5 Representational Gestures as Cognitive Artifacts for Developing Theories in a Scientific Laboratory

Amaya Becvar, James Hollan, and Edwin Hutchins

Abstract

This research examines how representational gestures (Kita 2000), made by scientists during collaborative discussion in a biochemistry lab, are used in formulating scientific theory. By analyzing digital video of lab meetings and interviews, we find that representational gestures are frequently used to reference, modify, and embody portions of existing material structure such as models, diagrams, and graphs. Representational gestures appear to play a significant role in how scientists both conceptualize and communicate theories. We believe that representational gestures operate as instantiations of essential spatio-dynamic features that are not efficiently conveyed in other modalities, like language and graphical representations, and, as such, are essential resources for shaping theoretical understandings when used in collaborative, face-to-face activity. Gestures may also serve to align cognitive processes in a "community of practice" (Lave 1991) and can package theoretical conjectures into a single semiotic form that can be used symbolically to evoke a rich, shared conceptual history. We use a theoretical framework provided by distributed cognition and embodied cognition to examine jointly shared representational gestures as cognitive artifacts produced and modified by the biochemistry lab community during the practice of theory construction.

5.1 Introduction

In 1951, Linus Pauling published a series of papers detailing the molecular structure of the most basic form of a protein chain, the alpha helix. This was an astounding breakthrough, opening the door for an understanding of biology at the molecular level, and laid the foundation for the entire field of modern molecular biology. In order to formulate these accounts,

Published in:
Resources, Co-Evolution and Artifacts: Theory in CSCW, Ackerman, M.S., Halverson, C.A., Erickson, T., and Kellogg, W.A. (Eds.), 2008, 117-143.

Pauling engineered an extensive set of physical models, using wooden balls, clamps, screws, and wire. Though molecules are a billion (10^9) times too small to be seen by the unaided eye, Pauling was able to formulate a theoretical account of molecular structure. Building and manipulating tangible macroscopic models facilitated Pauling's theorizing. In his own words,

> I was so pleased with the alpha helix that I felt sure it was an acceptable way of folding polypeptide chains and that it would show up in the structure of some proteins. I believe that the same process of moulding plastic materials into a configuration complementary to that of a molecule is analogous to the process responsible for all biological specificity. (Linus Pauling 1951, note to E.B. Wilson)

Molecular models are essential cognitive tools for chemists. These models range from physical "tinker-toy" modeling kits, to skeletal structural drawings, to three-dimensional computer models. Throughout its history, chemistry has been a remarkably visual science. However, the physics of the molecular world is fundamentally different than the physics of the macromolecular world where we live and operate. In reality, humans have very few perceptual resources for directly relating to molecules. Even the images produced by the most powerful scanning tunneling electron microscopes give a misleading impression of molecules. Molecular models allow chemists to use their perceptual resources to help generate and test chemical theories. Historical analysis indicates that the materiality of these molecular models has played a central role in the development of chemistry (Francoeur 2000). In a similar vein, a large body of research on the use of graphical representations in scientific practice in general indicates that these physical images are integral to the production of scientific facts (Fleck 1979; Latour 1979, 1990; Lynch and Woolgar 1990; Goodwin 1995). That is, theoretical and empirical results are not only communicated, but also enabled by the visible, tangible molecular models that they construct and manipulate.

In this chapter we examine the role of representations in how theories get produced. In our analysis, we extend the concept of "representation" to include other representational forms besides physical objects and graphical representations. In particular, we look at how representations are produced and used in interaction during instances when scientists are negotiating theories. We use cognitive ethnography to examine the interactions of a scientific "community of practice" (Lave 1991), composed of biochemists during laboratory meetings, scientific conferences, and interviews. As these scientists talk and gesture about theoretical entities like proteins, molecules, and chemical bonds, we can attempt to understand the conceptual structures that underlie their interactions.

This research calls upon the theoretical frameworks provided by distributed cognition (Hutchins 1995; Salomon 1997) and embodied cognition (Johnson 1987; Clark 1996; Nunez 1999; Varela et al. 1991). Distributed cognition expands the unit of analysis for cognition beyond individual brains to include bodies, material structures, and social contexts of cognitive activity and provides a framework for examining the propagation of information through representational forms, such as spoken language, gesture, graphical models, text, and so on.

Research in cognitive linguistics indicates that we conceptualize abstract concepts in terms of our everyday, bodily experience of the world (Lakoff 1987; Nunez 1999; Lakoff and Nunez 2000). The theory of embodied cognition (Johnson 1987; Clark 1996; Varela et al. 1991) holds that our conceptual understandings, derived through our bodily experience of the world, both enable and constrain our ability to think about and represent abstract phenomena (in this case, how scientists understand entities that cannot be directly perceived, like molecules). We use the term "embodied" to refer to representational forms (such as gestures, utterances, and inscriptions) and highlight how these representations are organized by conceptual systems grounded in the experienced world.

5.2 Cognitive Artifacts and Representation

Cognitive artifacts are tools used for aiding, enhancing, or improving human cognition (Hutchins 1995). In this definition, an "artifact" is a human-constructed object of cultural significance. Close investigation of artifacts and their use can provide insight into the meaningful cognitive practices of a culture. Often the nature of these practices is not crystallized, but is dynamically adapted through time and circumstance.

Cognitive artifacts support reasoning processes and transform cognitive tasks. By using cognitive artifacts, we can abstract and represent information in such a way as to replace cognitively challenging tasks, such as mental arithmetic, memorization, complex simulations, by "cognitively robust perceptual processes" (Hutchins 1995). We can represent perceptions, experiences, and thoughts in media other than those in which they originally occurred (Norman 1990) and perform complex transformations in media that allow us to make full use of our powerful perceptual skills. Research has shown that the nature of the representation determines how a problem might be conceptualized and that certain types of representations render problems more amenable to human cognitive abilities (Rumelhart 1980; Kirsch 1995; Goldstone and Barsalou 1998). Different representations of a problem can have a dramatic impact on problem difficulty even if the formal structures are the same (Norman and Zhang 1994). In this light, we should look at the role of representational artifacts when attempting to understand the reasoning processes of scientists as they analyze empirical data and produce theories. This analysis should include not only static representations, such as data tables, diagrams, and graphs, but also the more "ephemeral" representational forms expressed in human interaction, i.e., gesture and speech.

In particular, we focus on how representational gestures, coupled to molecular models, are used in scientific activity to develop theories about molecules in a biochemistry lab. Exploring gesture-in-interaction permits a glimpse into the schematic ways scientists in this lab understand the behavior of protein molecules. We use *cognitive ethnography* to examine the interactions of a scientific "community of practice" (Lave 1991), composed of biochemists during laboratory meetings, scientific conferences, and interviews. As these scientists talk and gesture about theoretical entities like proteins, molecules, and chemical bonds, we can attempt to understand the conceptual structures that underlie their interactions, and document the role played by gesture and embodied physical experience.

5.3 Gestures

Human conversation involves a rich interaction among multiple modalities of verbal and nonverbal communication. Recently, there has been a growing interest in gesture studies (Kendon and Muller 2001), brought about in large part by a change in the theoretical foundations of many of the disciplines that traditionally viewed gesture as peripheral and incidental to spoken language. Recent work on gesture has begun to elucidate the role played by bodily engagement with the world through basic practical actions, which provide structure to cognition and conceptual development (Roth 2001). This work is largely influenced by the theory of embodied cognition. For example, it appears that many gestures are derived from manipulating real objects and making practical actions. However, gestures are also tied to verbal utterances that express very abstract ideas. Analysis of these gestural expressions promises to tell us much about the way cognition is grounded in our engagement with the physical environment (Nunez 1999; McNeill 2000; Parrill 2000).

Gestures are ubiquitous in everyday communication. People use gestures to point to or index objects (e.g., this one, over there) (Clark 1996; Goodwin 2000), to indicate meaningful spaces (Liddell 2000; McNeill 2000), to demonstrate an action without really doing it (LeBaron and Streeck 2000), to illustrate concepts (e.g., pinching between thumb and forefinger to indicate size) (McNeill 1992; Nunez 1999; Roth 2001), and to communicate symbols and signs (Kendon 1987). Thus, movements of the body, especially the arms and hands, that are often integrated with spoken language, the manual and bodily action to communicate something without words, are all recognized as "gesture"[1] (McNeill 1992).

Our research focuses on the use of representational gestures in collaborative scientific discourse. *Representational gestures*[2] (Kita 2000) bear meaningful relationship to the semantic content of the speech they accompany.

Gestures often co-occur with spoken language and are intelligible only in the context of the associated verbal utterances (Kendon 1987; McNeill 2000; Quek et al. 2001). While gesture and speech clearly belong to different

[1] As defined by Kendon (1987) and McNeill (1992), a gesture passes through up to five phases: preparation, pre-stroke hold, the stroke itself, post-stroke hold, and retraction; all are optional except for the stroke. The stroke carries the imagistic content of the gesture and is the phase whose synchrony with speech is maintained by the speaker. Several researchers have addressed how to classify gestural forms. Perhaps the most widely recognized classification system for spontaneous gestures is that introduced by McNeill (1992).

[2] There are several types of gestures that fall into this category. When deictic gestures point to a seemingly empty space in front of the body as if establishing a virtual object in the gesture space, they simultaneously bring these abstractions into being. In this case, such gestures are referred to as *abstract deictic gestures*. In *pantomime gestures*, the hands depict actions with objects. These gestures are imitations of functional motor activities. In pantomime gestures, as in abstract deictic gestures, hands are still hands, albeit interacting with imaginary objects. *Kconic gestures* have an "isomorphism between shape of gesture and the entity expressed by gesture" (McNeill 1992; Taub 2001). In an iconic gesture, the hand may no longer be viewed as a hand, but rather begin to stand in as a physical manifestation of the referent. *Metaphorical gestures*, as defined by McNeill (1992), depict concrete representations of abstract discourse topics. Many have noted that this distinction between iconics and metaphorics is somewhat problematic and is viewed by some (deRuiter 2000) as superficially descriptive and not necessarily fruitful—for instance, an iconic hand shape can be used to depict a metaphoric scene. Much more interesting may be the question of the cognitive mechanisms underlying the translation of a metaphorical abstract concept into a concrete, physical gesture representation.

modalities of expression, they are linked on several levels and work together to present the same semantic idea units. The two modalities are not merely redundant; they are "co-expressive," in that they arise from a shared semantic source but are able to express different aspects of information. McNeill claims the close synchrony between gesture and speech shows that the two operate as an inseparable unit, reflecting different semiotic aspects of the cognitive structure that underlies them both.

Gestures are visual displays. It is thought that gestures achieve their power because they convey visual/spatial/dynamic information directly (McNeill 1992), unlike spoken language, which is symbolic and often bears arbitrary relationship to its referent. In a gesture, in contrast, the signifier (the gesture shape) and the content are connected non-arbitrarily.

As talk-in-interaction is an important cognitive activity, and gesture is intimately involved in acts of spoken linguistic expression, then it is reasonable to look closely at gesture for the light it may cast on cognitive activity.

Iconic mapping (Taub 2001) is one of the frameworks that make it possible to describe these connections and to understand the *mappings* between the form and motion of a gesture and the underlying conceptual structure. An *icon* is a sign that is related to its real-world referent through physical resemblance. A *mapping* refers to a perceived resemblance between aspects of the gesturing body and some referent, based upon the preservation of shared features. Gestures are typically recognizable as "iconic" only if one has knowledge of the topic of conversation, since the same hand shape or trajectory of motion can be mapped onto a number of different schematic scenes. Contextual information is required to understand exactly what is being mapped onto the gesture. The recognition of these essential features is determined by the way we categorize and conceptualize objects and events.

5.4 Methods

5.4.1 Cognitive Ethnography

Over the past decade in the field of cognitive science, we have seen an increasing interest in the role of the material and social world in cognitive processes. We are now beginning to recognize that patterns in the material and social world play a crucial role in how cognitive task demands are constructed and that many cognitive processes extend beyond the individual and are played out in interaction with the environment (Goodwin

1994). Currently, such questions are being explored in the fields of distributed cognition (Hutchins 1995) and embodied cognition (Clark 1996). These approaches emphasize the importance of examining human cognition in naturalistic settings (i.e., "in the wild") (Hutchins 1995) and challenge traditional approaches toward system design and usability.

Ethnography is a methodology to study the fine-grained details of real-world activity. Using ethnography provides us with better functional specifications for the human cognitive system. *Cognitive ethnography* focuses on understanding cognitive processes as they are enacted in naturally situated activity. A cognitive ethnographer typically makes recordings (audio, video, photographic) of ongoing activity. The widespread availability of inexpensive digital recording and storage devices now enables us to go about easily collecting ethnographic data on real-world activity for review and analysis.

5.4.2 Field Site

The field site for this study was a biophysics research and training laboratory at the University of California, San Diego. This lab uses a variety of experimental techniques to study the structure, dynamic properties, and nature of the interactions of protein molecules involved in blood clotting.[3]

The corpus of data for this project was drawn primarily from the research group's weekly lab meetings.[4] Lab meetings are a rich source of

[3] One of the reasons this laboratory was selected as a field site is because one of the authors (Becvar) completed a master's thesis in this lab from 1999 to 2002 (Becvar et al. 2003, in press). During graduate study, she was an active member of the laboratory, participating in every element of its functioning: performing laboratory research, maintaining the lab, training new students, generating theory, documenting findings, developing laboratory practices, and helping to write grants and scientific journal articles.

[4] All the lab members are present at the weekly group meeting. Twelve laboratory group meetings were videotaped spanning the period of September 2002 to February 2003. During a typical group meeting, the 12 lab members meet in a small conference room for approximately two hours. One student formally presents experimental work that s/he has accomplished over the past few months. The presentations generally consist of a brief description of relevant background on the system of inquiry and methodology used, the data obtained, experimental design and "stumbling blocks," and a preliminary interpretation of results. Students typically use overhead transparencies to present text, schematic diagrams, graphs, and visual models of the proteins they study. Often after the presentation of research findings, the tone of the meeting changes from a presentation to a

data as they involve multimodal interactions of lab members collaboratively constructing and negotiating scientific theory. The lab meeting often serves as a community forum for deciding how to integrate newly obtained empirical data into the lab's theories regarding the biological system of interest. Another reason to analyze the discourse of the lab meetings is because during this time scientists are often more explicit about their conceptual models while communicating them to others than when they are engaged in everyday laboratory work. In addition to lab meetings, video data were also collected during a follow-up interview[5] with a graduate student who had been present for all other recorded sessions.

Proteins

Proteins are large molecules that are made from long chains of simpler molecules known as amino acids. Although proteins are built of chains of amino acids, they are usually not linear and stretched out; rather, the chain of amino acids folds into an intricate three-dimensional structure that is unique to each protein. It is this three-dimensional structure that affords proteins many of their diverse functions. In biochemistry, typically an intimate *structure-function relationship* is assumed, and so research done to reveal protein *structure* often is used to speculate about the way proteins *function* in living systems. The laboratory in which this ethnographic analysis was performed also believes that to understand protein function, they must understand protein *dynamics* as well. Much of their research is aimed at characterizing not only the structure of proteins, but the internal motion of proteins.

Biochemists have devised a number of methods to show the three-dimensional structure of proteins. In order to fully explore protein structure in detail, scientists use different types of molecular models, including "ribbon diagrams," "cartoon" views, and three-dimensional computational models. These representations range from complex models, in which every atom of the structure is shown, to the simpler "ribbon diagrams" that trace

discussion about the theoretical implications of the data. The principal investigator of the lab, referred to as "B," generally takes on a more central role at this point, often speaking more frequently.

[5] The interview lasted one hour. During the interview, the student was asked to discuss some of the recent findings from her own research with the interviewer. The student brought with her printed copies of graphical models and text to supplement the discussion. The interviewer consciously withheld from making any representational gestures during the interview.

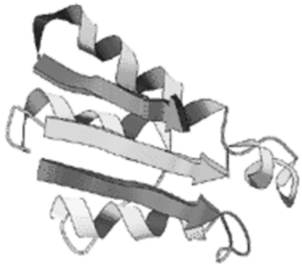


Fig. 5.1. Ribbon diagram of a protein, from Banner (2000).

the position of the amino acids in three-dimensional space (Figure 5.1). A ribbon diagram is a skeletal model of a protein. More schematic representations like the ribbon diagram omit detail in order to highlight specific aspects of structure such as helical components and loops.

The Biochemistry of Blood Clotting

The biophysics group participating in this study primarily does research on the protein **thrombin**, which is involved in shutting down the process of blood clotting (see Banner 2003 for a review). Thrombin is an enzyme, one of a family of proteins that chemically cleaves other proteins. This cleavage takes place in the enzyme's *active site*, a cavity exclusively structured for particular substrates to fit.

One of thrombin's roles is to activate the protein fibrinogen, which forms mesh-like clumps that make up blood clots. When a body forms aberrant blood clots, it produces another protein, called **thrombomodulin**. Thrombomodulin binds to thrombin (see Equation 1) in a site distal to the active site. When this happens, a change occurs in thrombin that causes thrombin to stop binding fibrinogen into its active site and instead bind another protein, **Protein C**. When activated, Protein C breaks down blood clots. So depending on whether thrombin accepts fibrinogen or Protein C into its active site determines whether blood clots are being formed or broken down in the body. One aim of this research group is to determine how the binding of thrombomodulin to thrombin causes thrombin to accept Protein C, and not fibrinogen, into its active site. This research is aimed toward designing therapeutic drugs for heart attacks and strokes, diseases that are caused by aberrant blood clots. The laboratory is particularly interested in what happens between thrombomodulin and thrombin, which causes thrombin to bind Protein C.

A) thrombin + thrombomodulin → active thrombin

B) active thrombin + Protein C → active Protein C (Eq. 1)

5.5 Results and Analysis

In biochemistry, understanding the internal dynamic properties of protein molecules is essential for characterizing how proteins interact with each other, and what sorts of changes occur when they do interact. The examples presented here demonstrate how representational gestures, acting as instantiations of embodied schematic understanding, may play an essential role in how scientists both represent *and* conceptualize molecules and molecular dynamics, and how these understandings are symbolized in a cognitive system. These gestures have a complex, interdependent relationship with static molecular models, spoken language, and conceptual structure. Digital video provides a format that allows us to examine the propagation of representations through time and collaborative interaction, and the construction of a symbolic gesture.

The following data were obtained during one lab meeting in October 2002 and in a follow-up interview that took place in April 2003. During the lab meeting, "C," an advanced graduate student, presented at the lab meeting. "B" is the research advisor of the lab. "S" and "J" are graduate students in the lab. During this meeting, C showed new data that several members of the lab had not yet seen. The following micro-analysis was taken from a 6-minute section of video from the lab meeting and a 3-second section of the follow-up interview. Only select sections are discussed and presented in the accompanying transcripts.[6]

---

[6] This project aims to study speech, gesture, graphical representations, and conceptual structure, and how they interact. The transcription and coding conventions selected reflect this choice. The gesture phrase, which is the interval from rest to rest or from one gesture to the next, is shown with brackets, and the phases of the gesture (preparation, stroke, retraction, plus holds) are located with respect to the speech transcript. Typographic features (curled brackets and/or carets) designate the hand's motion relative to speech—{ is the onset of motion, } is its end. Deictic (pointing) gestures are marked with ^carets^; representational gestures are marked with {curled brackets}. Boldface shows the stroke phase of the gesture—the phase with semantic content and the quality of effort. Unbolded speech within brackets and before the stroke is the preparation phase; after would be the retraction phase. Underlining shows holds in which the hand(s) are held in mid-air.

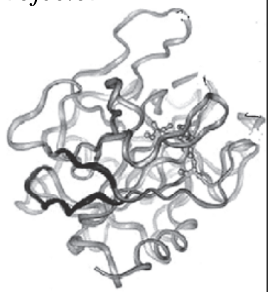
The speech transcription conventions are those outlined by the discipline of Conversation Analysis and closely follow those as used by Charles Goodwin (see Goodwin 1994), with one slight modification. Whereas Goodwin uses boldface italics to convey word emphasis, we use italics (as boldface conveys the

The segment of video depicted in Segment 1 was taken near the end of a lab meeting during which C, a graduate student, had presented experimental measurements taken on thrombin that show differences before and after thrombomodulin binds to it. After C presented the data, the PI of the lab, B, rose from her chair. In Segment 1, B stands beside an overhead projector showing a graphical model of thrombin (frame 1.6).

Using a combination of indexical language and gesture (frames 1.1 and 1.2), B points out four distinct "loops" surrounding the active site of thrombin. She uses the projected shadow of her left hand over the over-

Table 5.1. Segment 1.

Section 1. Gesture as a Cognitive Artifact

1.1 (37:10;00)	**1.2 (37:14;10)**	**1.3 (37:18;20)**
 **B:** ^See how (0.8) you have ^(0.3)^ all these little loops^ (0.3)	 ^this loop^ ^this loop^ (0.6) ^this loop^ and ^this loop^ (0.8)	 **{all kin' of:** (0.3)
1.4 (37:20;10)  **in three-dimensional** space they're like this	**1.5 (37:21;00)**  (1.1) an' that's the ^active site (0.3)^}	**1.6** *Model of Thrombin on Overhead Projector* 

stroke of an accompanying gesture). Places where boldface italics occur in my transcript are examples where spoken emphasis and gesture stroke coincide.

head projector to annotate the graphical model. After highlighting four loops, B cups her left palm with fingers rigidly extended and lays it next to the protein model on the overhead. Onscreen, the shadow of her fingers and thumb lie near to the previously referenced "four loops." B twists her wrist in an awkward angle, preserving both the orientation (pointing towards her left) and morphological similarity between her fingers and the four loops (rounded projections pointing away from a globular central body). The mapping between fingers and loops is drawn through both iconic similarity and the hand's close physical proximity to the model.

After indexing the model and laying her hand next to it, B virtually "lifts" the thrombin model off the transparency, and by embodying it in her hand, she presents it, palm outward to the group, stating (frame 1.4), "In three-dimensional space they're like this." B's utterance draws attention to one of the essential features of her hand that is not a feature of the graphical projection of thrombin: namely, her hand's "three-dimensionality." In this moment, we see the transformation from indexical gesture (hand pointing to referent in meaningful space) to iconic gesture (hand as referent). At the same time B transforms a two-dimensional representation of the molecule thrombin into a three-dimensional *meta-representation* (Norman 1990).

In the next frame (1.5), B uses both speech and gesture to index another feature of the thrombin model embodied in her left hand—the active site. By concurrently saying "and *that's* the active site," while pointing at the palm of her left hand, B indexes a portion of the thrombin model relative to her hand through both deictic noun ("that's") and co-occurring indexical gesture (right hand pointing). B further builds upon the iconic mapping between the thrombin model and her hand. The mapping relates essential morphological features of both the active site of thrombin and her concave palm, both of which are cavities surrounded on all sides by loop/finger projections. Notice how the gesture preserves not only the *topology* and *shape* between both the loops and fingers, and the active site and palm, but also the *relative orientations* of the loops and active site (fingers surrounding palm, projecting outwards). B's hands remain configured in a fashion that can be, in this context, recognized as an index to the model of thrombin. The "virtual" presence of the molecule can be jointly inferred by those in the room, and it appears that B almost "wears" the model on her hand. Indeed she holds the hand-as-model stiffly up and away from her body, engaging musculature through her entire left shoulder, arm, wrist, and hand.

Because of the structural affordances of the thrombin hand model, B is able to demonstrate to the group the orientation of the loops in three-dimensional space, and their orientation with respect to the active site. The

Table 5.2. Segment 2.

2.1 (00:37:04;00)	**2.2 (00:37:08;00)**	**2.3 (00:37:11;30)**
		
B: {And so (0.3) our new theory is (0.5) that **(1.1)**	**thrombomodulin does something like this (0.5)**	**or like} {this (1.5) okay (0.3).}**

assignment of relative spatial position in three dimensions accomplished via B’s gesture is not possible with the flat, two-dimensional projection of the protein model.

Segment 2, shown in Table 5.2, immediately follows the clip discussed in Table 5.1. B prompts the introduction of a theoretical conjecture by saying “our new theory is (0.5) that ....” By using the third-person possessive noun “our,” she draws attention to the mutual importance of the “new theory,” a theory jointly possessed by all competent practitioners in the lab. What follows next is a pregnant pause in spoken discourse (1.1 seconds), while B squeezes her fingers, representing the loops around thrombin’s active site, slowly in and out. B directs mutual attention toward the gestural model through a variety of bodily cues. For instance, her overall body posture—crouched position, head tilted down while maintaining an intense gaze over the group her orientation of the gesture—seems to convey the significance of the gesture. She orients her gesturing hand outward toward the group and shifts her eye gaze to her hand. These bodily cues, such as orientation and eye gaze, can function deictically (Scheflen 1976; Gullberg and Holmqvist 1999). The process that occurs here is comparable to how a state of mutual orientation is negotiated prior to the production of a coherent sentence in conversation (Goodwin 2000). Furthermore, B uses a slow, intentional manner when moving her fingers. Levy and Fowler (2000) propose that gestural intensity, or energy, can indicate that a gesture is carrying new, significant information content into the stream of discourse.

After producing the squeezing gesture for 1.1 seconds, B states, "Thrombomodulin does something like this," as she continues the squeezing gesture. Then she says, "or like this" while twisting her fingers around a central pivot. This is a very complex statement spoken to a community of experts and requires a good deal of domain-specific knowledge in order to "unpack." Thrombomodulin is a binding partner of thrombin, and one of the aims of this research group is to determine how the binding of thrombomodulin to thrombin causes thrombin to accept Protein C, and not fibrinogen, into its active site. In the statement in frames 2 and 3, what B is implying is that, "[The binding of] **thrombomodulin** [to Thrombin] **does something like this** (squeezing loops in) **or like this** (twisting loops around) [the active site of thrombin]."

It is interesting that B uses verbal language to refer to elements of the theory (thrombomodulin) that are not directly indexed in her gesture. Thrombin, its loops, and active site, all symbolized by her hand, by a previous indexicalization, are *not* nominally referenced by the utterance in Segment 2, whereas the binding of thrombomodulin does not have a gestural analogue and is referenced through spoken dialog only. Both verbal and visual modalities come together in this instant to convey more than either mode could alone.

Through this gesture, B describes to the group her conception of the nature of the structural and dynamic changes that occur in thrombin. Her gesture is no longer an iconic (referencing salient features of referent) or a *meta-representation* of the structure of thrombin, as it was during Segment 1, but instead becomes an instantiation of her conception of the dynamic state change of the protein, which is in alignment with experimental measurements made in her laboratory. The gesture conveys *new spatio-dynamic features* not present in the static structural model. B's prior iconic mapping of component parts, set up in Segment 1, serves to connect the movement of the loops around the active site of thrombin with the movement of her fingers in one of two motions, either rotation or squeezing inwards. By transforming the static graphical representation into a hand model, she can do things that cannot be done with the graphic display because of the specific *dynamic* and *spatial* affordances (Norman 1990) of her hand. The gesture relies upon certain visual-spatial correspondences between the model and the hand, while at the same time offering new features to the model. Her gesture introduces spatio-dynamic properties, in line with indirect experimental measurements that B is using to draw inferences about the biochemical system.

B's gestural conception draws upon more than a superficial analogy between the hand and the molecular model. The theoretical inferences B makes in light of the data that C has presented rely upon a conception of loops in proteins moving in ways analogous to tangible, dynamic, three-dimensional objects like fingers. Therefore, B draws on the inferential structure provided by her embodied experiences with tangible objects in order to formulate conjectures about the dynamic nature of proteins. The thrombin hand gesture exists as a stabilizing structure that juxtaposes indirect experimental measurements, which are numerical, the graphical model, which is static, and the embodied schematic structure derived from the spatio-dynamics of tangible objects and hands. Drawing inferences in the tangible world allows B to theorize about what's going on in the molecular world.

Section 2. Formation of a Gestural Symbol

In Segment 3, shown in Table 5.3, B refers to the experimental evidence from another research group that corroborates her theory, and the evidence C presented earlier in the lab meeting, which supports the theory that thrombomodulin's binding to thrombin causes a conformational or dynamics change in the loops around the active site of thrombin. It is interesting how B reinstantiates the thrombin hand model in her left hand, in order to describe the molecular details of the experimental findings of the other research group.[7] She uses her right hand as thrombin's binding partner,

Table 5.3. Segment 3.

3.1 (00:38:18;00)	**3.2 (00:38:19;30)**	**3.3 (00:38:29;10)**
		
B:{but when you **bind thrombomo::dulin** to the back side of thrombin}	{suddenly that Protein C **Inhibitor is in there (0.5) a:** *THOUSAND} FOLD FASTER* (0.5)	**{So there's a lo:tta evidence sugesting} {that so:mething like *this* is going on. (2.0)}**

[7] The reinstantiation of the left hand as thrombin and B's repeated use of the gesture constitute what McNeill (1992) calls a *catchment*. A catchment is recognized when one or more gesture features recur in at least two (not necessarily consecu-

thrombomodulin and later, the Protein C inhibitor molecule, against the backdrop provided by the thrombin hand shape, held stationary for a full 20 seconds.

In frame 3.1, B then uses the "thrombin hand" gesture in a fundamentally different way than she has used it previously. Now, the hand shape and dynamics are used as a *symbol*, when she says, "So there's a lot of evidence that something like *this* is going on." The deictic noun "this" references the co-speech gesture, which is a blend between the "thrombin hand" squeezing and "thrombin hand" twisting gestures. At this point, speech provides the syntax needed to support a gesture-based lexical item. The gesture functions in a form of discourse deixis (Levinson 1983), pointing back to the moment in prior discourse when B presented the theory of the dynamic changes in thrombin's loops. Standing behind the gesture is an astonishing representational cascade, made up of experimental data, structural models, and over two minutes of discourse to which the gesture is anchored.

According to LeBaron and Streeck (2000), a paradigmatic instance of symbol formation is the situated creation of a form-meaning pair that embodies a nexus of locally produced, shared knowledge. B's raised hand, presented with a recognizable shape and motion, denotes a complex of actions, theories, objects, and inscriptions and has become a socially shared symbol. LeBaron and Streeck (2000) also contend that shared knowledge of communities grows through the creation, reuse, and transformation of symbolic forms. In the following passages, we see how the thrombin hand gesture is now available to be used in various communicative purposes, syntactic contexts, and semantic roles.

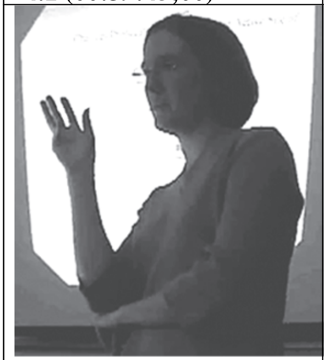
B is not the only lab member who uses the symbolic gesture in the ongoing discourse to reference the theoretical account of thrombin. A few minutes later, C, a graduate student, invokes a similar gesture to B's in order to elaborate on the theory. C holds her right hand up facing the group, mimicking the squeezing loop theory gesture as she speaks, "there's some sort of dynamics or (0.3)/conformational change" (frame 4.1). She uses the indexical speech term "this" to bring the gestural semiotic term grammatically into the spoken dialog.

C's gesture mimics many features of B's gesture. C supports her left elbow with her right hand similarly to how B propped her left elbow up on

tive) gestures. Identifying catchments allows us to see what concepts a speaker is grouping together into larger discourse units that have related meaning.

Section 3. Propagation of a Symbolic Gesture

Table 5.4. Segment 4.

4.1 (00:39:45;00)	**4.2 (00:39:47;30)**
	
C: I mean so: so {there's two things going on (0.1)	**There's this sorta dynamics (0.3), or conformational change right in the loops-**}

the conference table. C's palm faces outward, toward the center of the conference room, and she squeezes her fingers in and out. Still, it is also interesting how C's gesture is slightly different from B's gesture. C's palm faces slightly upward, while B's palm faced toward the group. Also, though C moves her hand in similar way as B has done, her fingers move with a less structured motion with a quicker frequency. Note the relative "limpness" of her hand in contrast to B's left hand in Segment 2. Levy and Fowler (2000) note that gestures and speech referring to topics that have already been established are marked by patterns of lesser energy. Despite these differences, the gesture is rendered intelligible through the surrounding context and co-gesture speech.

In Segment 5, S, a postdoctoral student in the lab, indexes the loop theory three times ["these effects", "this (0.5) thing you're doing," "those steric effects"]; however, he only explicitly uses the symbolic gesture once, making the gesture with his right hand as he speaks, "you know this (0.5) thing you're doing." It is interesting how he uses the gesture to self-repair his statement from line 2, "Are these effects." The gesture allows him to refer back to a previous moment in the discourse in a way perhaps more descriptive than he could convey with speech alone.

Table 5.5. Segment 5.

5.1 (00:42:51;00)	**5.2 (00:42:55;30)**
	
S: {Are these effects, **you know this: thing you're do**ing (0.3)}	Is this- (0.2) {You think it's all those **steric effects}**

Figure 5.2 is a representation showing the evolution of repeated gestural forms relating to the theory about the protein thrombin through time in order to demonstrate the ubiquitous use of the "thrombin hand" gesture form and its modifications.

Through the recycling the "thrombin hand" gesture, both the gesture itself and the accompanying indexical dialog have become intersubjectively recognized discourse elements. The symbolic gesture appeals to community knowledge, knowledge that may have been acquired over the course of the current situation, and also in a cultural and physical world that is shared by members of the community of practice. The prior discourse activity situates this symbolic gesture, imbuing it with meaning and communicative power well beyond what is explicitly conveyed. B's hand is just a hand in the absence of the surrounding aural, visual, and social context. The gesture packages a complex theory into a simple, easily manipulable form. Recognizing a gesture as a meaningful display involves not just orientation to someone's moving hand, but also to the ongoing creation and mutual alignment of disparate information forms emerging through time and interaction (Goodwin 2000). The elements required to assemble the meaning of a gesture are distributed, composed of different media (graphical representations, moving hands, and speech) and also, in this case, the activities of several participants.

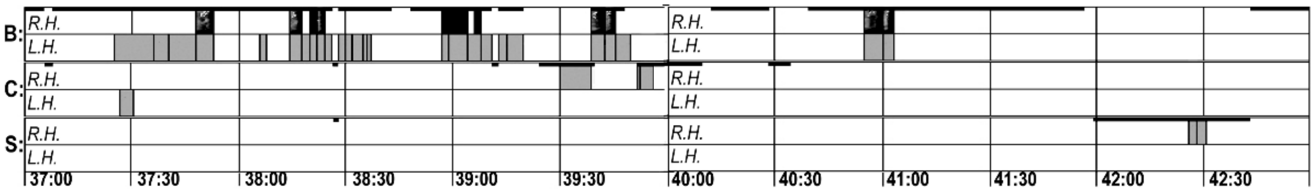


Fig. 5.2. Timeline showing the temporal distribution of repeated gesture forms relating to thrombin for three speakers in a segment of discourse (B, C, and S). Left and right hands (L.H. and R.H.) are indicated separately. Thick bars represent the presence of repeated gesture forms and are segmented at gestural transitions. Gray bars indicate when the speaker is invoking the "thrombin hand" gesture form. Stippled bars indicate the opposite hand entering the palm of the "thrombin hand." Black bars indicate the opposite hand hitting the backside of the "thrombin hand." Speech is indicated by a bold black line above each speaker's row in the timeline.

5.6 Section 3: Stability of a Symbolic Gesture

The data in this segment are taken from a follow-up interview with J, a graduate student in the lab, who has done experiments comparing the structural and dynamic differences between thrombin with and without thrombomodulin bound. This interview was completed six months after the laboratory meeting from which the video Segments 1–5 were extracted. In Segment 6, shown in Table 5.6, J is summarizing the research she did, which has recently been submitted for publication. As shown in Figure 5.3, J's gestures are remarkably similar to B's when she discusses the outcome of new experimental measurements of thrombin.

J calls upon the very same "thrombin hand" gesture that B used roughly six months earlier as she expresses her conceptualization of the structural changes that occur in thrombin in light of new empirical data. Here we see evidence the "stability" of the gesture as a meaningful and conceptually useful representation, as J reinstantiates the very same hand shape and dynamic motion in order to discuss similar concepts in light of new experimental data that corroborate B's initial conjecture.

Though J's speech and word choice are different than B's were, her gestures are not. Moreover, neither J's speech nor her gestures are arbitrary: They preserve key elements of conceptual structure that are essential for

Table 5.6. Segment 6.

6.1 **(00:28:48;00)**	**6.2** **(00:28:51;10)**
	
J: an' we were looking at how (0.2) {if you (0.1) bind thrombomodulin	**what's going on in the** rest of the thrombin}

Fig. 5.3. B (left) and J (six months later) as they discuss a molecular-level model of changes taking place in the active site of thrombin when thrombomodulin binds. Subtle differences may be due to the differing camera angle. However, note how in both cases, the iconic mappings of the gesture are the same (palm = active site, fingers = loops around active site, and so on).

doing reasoning and drawing inferences in alignment with new empirical measurements and prior research findings. In Figure 5.2, evidence was presented of the propagation of the "thrombin hand" gesture, extending over several moments of discourse, and being used to support a number of theoretical inferences about the nature of the thrombin–thrombomodulin interaction. In Segment 6 and Figure 5.3, it appears that this gesture form has been "conventionalized" through conceptual and discursive practices taking place over the ensuing six months between the initial lab meeting when the "thrombin hand" gesture was conceived, and the follow-up interview.

5.7 Discussion

By examining video segments of scientists engaged in collaborative activity, we have studied the development of a scientific theory through various representational forms, graphical representations, language, and gesture, ultimately to come to reside in a symbolic gesture. In this case study, we first observed how a researcher used gesture and speech to transform her left hand into the static molecular model of a protein, which was projected on the wall of the conference room. By constructing the hand model, she was then able to adapt and modify the molecular model of thrombin, animate it in a way that was consistent with the new theory, and bring it into the ongoing discourse stream. The group members reintroduced and built upon the hand-model through gestural imitation and indexicalization practices (LeBaron and Streeck 2000), such as spoken language and gaze shifts.

We have focused on how representational gestures, coupled with molecular models, are used in scientific activity to develop theories about molecules in a biochemistry lab. Exploring gesture-in-interaction has permitted a glimpse into the schematic ways scientists in this lab build meaningful understandings about the behavior of protein molecules. And as the end product of scientific activity is theory [or scientific facts (Fleck 1979)], this process may play a special role in scientific communities. Nevertheless, although the examples presented in this chapter describe in detail an isolated instance of a symbolic gesture, the phenomenon we describe is much more general, and we would expect to see similar processes taking place in myriad communities of practice, both scientific and non-[8].

The construction of knowledge is a shared process of forming symbols that "embody experiences that have emerged in situated action" (LeBaron and Streeck 2000). In the scientific laboratory, when the activity is theory negotiation, shared symbols are often representations of scientific phenomena that may be conceived and instantiated in many different media, such as inscriptions (Latour 1990), scientific language (Halliday 1987), and, in this case, gesture. In the scientific laboratory, where the most significant product of activity is the scientific theory itself (and representations of theories), symbols play an integral role in the evolution of bodies of knowledge.

Symbol formation is a powerful process in the fabrication of shared knowledge because it allows participants to reinvoke shared experiences (LeBaron and Streeck 2000), which in this case are conceptualizations of molecular action. Also particularly significant is that this gestural symbol not only packages a scientific concept into an easily manipulable sign, but

[8] For example, LeBaron and Streeck (2000) describe how an iconic gesture referencing part of an architectural model takes a symbolic role in discourse of architecture students. And on a more anecdotal level, the "thrombin hand" gesture has taken on a related, though subtly different meaning in our own lab community (Distributed Cognition and HCI Laboratory, UC San Diego): We use the gesture when working collaboratively to negotiate theories of our own, in particular to reference the key example described in this paper, which demonstrates the human capacity to create interactive cognitive artifacts in communities of practice.

that its form may actually shape the way this theory is conceptualized, i.e., as a protein with loops that move like fingers do. The thrombin hand gesture both indexes elements of the surrounding material environment and introduces new spatio-dynamic properties, which allows the community to further develop the conceptual theory regarding the biochemical system of study.

This is significant because it indicates that representational gestures can be built upon, and referred back to, during a stream of discourse and, moreover, stabilized. That is, seemingly "spontaneous" gestures (McNeill 1992) are *historically contingent*. This is important because it suggests that certain gesture forms have a representational stability through time. It is surprising because representational stability is a property we might expect from physical artifacts like inscriptions, but not necessarily ephemeral representations like speech or gesture. The "thrombin hand" gesture, existing at the end point of a "cascade of inscriptions" (Latour 1990), is a stabilizing cognitive structure that is recycled and conserved over time, via discursive practices in the community of practitioners.

Lave (1991) has noted that "the sense and intelligibility of objects ... arises within the course of particular actions and activities, and their meaning and relevance does not remain stable through time and space." Though indeed it is the dynamically updated context, shaped by both discursive activity and static external representations in the immediate environment, that imbues the "thrombin hand" gesture with meaning, transforming a hand into a protein, this gestural form achieves stability in the community over time via the ongoing cultural practices of the biochemistry lab, spanning over six months and beyond. As a representation of an intellectual product of a biochemistry lab (a theory), this gesture-as-cognitive-artifact represents a vast amount of empirical and intellectual work.

Cognitive artifacts support reasoning processes (Hutchins 1996). Gestures can serve as cognitive artifacts when they are used to represent concepts, and support thinking, communication, and collaboration. B opportunistically makes use of the structure and dynamic potential afforded in her hand. She exploits the natural structure of her hand and its natural movements. If the gesture-based model described here changes the task of working with a conceptual model of the dynamics in the protein thrombin from a conceptual to a perceptual task, representational gesture is actively being used as a cognitive artifact. One of the basic issues in developing an artifact is the choice of mapping between the *representing* world and the *represented* world (or between the surface representation and the task domain being supported by the artifact). Also, because of its physical form and its contextual basis, like a particle of language, the specific "thrombin hand" gesture can later be used as a form of discourse deixis to point back to the moment of discourse wherein the gesture was conceived. The gesture has now become a symbol (albeit ephemeral and highly context-dependent) that serves to package the scientific theory about the loops around the active site of thrombin. But gestures can be reinstantiated by any competent practitioner having gesturing hands.

Research has shown that the nature of the representation determines how a problem might be conceptualized and that certain types of representations render problems more amenable to human cognitive abilities (Rumelhart 1980; Kirsh 1995; Goldstone and Barsalou 1998). Most of these studies, both empirical and observation-based, have involved the use of inscriptions, written symbols, language, or inanimate objects to represent abstract tasks. Gestures also have significance as material representations. Gestures have a visual and spatial component, but they possess the additional attribute of dynamicity and can convey complex spatio-dynamic properties, such as motions, trajectories (McNeill 1992), and aspects (Parrill 2000) of time-based events. Gestures exist in the material world, and in order to form a gesture, we call upon embodied schematic knowledge about our bodies and our interactions with the material world (Taub 2001). By using a gesture to represent an abstract concept, perceptual processes can replace or support cognitively difficult conceptual processes. Perceived through gesture, we can think about and "see" abstract concepts using perceptual processes. Therefore, using gestural representations of abstract concepts alters the nature of the conceptualization task. The framework provided by distributed cognition takes speaker(s) and listener(s), and inside and outside the head, as parts of a whole cognitive system, enabling us to see representational gestures as both emerging from and influencing the activity of a complex cognitive system. In this analytical framework, it is possible to see that a scientist's gesture both came from a conceptualization of a molecular system and shaped this conceptualization.

The framework of analysis presented here also allows us to examine gestures taken in "naturalistic settings," which often occur against a rich social and material backdrop, receiving elements of their sense and significance from the surrounding cognitive ecology (Hutchins 1995). A core group of researchers (Hutchins and Palen 1993; LeBaron and Streeck 2000; Goodwin 2000; Heath and Hindmarsh 2000) have pointed to the crucial role of the shared environment in providing structure and meaning to gestures. We cannot ignore the complex material and social ecology in which gestures are performed, an environment that clearly plays a role in how gestures are both produced and understood. It is important to look at cognition in complex activity systems, where practitioners are engaged in meaningful work, when studying the role of gesture in conceptual processes.

Furthermore, it is essential that when designing collaborative technology, we integrate systems that can support gestures and other non-verbal displays, which are essential for constructing meaning where practitioners are engaged in collaborative work (Billinghurst and Kato 2002; Cheok et al. 2002).

References

Banner D (2000) Enzymology: Not just an active site. Nature 404(6777): 449–450.

Becvar LA, Wood MJ, Prieto JH, Melacini G, Komives E (2003) NMR structures reveal how oxidation inactivates thrombomodulin. Biochemistry 42: 11932–11942.

Billinghurst M, Kato H (2002) Collaborative augmented reality. Communications of the ACM 45(7): 64–71.

Cheok A, Weihua W, Yang X, Prince S, Wan F, Billinghurst M, Kato H (2002) Theatre experience in embodied + wearable mixed reality space. In Proceedings of the International Symposium on Mixed and Augmented Reality (ISMAR’02), pp. 317–332.

Clark H (1996) Using Language. Cambridge University Press, New York.

DeRuiter JP (2000) The production of gesture and speech. In McNeill D (ed.) Language and Gesture. Cambridge University Press, New York, pp. 201–226.

Fleck L (1979) Genesis and Development of a Scientific Fact. University of Chicago Press, Chicago.

Francoeur E (2000) Beyond dematerialization and inscription: Does the materiality of molecular models really matter? HYLE: Journal for the Philosophy of Chemistry 2(6): 63–84.

Goldstone RL, Barsalou LW (1998) Reuniting perception and conception. Cognition 65: 231–262.

Goodwin C (1994) Professional vision. American Anthropologist 96(3): 606–633.

Goodwin C (1995) Seeing in depth. Social Studies of Science 25: 237–274.

Goodwin C (2000) Gesture, aphasia, and interaction. In McNeill D (ed.) Language and Gesture. Cambridge University Press, New York, pp. 145–171.

Gullberg M, Holmqvist K (1999) Keeping an eye on gestures: Visual perception of gestures in face-to-face communication. Pragmatics & Cognition 7(1): 35–63.

Halliday R (1987) The construction of objects in scientific discourse. In Halliday R, Martin L (eds.) Writing Science. Cambridge University Press, New York, pp. 191–214.

Heath C, Hindmarsh J (2000) Configuring action in objects: From mutual spaces to media spaces. Mind, Culture and Activity 7: 81–104.

Hutchins E, Palen L (1993) Constructing meaning from space, gesture, and speech. In Resnick LB, Saljo R, Pontecorvo C, Burge B (eds.) Proceedings of NATO Workshop on Discourse, Tools and Reasoning: Situated Cognition and Technologically Supported Environments, pp. 59–79.

Hutchins E (1995) Cognition in the Wild. MIT Press, Cambridge, MA.
Hutchins E (1996) Cognitive artifacts. In MIT Encyclopedia of Cognitive Science. http://cognet.mit.edu/MITECS/Articles/hutchins.html (as of 1/7/07).
Johnson M (1987) The Body in the Mind. University of Chicago Press, Chicago.
Kendon A (1987) Alternate Sign Languages. Oxford University Press, New York.
Kendon A, Muller C (2001) Introducing: GESTURE. Gesture 1(1): 1–7.
Kirsh D (1995) The intelligent use of space. Artificial Intelligence 73(1–2): 31–68.
Kita S (2000) How representational gestures help speaking. In McNeill D (ed.) Language and Gesture. Cambridge University Press, New York, pp. 379–415.
Lakoff G (1987) Women, Fire, and Dangerous Things. Basic Books, New York.
Lakoff G, Nunez R (2000) Where Mathematics Comes From. Basic Books, New York.
Latour B (1979) Laboratory Life. Sage Publications, Inc., Thousand Oaks, CA.
Latour B (1990) Drawing things together. In Lynch M, Woolgar, S (eds.) Representation in Scientific Practice. MIT Press, Cambridge, MA, pp. 45–87.
Lave J (1991) Situating learning in communities of practice. In Resnick L, Levine JM, Teasley SD (eds.) Perspectives on Socially Shared Cognition. APA, Washington, DC, pp. 63–83.
LeBaron C, Streeck J (2000) Gestures, knowledge and the world. In McNeill D (ed,) Language and Gesture. Cambridge University Press, New York.
Levinson S (1983) Pragmatics. Cambridge University Press, New York.
Levy E, Fowler C (2000) Grounding references in perception. In McNeill D (ed,) Language and Gesture. Cambridge University Press, New York, pp. 215–234.
Lidell S (2000) Blended spaces and deixis in sign language discourse. In McNeill D (ed.) Language and Gesture. Cambridge University Press, New York, pp. 266–289.
Lynch M, Woolgar S (1990) Representation in Scientific Practice. MIT Press, Cambridge, MA.
McNeill D (1992) Hand and Mind: What Gestures Reveal About Thought. University of Chicago Press, Chicago.
McNeill D (2000) Catchments and contexts: Non-modular factors in speech and gesture production. In McNeill D (ed.) Language and Gesture. Cambridge University Press, New York, pp. 215–233.
Norman DA (1990) Things That Make Us Smart. Doubleday, New York.
Norman DA, Zhang J, (1994) Representations in distributed cognitive tasks. Cognitive Science 18: 87–122.
Nunez R (1999) Could the future taste purple? Reclaiming mind, body and cognition. Journal of Consciousness Studies 6(11–12): 41–60.
Parrill F (2000) Hand to mouth: Linking spontaneous gesture and aspect. Unpublished BA thesis, University of California, Berkeley.
Pauling L (1951) Personal letter to E.B. Wilson March 7, 1951, Linus Pauling and the Race for DNA: A Documentary History. http://osulibrary.oregonstate.edu/specialcollections/coll/pauling/dna (as of 1/5/07).
Quek F, Kendon A, McCullough K, Duncan S, Ansari R (2001) Catchments, prosody, and discourse. Gesture 1(1): 9–33.
Roth WM (2001) Gestures: Their role in teaching and learning. Review of Educational Research 71: 365–392.

Rumelhart D (1980) Schemata: The building blocks of cognition. In Spiro R, Bruce B, Brewer W (eds.) Theoretical Issues in Reading Comprehension. Lawrence Erlbaum Associate, Hillsdale, NJ, pp. 38–58.
Salomon G (1997) Distributed Cognitions: Psychological and Educational Considerations. Cambridge University Press, New York.
Scheflen A (1976) Human Territories: How We Behave in Spacetime. Prentice-Hall, New York.
Taub S (2001) Language from the Body: Iconicity and Metaphor in American Sign Language. Cambridge University Press, New York.
Varela F, Rosch E, Thompson E (1991) The Embodied Mind: Cognitive Science and Human Experience. MIT Press, Cambridge, MA.