, timing of gestures and speech and the coordination between the two modalities is accurate to within one video frame.

EMBODIED COGNITION: EVIDENCE FROM GESTURE STUDIES

When people (teachers and students) explain empirical phenomena that they have investigated some time before, we observe two phenomena. On the one hand, there are (increasingly so) metonymic movements (hand, arm, body) that, in an abstract way, stand for an action (series of actions). On the other hand, and more so when the individuals are less familiar with providing an explanation, there are physical (most often gestural) enactments of sensorimotor (image) schemata prior to the appearance of words in the speech channel.

Ultimately, then, when learners engage in activity or gesturing, they activate kinesthetic schemata, which are *subsequently* associated with words and sentences. Learners' basic level concepts of physics are build up out of the basic level experiences that have led to particular sensorimotor schemata. Their first understandings of atomic and subatomic phenomena are in terms of an object world and the forces characteristic of it. We observe that (under certain conditions) students image schemata *enacted* in manipulations and gestures prior to being *articulated* in words. Furthermore, a non-negligible part of the development occurs through a process of metonymic representation of experience in brief gestures, which subsequently is taken over by linguistic (and diagrammatic) means. Ultimately, this leads two basic observations:

1. Gestures are bodily movements with symbolic function, that is, they are for communicative purposes, but they are often directly associated with prior movements that had sensorimotor purposes. The meaning of words and sentences involve patterns and gestalt structures that derive from physical participation in activity.
2. Communication and shared understanding is not merely a matter of shared words and propositions. Rather, it is a matter of structures of shared bodily experience in and of the world. As they explored and explained a variety of phenomena, students represented core aspects in terms of abridged gestures that stood in a metonymic relation to earlier manipulations and much longer gestures. These abridged gestures came to be used by students and teachers alike in communicating about the phenomena.

When people gesture, they enact sensorimotor schemata that precede or occur simultaneously with the words to which they correspond. Gestures never completely disappear from communication but their frequency and role changes from the early learning experience to the moment when the individual masters a suitable language for describing and explaining some physical phenomenon. This then supports claims that sensorimotor schemata are always present, even in the absence of (suppressed) gestures.

Observations, Gestures, and Discourse

In this section we briefly outline different stages of coordination of initial sensorimotor expression (gestures) and categorical expression in science laboratories where students experience new phenomena and appropriate a language to describe and explain them. Parallel and sometimes cross-cutting this process, we observe the following: (a) actions precede topologically similar (iconic) gestures used to express the former; (b) gestures precede the speech that corresponds to them; and (c) there are initial delays between gesture and corresponding speech that gradually disappear.

All episodes in this section come from a grade 12 physics classroom in which students learned Newtonian concepts by conducting and explaining motion phenomena in a computer modeling environment. Over the course of 4 weeks, students investigated the relationship between the motion of a circular object and two arrows as well as the interaction between the two arrows. At the outset of the activities, students did not know that physicists use these arrows to model the velocity of the object and the force acting upon it.

Coordinating Actions and Instructions

When students are unfamiliar with object and phenomena that they are to learn about, gestures allow them to delineate and disambiguate entities that they want to make salient. Iconic gestures enact sensorimotor schemata. These schemata are associated with the words, propositions, and discourse that are used to describe and explain the phenomena under investigation. Before students develop a suitable language to describe and explain the phenomena in words, gestures, embodying sensorimotor and visual schemata, constitute basic forms of communication.

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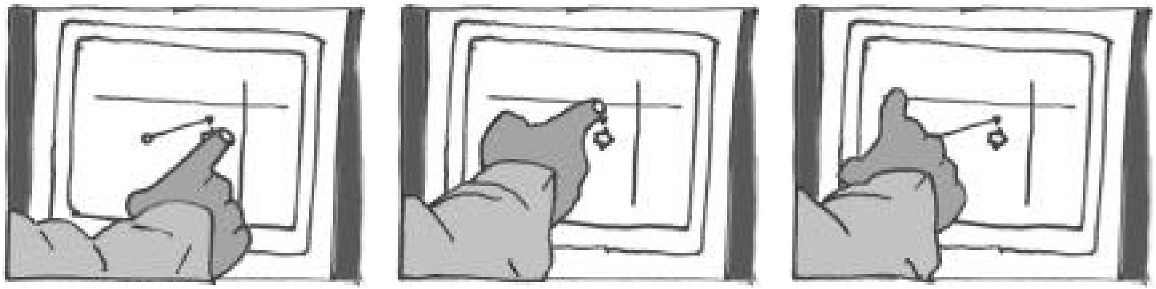

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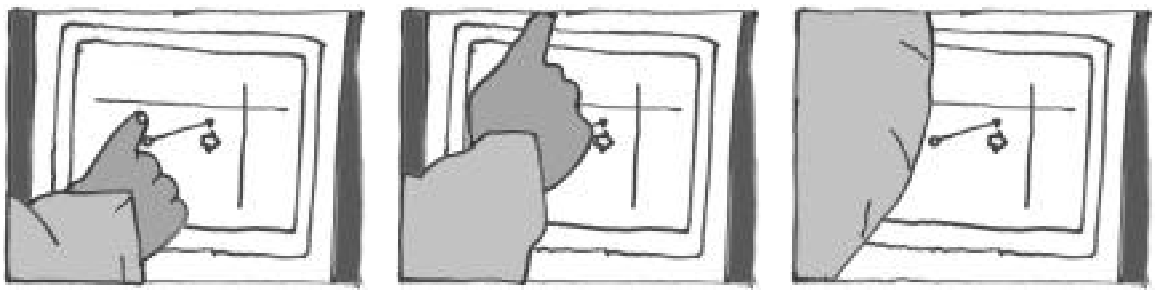

tha upwards.

The first episode (Figure 1) was recorded at the beginning of students' interaction with the microworld during which they came to establish salient objects and events. Mike and Jo are part of a four-person group; Jo manipulates the entities in the microworld and runs the experiments, after receiving input or instructions from the other peers. At this point, Mike wants Jo to conduct an investigation. Here, we can see hand-arm already enact the description of what Mike wants to have done by his peer onto the arrow while the verbal expression appears to have difficulty in forthcoming. Mike wants Jo who operates the mouse to move the arrow in an upward (vertical) direction yet experiences difficulties expressing his instruction in words. He does not articulate which arrow Jo was to manipulate nor does he refer to an arrow in the utterance. But his gestures enact, visible to the other three students, the central sensorimotor schemata relevant to the instruction (Figure 2). His finger points to the tip of one arrow and rotates with the hand into the position where he (apparently) wants it to be. From there, his arm moves up considerably before he actually utters the word 'upward,' which seems to be part of the verb 'put' from which it has become temporally separated.

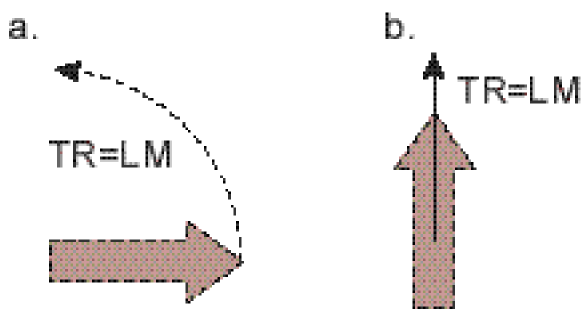

Figure 2. The gesture enacts the instruction in the form of two schemata involving a trajectory (TR) and a location marker (LM) (see Johnson, 1987).

In this situation, the finger enacts an iconic image of the arrow that is to be turned. The finger then moves through the trajectory (TR), which serves as a location marker (LM). With the arrow in the upright position, the student enacts an 'upward' schema in which the trajectory is again a location marker. Notice that the arrow is not articulated in speech (broken lines for arrow). This is an example of what Lakoff (1987: 106) refers to as an instance of an image-schema transformation. In this case ‘up’ or ‘upward’ is a trajectory schema that is transformed to designate long thin objects in a vertical position, that is, parallel to the body axis, which is central to the human experience of walking upright. Here, we see the opposite of a metonymy at work: the action is the elaborated version that is re-presented in the arrow that functions as a metonymy.

Johnson (1987: 43) suggested that the path of motion (TR) is associated and ‘tied up with the vector quality of forceful movement.’ The student’s gesture therefore is not only an indication of ‘up’ but also embodies the implied force that would cause the object to move upward in the situation under consideration. The gesture is a kinesthetic model of ‘up’ that runs parallel to and is connected with the utterance (Streeck, 1996b); the gesture has a non-negligible contribution to the meaning of ‘up.’ We show below that such sensorimotor enactments become abbreviated such that, for example, the trajectory in Figure 2b becomes represented by means of a pointing finger. As such, a part of the original gesture comes to stand for the whole.

Simple Observation Sentences

In the course of their investigations, students begin to describe objects and events in terms of simple observation sentences that later become connected to observation categoricals involving two or more simple observation sentences connected in a correlative or causal manner. As during the exploration phase, gestures are central and, generally, initially appear prior to language; soon afterwards, however, gestures begin coincide with their lexical affiliates (e.g., Roth, in press-b).

Immediately prior to the episode, the three students (Elizabeth, Glen, and Ryan) sitting around the computer conducted an investigation in which the outline arrow was detached from the circular object. When they ran the experiment, the object moved in a straight line and the thin arrow [velocity] did not change in length or direction. However, students did not (were not ready to) articulate this as an observation. Rather, the first instantiation of an observation occurred in the form of a gesture and therefore, in the form of a sensorimotor enactment.

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In this episode (Figure 3), Glen attempts to describe what he had just observed. He articulates the object ('The arrow') and describes it in terms of a generalized action ('just goes'). The utterance is accompanied by a gesture. In the course of the 5 frames displayed (Figure 3), we see his arm moving from a position in front of his body high above his shoulder and toward the camera standing behind him. We also see that the utterance is delayed as the verb and its qualifier ('just goes') are uttered only after the arm is already through its trajectory. This trajectory constitutes an enactment of the process (motion) schema (source-path-goal) in which something moves along a path (trajectory) from a beginning point toward a specific or unspecified endpoint (Figure 4). The arm enacts the path schema considerably prior to the utterance 'just goes.' More so, the gesture enacts a straight-line motion, which is not apparent in his verbal description. 'Just goes' could mean that it goes without a force or that it moves straight. In any event, this 'just goes' stands in contrast to other previous observations where the object, when the second arrow is attached to it, moves on non-linear trajectories unless [velocity] and [force] are aligned.

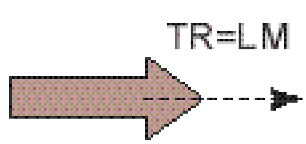
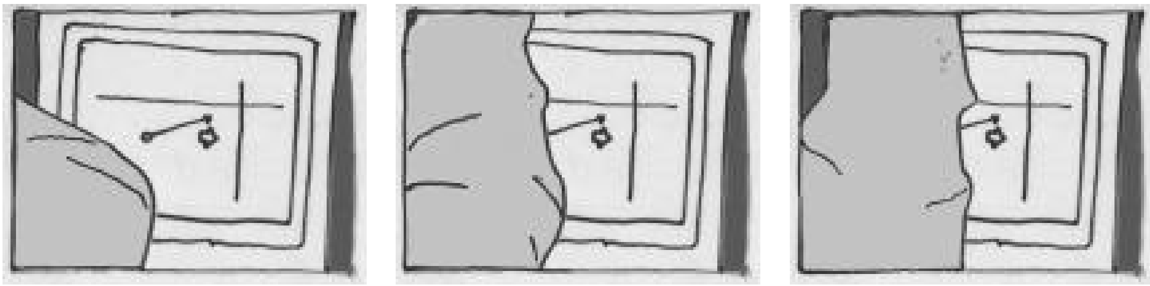
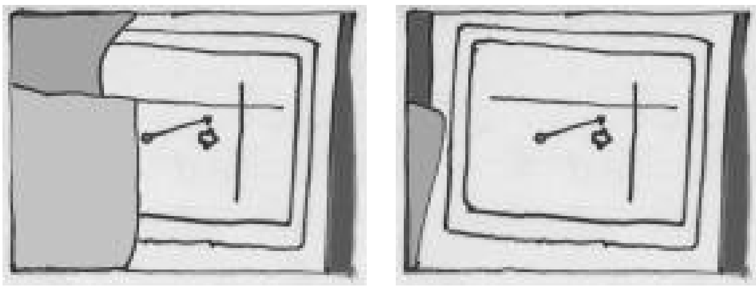


Figure 4. 'The arrow just goes.' The gesture enacts the sensorimotor schema for displacement.



G: The, the arrow just



G: Go:::es

In contrast to the first example (Figure 1), Glen verbally names the object (arrow). We reported previously that such naming succeeded earlier periods where objects remained unnamed or were simply pointed to without an accompanying utterance (Roth & Lawless, 2000).

Observation Categoricals

Once students have more experience in a topical area and have isolated and are familiar with objects and events, they begin to describe and explain phenomena in terms of observation categoricals. Observation categoricals consist of statements in which two or more observations are linked in causal or correlational fashion (Quine, 1995). Our analyses of diverse databases show that observational categoricals find their first expression in gestures (Roth & Lawless, 2000). We now understand these gestures as sequences of schemata articulated in sensorimotor terms. The different gestures are enacted together (often expressing covariation) or in sequence (often expressing cause-effect relations). For example, two hands can be used to embody two entities, one causally affecting the other.

In the present episode (Figure 5), Mike expresses the causal relationship between energy transfer and motion in two gestures that follow each other; the first event (energy transfer) causes the second event (motion) to occur. The (mixed) gesture does more than just accompany the story. The deictic components of the gestures place specific entities as objects [bodies] in particular places. In this sense, these components are central to the story, for they serve to locate the principal players, but without describing these locations in so many words. The iconic components of the gesture enact particular events, again without the need to describe these events, for they are visible to the interlocutors.

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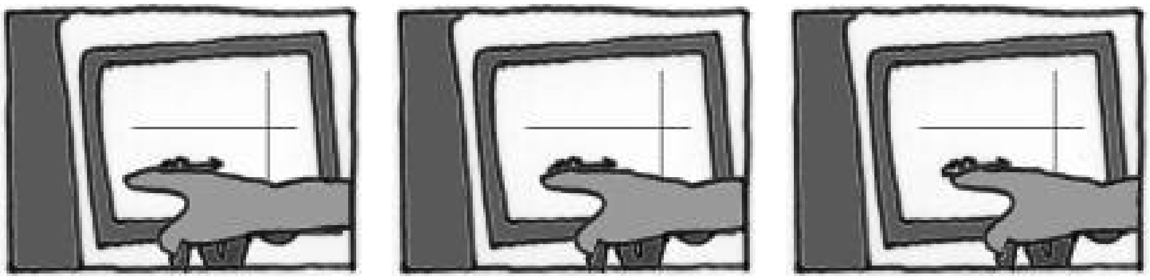
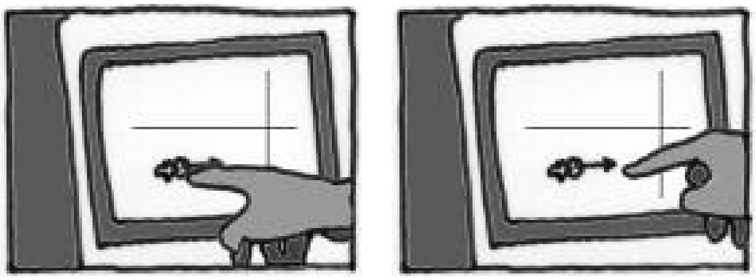


Kinetic energy is transferred from here to the ball



So the ball moves forward

At one instance, then, the finger stands for the energy that is transferred from one location to another; the gesture is based on the source-path-target schema, projected onto the notion of kinetic energy. Physicists would object with Mike's characterization, as they do not think in terms of kinetic energy as an object. In the second instance, the finger enacts a trajectory along which the circular object (ball) is said to be moving. If we think of the finger as signifying the object, we have a physically embodied metaphor of the source-path-target schema. Both verbs 'transfer' and 'move' evoke change, one in which some entity is moved from one (here unspecified) container to another (ball), the second in which an object moves along a trajectory with an unspecified end. In the first instance, the finger takes the place of kinetic energy—here in a 'thingified' version; in the second instance, the finger stands for the ball that is being moved. In both instances, the finger (and arm) actually enacts some trajectory, here the one that is supposed to be seen once the experiment is run.

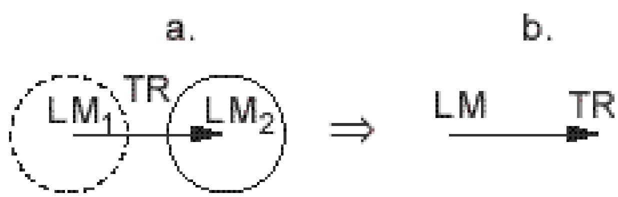


Figure 6. 'Kinetic energy is transferred from here to the ball. So the ball moves forward.' Object and conduit metaphor depict an entity (kinetic energy) that does not exist as such in the physicists' world.

Mike's communication embodied in gesture and talk can be expressed in terms of two schemata, the first implying the second (Figure 6). (For the use of such diagrams see Johnson [1987] and Lakoff [1987].) In the first, energy is moved from an unspecified place 'here' into a specific target landmark (LM), the ball. Movement occurs with respect to the landmark and along the trajectory (TR) while the trajectory and the landmark stand in a figure ground relation (Johnson, 1987: 33). In the second instance, the ball moves from an unspecified landmark toward an unspecified goal along the trajectory TR.

Kinetic energy is not some physical body, and physicists are not clear about why, for example, moving objects exchange kinetic and potential energy nor have any notion of where the kinetic energy goes (Gregory, 1990). Kinetic energy is simply a way of keeping account of a system without drawing on the concept of forces. However, schemata and their metaphoric applications allow the talk about entities that have no physical equivalent to be turned into talk about objects, which can be located in space, followed in terms of the changes and trajectories that they describe. In this sense, these objects are in a narrative space—largely identified with the inscription or material set up at hand—within which they are said to move.

Actions, Gestures, and Discourse

In the previous section students observed events in a computer-based microworld where the objects and events are only perceptually available and do not constitute novel sensorimotor experience. In this section we show that when students interact with the physical world to produce phenomena, they produce new sensorimotor schemata that come to be expressed in gestures, which are subsequently transformed into increasingly abridged gestures. Some of these abridged gestures (standing for the original [longer] gestures in a metonymic way) come to be used by the members of the group and therefore constitute a shared form of communication that arose from a shared physical experience.

The examples in this section are taken from a four-month investigation of learning about electricity through student investigation. The students were enrolled in a grade 10 physics course taught at a German university-preparatory school (Gymnasium). As part of this study, the students investigated phenomena in electrostatics by conducting their own and teacher-designed investigations, discussing their findings, and listening to occasional brief lectures on the topic. During student investigations there was an emphasis on the construction of descriptions and explanations for the phenomena in the presence of the materials that they had used for their inquiries. In this context we recorded students' repeated efforts to construct and negotiate just what they had seen including how to describe it.

Action Schemata and Metonymy

As students interact repeatedly to construct observations and explanations, extended gestures become shortened so that in the end often a simple hand position is understood to represent a complex action or phenomenon. That is, the hand position stands for an extended action in a metonymic way.

In this example (Figure 7), Jessica explains contact electricity, that is, the generation of electrostatic charges in materials that come into close contact. She begins her explanation with the statement 'The, the atoms are at first…'; at the same time she begins to slide the two hands one past the other. Next, one hand sweeps away in an arc toward the left while Jessica utters 'they push something away.' Coming to help, another student, Caren, says at the same time and in a drawn out fashion 'the electrons.' Jessica restarts and, while her hand turns outward and away from her, she explains that 'the electrons are given away.' In the final segment of the episode, Jessica suggests that 'they complement each other again, respectively' while her hands form into U-shapes and slip into each other.

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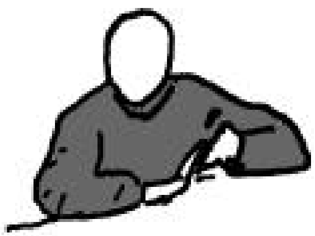
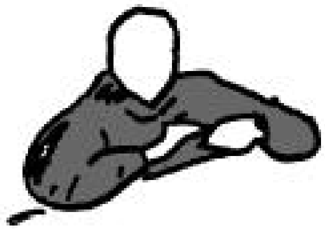
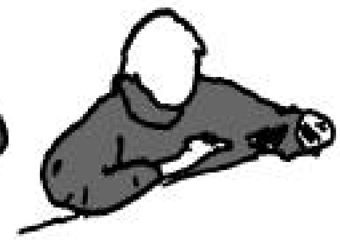
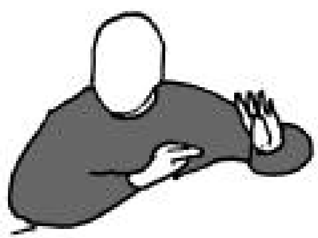
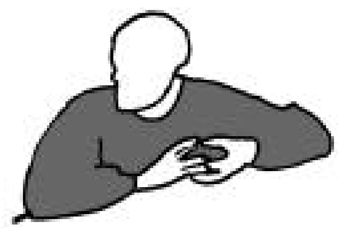
In this brief episode, Jessica enacts gestures that depict the two major aspects of communication in novel domains: metonymy and metaphor. First, the other people present in the situation recognize the two hands, which slide past each other, as a metonymic abstraction of a more extended (complex) process by means of which transparency films are charged. During earlier moments, students not only used gestures and actual transparency films to gesture the

J:   

J: The, the atoms are first, there hm [they push something away]
[*rubs hands*] [*hand moves out, pushingly*]

C: [the elec::::tro::::::::::]:::ns=

J:  

J: the electrons are given away and afterward they complement each other again, respectively
[*turns palm out* [*hands move together to form a whole*

process of charging but they also re-enacted the entire process in order to show the audience the effect a charged material has on some other test object (lamp, styrofoam piece). A quick sliding of the two hands past each other is sufficient to be an index for the friction created by the rubbing of the original transparency films (one of which may be replaced by various other materials). In the sliding of the two hands, Jessica can feel the friction (resistant force) (Figure 8a). As such, her gestures not only enact a motor schema but also are associated with a sensori experience. This may actually underlie a notion that it is the process of ‘rubbing’ that gets the electrons removed rather than the mere contact (which can be observed, for example, when some cling wrap film is removed from the substrate it had adhered to).

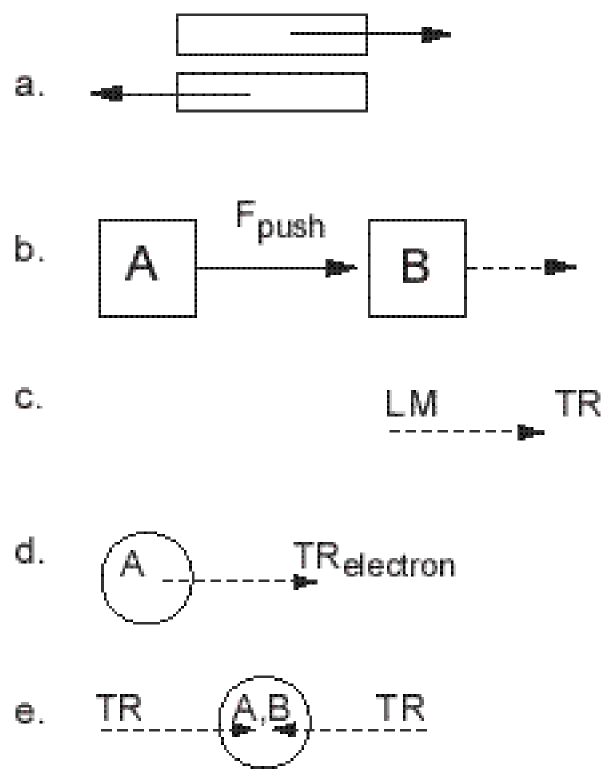


Figure 8. Jessica gesturally enacts different schemata as she attempts to explain how objects are electrically charged when brought into close contact.

Subsequently, Jessica gesturally enacts three schemata that have an origin in bodily experience and that, as Johnson (1987) argues, are central to our understanding of many aspects of language (via metaphoric extension). One of the fundamental experiential schemata is that of force, which itself has a number of subcategories including attraction, restraint or friction, repulsion, counter-force, and compulsion.

At first, as the hand moves out and away from her, Jessica talks about atoms that push something away. Her left arm-hand configuration enact this pushing (Figure 8b), which here looks like something we might do when we push something or someone out of the way (Figure 8c). Just after Caren provided her with another term, ‘electrons,’ Jessica added that these are given away while her hand rotates outward and away from her. Again, her hand enacts ‘giving away’ which implies both the part-whole (mass-count) and near-far schemata (splitting) (Figure 8d). The atoms (whole) give away (electrons) so that something that was an indistinguishable whole is separated (split) into countable parts. What remains, the rump of the atom therefore lacks something, the part (electrons) that had been given away. ‘Giving away’ also evokes the near-far schema and the associated ‘being together’/’being one’ (e.g., as one mass) and ‘being separate’ (countable pieces).

In the final part of the episode, Jessica suggests that the parts that had been achieved through splitting complement each other again. Her hands enact a merging schema (Figure 8e), as the interior of the U-shaped configuration move into each other. Prior to this, we recorded Jessica make the following observation: if two transparency films are rubbed and separated, they will be drawn toward each other when brought sufficiently close together. Although her words do not suggest this experience, her hands in fact enact the recombination that occurs between ‘electron-poor’ and ‘electron-rich’ transparencies.

The different schemata in operation are depicted in Figure 8. In the first instance some object A exerts a force and thereby pushes another object B that begins to move (Figure 8b). This second part can be represented in terms of its own schema in which some object moves out from its original location to some unspecified location. In the second instance, Jessica enacts the schema of giving away, a substance that moves out of a container without a specific target (Figure 8d). Finally, the two parts come back together and complement each other to form a coherent whole.

Shared Action Schemata and Metonymies

When asked to articulate what they had observed, students initially repeat their investigation. Thus, when asked to describe and explain their observations of approaching charged objects or bringing a charged object close to an electroscope, students actually take some object and charge it. During subsequent explanations a decreasing number of aspects of the original investigation is replaced by an increasing number of representations in gesture and utterance. With each reiteration gestures take on more typological character and become emblematic. Thus, a transparency film that was initially rubbed (i.e., charged) is subsequently used as if it had been charged (but without prior rubbing). Still later, either a sheet of paper or simply a hand came to stand not just for the transparency but for a charged transparency, implying a completed process of charging. The simplified gestures (such as the hand standing for film) came to be widely used first within small groups and, sometimes, across the entire classroom.

In the present episode (Figure 9) the teacher Manuela attempts to scaffold students' efforts to build an explanation for the phenomenon of charging an electroscope by means of electrostatic induction. The description and explanation constructed from the viewpoint of a physicist go as follows. A charged object is brought close to the top of the uncharged electroscope (needle vertical) with the result that the needle is deflected. This is explained as resulting from a separation of charges—one type of which is closer to the object (top) the other type closer to the bottom. By touching the center of the electroscope on its bottom part, it is discharged (needle moves into vertical position). But when the charged object is then removed, the needle deflects again—as a result of the charges that had accumulated at the top of the instrument and that now redistribute themselves through the entire device.

]]]]]]]]] Insert Figure 9 about here [[[[[[[[[

In the episode the teacher takes a turn just after one of the students had taken a charged transparency film and held it above the electroscope and, as he came to the end of his turn, withdrew his hand and film. The teacher brings the palm of her left hand above the instrument while uttering ‘then it has here’ followed by a long pause. She does not use a rubbing movement, but simply holds her hand above the instrument in a way (flat palm down) to provide a visual image of a flat object—the transparency film. The hand becomes a metonymic abstraction for the process of rubbing transparency films against each other and then holding one of them above the electroscope. Nevertheless, despite this abstraction, everyone in the classroom understands this gesture. This would suggest a transition from iconic to emblematic gesture, that is, a transition from a unique and isolated signifier into a culturally understood sign.

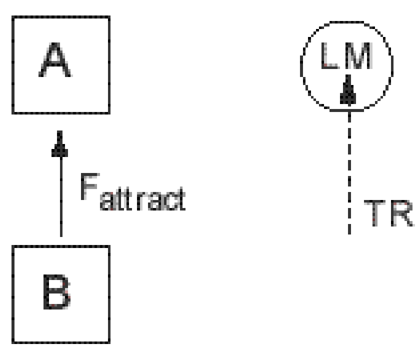
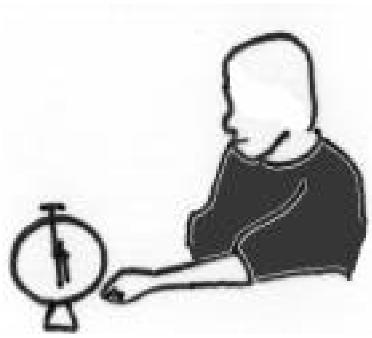
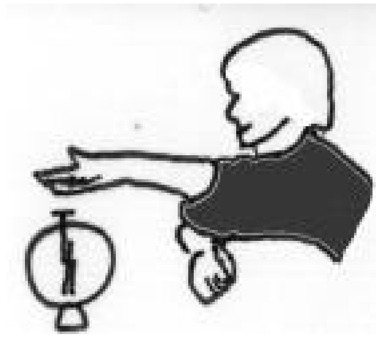
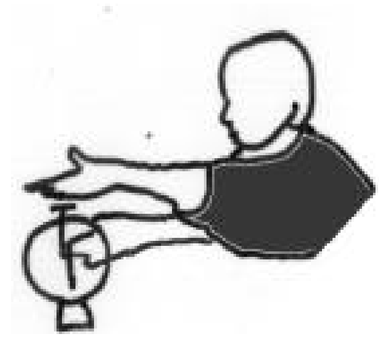


Figure 10. Force ($F_{attract}$) and conduit schemata are metaphorically applied to the subatomic world.

In the second part of the episode, the teacher enacts an attraction schema (Figure 10a). Initially, her right hand moves forward until it was below the left hand. The hand then moves up







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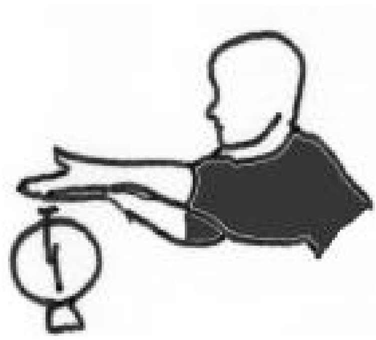

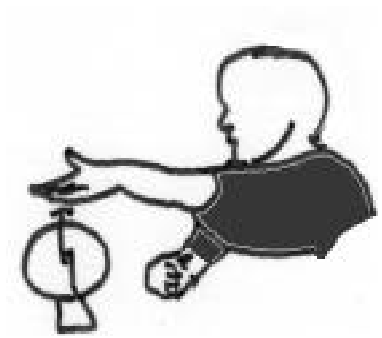

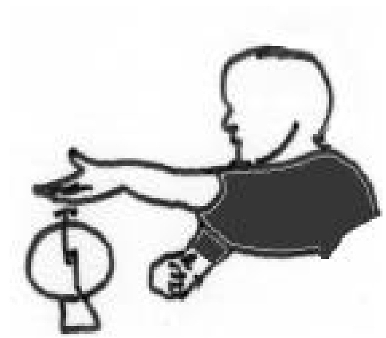

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|die Elektronen ‘rangezogen

|attracted the electrons

and along the trajectory TR, while turning, until the right-hand palm almost touches the left palm ('it'). The right hand then moves back and comes to rest on the table. Finally, Manuela completes the sentence 'attracted the electrons.' In essence she says that when the film is above the electroscope ('here') it attracts the electrons inside to the top plate. 'It attracted' is enacted considerably before (800 milliseconds) the teacher actually begins to provide the theoretical description in words. Of course, the 'attraction' is one of the fundamental experiential schemata that are, by means of metaphoric transposition, used in a great variety of situations.

GESTURES REVISITED

In the preceding section we provide examples of gesture deployment in two physics classrooms where students (a) manipulate macroscopic objects and talk about events in a (computer-based) microworld and (b) manipulate and describe objects from the world of everyday experience but explain the associated events in terms of microscopic entities. In the examples from both contexts we show how students enact sensorimotor schemata while attempting to construct descriptions and explanations of phenomena. In the gestural action visual and, sensorimotor images are confirmed and images become correlated and connected to words. That is, the continuity of verbal representation and world is ensured through gestural activity.

Phylogenetic Model of Language Emergence

A number of researchers have advanced models for the historical development of language (e.g., Bates, in press; Donald, 1999; Ingold, 1993). In these models, gestures and language have not just developed as a result of neuronal additions but have made use of previously existing parts of the brain. Thus, the ability to employ gestures makes use of abilities that developed as sensorimotor abilities in response to evolutionary pressures. In hominid evolution, gesticulation was made possible in part by already existing abilities for moving body parts and was enhanced by the addition of neuronal assemblies that refined the expressive capabilities necessitated by communicative demands (Figure 11). Finally, language emerged on top of the previously existing sensorimotor and gesticulation abilities.

Already existing neuronal assemblies provided a starting point for the evolution of language; that is, previous capabilities were refined by the addition of neuronal groups (Gibson, 1993). Consequently, 'rather than being a 'fifth wheel,' perhaps gestures are the remains of the 'unicycle' on which language first evolved' (Corballis, 1999: 144).

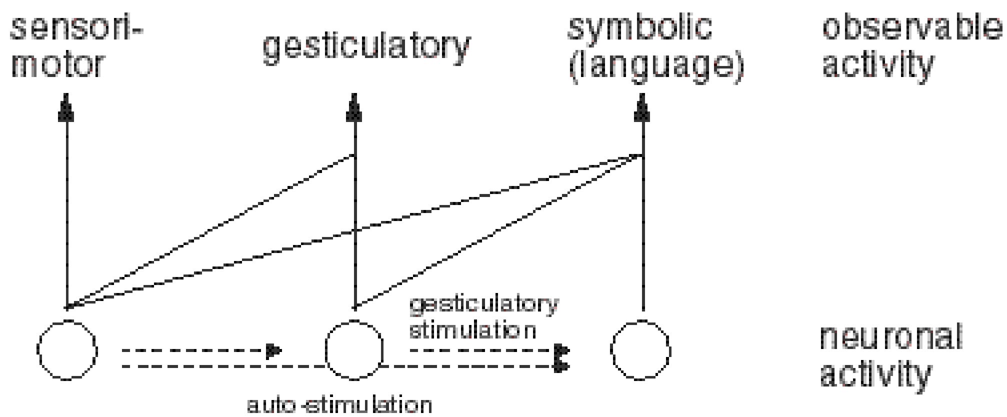

Figure 11. Model of relationship between actions, gestures, and talk. On a phylogenetic level, the capacities develop from left to right.

Neuroscientific research has shown that brains develop differently when physical access to the world is restricted and the organism is left with only visual access (Churchland & Sejnowski, 1992). More poignantly, single neuron studies with monkeys demonstrate that activation of F5 neurons (rostral part of monkey inferior area 6) evoked by object presentation 'better correlated with the way in which objects had to be grasped than with object pictorial aspects' (Rizzolatti et al., 1997: 190-1). In humans, Broca's area is responsible for linguistic tasks; however, it is also responsible for controlling hand-arm movements and muscles that participate in the production of speech. Broca's area and the F5 region in monkeys exhibit many similarities. Thus, when humans understand words they not only hear words that are subsequently processed in dedicated language centers but also enact sensorimotor and gesticulation neurons, which contributes to the human experience of understanding. From this, it should not be surprising that some researchers (e.g., Rizzolatti & Arbib 1998) propose a strong link between speech and action representations. On the basis of our observations of changing gesture-speech relations, during the development of new theoretical language about a domain we would expect a changing emphasis from the gesticulation to the speech modality (Figure 11). Such a change is plausible given the results of recent neural imaging studies of human adults that have shown marked changes in the configuration of highly active areas across a 20-minute period as the subject attains expertise in a new task (Petersen, van Mier, Fiez, & Raichle, 1998).

The model in Figure 11 is consistent with the observations of the development of gestures and language in school science laboratories described above. Accordingly, gestures first arise from earlier sensorimotor actions and observation. These gestures precede language at a macro level and are increasingly correlated with appropriate words as initial delays decrease until words and gestures are simultaneously produced. At this point, the students arrive at the stage described in the model by McNeill (1992): Gestures and speech appear to have a common underlying semantic origin. However, this model does not explain the observation that gestures appear prior associated language (e.g., Goldin-Meadow et al., 1993; Roth, in press-b). In our model, gestures and speech, because they also require activation from earlier stages, appear later in the development of language about new topics than manipulations. This model also accounts for the observations explained by the two dominant but competing models of gesture-speech relations. Thus, gestures (e.g., Beattie & Coughlan, 1998) and even simple body-focused hand-arm movements without semantic content (e.g., Freedman, 1977) occur in pauses of speech that are attributed to word search related delays in speech production because of a slow build-up of activation in the searched-for word. Here, by ‘raising the overall activation in the system through the production of a motor movement, the word will reach a firing level more quickly’ (Butterworth & Hadar, 1989: 173). Butterworth and Hadar also suggested that the gesture might actually contribute to word finding by exploiting a different route to the phonological lexicon.

Implicit in our model is the human capacity for mimesis, that is, for producing and recognizing motor actions based on perceptual resemblance (Donald, 1999; Rizzolatti & Arbib, 1998). In our databases of learning scientific language in school science laboratories, we see time and again that students and teacher come to use highly similar gestures that themselves have arisen from prior experiences in the same setting. That is, we see nonverbal aspects of communication emerge and eventually become shared at the classroom level. Although we provide some initial data supporting the notion of gestures as a shared way of communicating, further research should be conducted to investigate the prevalence of this phenomenon.

Gestures, Observation, and the Construction of New Concepts

What might be the role of gestures in observation of novel phenomena and in the learning of new concepts? Theorists of language origins often focus on the referential function of language—the most basic function of language on which other more sophisticated functions of language are dependent (Allen & Saidel, 1998; Steels, 1997)—as well as the role of joint reference in language acquisition (Bates et al., in press). In order to achieve a mapping between vocalizations and entities or processes in the world, non-verbal deictic reference is first achieved through deictic (pointing) or iconic gesture (Quine, 1995). Unless communicative forms are highly developed and conventionalized, pointing (deictic reference) alone does not assure that two individuals attend to the same thing at the same time. Hand-arm movements, on the other hand, may play a particularly important role because motion against a static background is more easily discriminated than a static object—which is the result of perceptual filling-in of invariant surfaces that stops at boundaries given by relative motion (e.g., Pessoa et al., 1998; Petitot, 1999; Smith & Casati, 1994). Reference emerges from the presumed similarity relation between the movement and whatever is in the ground such as the outline of an object, a moving entity, or a process (e.g., Roth & Lawless, 2000).

Given that learners (students [Roth et al., 1997] and scientists [Roth & Bowen, in press]) often do not know what the relevant structures are for understanding phenomena and complex representations, it is not surprising that we observe a high incidence of moving (iconic) rather than static gestures. For example, the gestures in Figure 1 (and their associate image schemata in Figure 2), if they are understood as bearing an iconic relationship with the entities in the ground (objects in the microworld), make salient an entity that can be rotated and pointed upward. Together with the 'pointer configuration' of the hand (Eco, 1984), this gesture clearly identifies the velocity vector as the object to be handled by the fellow student. Furthermore, the stop and go gestures in connection with the talk about energy transfer and object movement (Figure 5, 6) clearly identify trajectories and their beginning and end.

Understanding Physical Concepts: The Role of Object Schemata

Basic level schemata or phenomenological primitives have been shown to underlie students' intuitive understanding of the world and therefore the way they approach physics (e.g., diSessa, 1993). According to diSessa, phenomenological primitives (p-prims) 'often originate in nearly superficial interpretations of experienced reality' (diSessa, 1993: 112). These p-prims are primitive in the sense that they (a) are generally self-explanatory and frequently go without explanation and (b) are basic elements of cognitive functioning.

Learning from physical experience appears to lead almost certainly to an understanding of the world in terms of object (and associated container) schema. In this study, we provided examples of how the microscopic world (charges, electrons) is being constituted in terms of entities that have macroscopic properties, along experiential dimensions. Kinesthetic experiences and the gestures that arise from them reify midlevel objects. The microscopic world and the entities that populate it are constituted in a narrative space, which in the presence of materials, is iconically represented by the structures of macroscopic objects, tools, and materials present. The 'object' schema is applied to the invisible world said to underlie the world available to students' senses. These objects can then be located in the space constructed in the narrative, for example, electrons in the electroscope. They are mobile, respond to (repulsive, attractive) forces, and move along paths (identified in terms of macroscopic properties). The beginning and endpoints of the object trajectories can be pointed to. A closed hand signifies the object nature, a pointing finger signals the direction of the path. They are enacted in a gesture that is said to represent the electron trajectory in an iconic manner.

When physical entities are no longer understood in terms of the object and container schemata, we can expect learning problems to arise. In his exhaustive analysis, diSessa (1993) provided many examples of the (inappropriate) ways in which untutored people employ experiential force schemata (force as mover, resistance) where physicists use abstract and immaterial notions of force. Consequently, it is no surprise that the extensions of everyday schemata are often inappropriate and inconsistent across different physics phenomena ('knowledge in pieces'). That is, while physicists also use basic level schemata, they are well aware of their limitations and only deploy them in ways that are consistent across a variety of contexts (diSessa, 1993; Lakoff, 1987).

Whereas we agree with diSessa about the fundamental nature of phenomenological primitives we differ from him in at least two respects. First, rather than arising from *interpretation* we think of schemata as arising from non-thematic sensorimotor experience, which subsequently find metaphorical and metonymic extensions in a variety of contexts. Phenomenological primitives, in our reading, do not arise from *interpretation* of experience but directly arise from the structure of our physical experience in a physical world. Consistent with the framework developed by Lakoff and Johnson (1999) we hold that concepts are not merely understood intellectually but that they are associated with our everyday functioning in a material world. That is, our primary cognitive work is neither construction of representations nor representation of constructions but the construction of a world in which we can survive (e.g., Gibson, 1986; Ibáñez, 1994; Smith & Casati, 1994). Second, we consider phenomenological primitives not as something superficial but as fundamental patterns of human experience in the world. Common-sense understandings associated with and connected to sensorimotor schemata are robust because they are grounded in taking human experience prima facie. Of course, diSessa (1993) has no place for non-thematically embodied schema, for he attempted to develop a computational theory of common sense, which inherently requires entities that can be formalized and represented in symbolic form.

CONCLUSION

‘So how does the body get into the mind? ‘ Or would it be more appropriate to turn the question around and ask, ‘How does mind get into the body?’ Our earlier discussion and examples suggest two processes by means of which bodily experience (e.g., manipulations) come to be connected to verbal expression. On the one hand, there is a shift in which gestures, isomorphic to sensorimotor activity, are shortened to stand for the activity through a metonymic relation. In this metonymic shortening, we also see a shift from gestures as topological (e.g., moving hand/arm standing for moving object) to typological form of expression (e.g., open hand standing for transparency film). Because verbal expressions are essentially of typological nature, the transition from metonymic gesture to verbal expression is greatly facilitated. On the other hand, gestures serve in perceptual isolation of objects and thereby enact existing sensorimotor schemata that have metaphoric equivalents in language. Here, sensorimotor experience and metaphoric language are correlated in new experiential and conceptual contexts. Taken together, these two processes suggest that gestures and associated language are produced and received as meaningful means of expression. When students come to school science, their hands—as those of other people (e.g., LeBaron & Streeck, in press)—are already minded and their minds are, self-evidently, in a human body. From this, we suggest the possibility that optimal instruction is likely to occur when it draws on the existing capacities of mind *and* body to enhance the learning of students.

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