Interpretive Journeys: How Physicists Talk and Travel through Graphic Space

Elinor Ochs, Sally Jacoby, and
Patrick Gonzales
University of California at Los Angeles

Constructing an Interpretive Journey

A major facet of the work of scientific laboratories is making sense out of ongoing experimental activity and fashioning trajectories for future experiments, presentations, publications, and proposals. As studies of science have remarked, the construction of knowledge in this context is highly dependent on a variety of semiotic tools, especially natural language and visual representation. A prevailing neo-Whorfian view is that these resources are artefacts that organize worldviews among members of diverse communities of scientific practice, often rendering members' knowledge as observable, measurable, or otherwise credible.[1]

1. See, for example, Michael Lynch, *Art and Artefact in Laboratory Science: A Study of Shop Work and Shop Talk in a Research Laboratory* (London: Routledge and Kegan Paul, 1985); Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton: Princeton University Press, 1986); Charles Goodwin, "Perception, Technology, and Interaction on a Scientific Research Vessel," paper presented at the Conference on Rediscovering Skill in Science, Technology, and Medicine, University of Bath, UK (1990); Michael Lynch and Steve Woolgar, eds., *Representation in Scientific Practice*, (Cambridge, Mass.: MIT Press, 1990); Charles Goodwin and Marjorie Harness Goodwin, "Professional Vision: Talk, Interaction, and Technology in the Workplace," plenary address given at the International Conference on Discourse and the Professions, University of Uppsala, Sweden (1992); Andrew Pickering, ed., *Science as Practice and Culture* (Chicago: University of Chicago Press, 1992); Charles Goodwin, "Transparent Vision," in *Grammar and Interaction*, ed. Elinor Ochs, Emanual A. Schegloff, and Sandra Thompson (forthcoming); Charles Goodwin and Marjorie Harness Goodwin, "Formulating Planes: Seeing as a Situated Activity," in *Distributed Cognition in the Workplace*, ed. D. Middleton and Yrjo Engestrsom (Philadelphia: John Benjamins, in press).

Configurations, 1994, 1:151–171

In the present discussion, we take the reader into a kind of liminal world that working scientists routinely construct through linguistic and graphic means. In this world, scientists engaged in collaborative interpretive activity transport themselves by means of talk and gesture into constructed visual representations through which they journey with their words and their bodies. In so doing, they symbolically experience the same physical processes conventionally indexed by representations of past, future, or hypothetical experimental procedures.

Visual representations are treated through this collaborative interpretive activity as stages on which scientists dramatize understandings of their own and others' work. In these scientific dramas the participants take on a variety of roles, including set designer, author, director, actor, protagonist, and audience. As set designers, for example, members of a laboratory may journey through a previously constructed figure without disturbing its design, but more usually they transform such a figure by redrawing it for present purposes, annotating parts of it with a pencil or piece of chalk, and/or superimposing figures representing other scientific work. As "set designs," then, visual representations are not treated passively, as fixed, "immutable" objects,[2] but rather are reauthored visually and conceptually in light of understandings-in-progress within the moment-to-moment interaction of a laboratory. In this paper we explore how, when scientists journey through representations, they create an intertextual space in which the identities of scientist-as-subject and constructed-scientific-world-as-object are deconstructed and reconstructed as a single blended identity.

Background to the Study

Our observations are drawn from an ongoing study of a physics research group located in a large American university whose weekly meetings we videotaped for six months. The group's work is in the general area of condensed matter physics—more specifically, in the subfield of spin glasses and other random magnetic systems. At their weekly meetings, the most prevalent activity is the presentation of work-in-progress, incorporating visual representations of many kinds, such as blackboard sketches, overhead transparencies, computer printouts, and other printed matter. For long stretches of interaction, members lean graphs on a table or gesture toward a blackboard sketch while they think through their findings. It is

2. Bruno Latour, "Drawing Things Together," in Lynch and Woolgar, *Representation in Scientific Practice*, pp. 19–68.

through this multimodal, distributed discursive activity that these physicists narrate their scientific stories and journey through graphic space and other constructed worlds.

Role-Taking on Representational Stages

Constructing and journeying through visual representations is a collective activity involving laboratory members in different roles at different interactional moments. In some moments, for example, one member may choreograph a coauthored narrative journey while a second member enacts it:[3]

```
PI*:       ((resting head on right hand)) Now let's just s- (.)
           take your finger and start abo:ve (.) the the::
           upper transition line.
Student:   Yes.  ((Student turns toward board))
PI:        You're going to say I'm in the paramagnetic state
Student:   [Mm hm? ((turns to Ron))
           [((vertical headshakes))
PI:        Just draw your line. ((Student turns to board))
Student:   [Okay:. (      )
           [((moves finger from a to b))

* PI is an abbreviation for Principal Investigator.
```

[1] RO LAB (1-3)

At other times, one participant both choreographs and enacts a journey to dramatize his or her own version of scientific events to an audience of other laboratory members:

```
Student:   [And let me tell you (0.2) there's something (.)
           [((moves toward board; adjusts glasses))
           mo:re I can say: mtsk is [that that (0.2) those gu-
                                    [((points to j))
           that dynamics starts (0.5) not at the moment you
           [reach this point (0.5) [but [at the moment
           [((points to b, looks at PI))[((looks at board))
                                        [((points to a))
           you [cross this line.
               [((looks at PI))
```

[2] RO LAB (1-3)

3. All of the data segments in this paper are transcribed according to the conventions of conversation analysis (e.g., Max Atkinson and John Heritage, eds., *Structures of Social Action: Studies in Conversation Analysis* [Cambridge: Cambridge University Press, 1984], pp. ix–xvi). These conventions include the following: .hhh = inbreath; hhh = outbreath; *underline* = emphatic stress; : = sound stretch; (0.2) = pauses in seconds and fractions of seconds; (.) = micropause (less than 0.2 seconds); ((*comment*)) = nonvocal

The above interactional segments are but a sample of participants' ever-changing role perspectives as they act out scientific dramas on the intertextual stage space of visual representation. Below we consider how visual representation links linguistic constructions and embodied gestures and how, through this multimodal interpretive activity, physicists and constructed physical entities journey together through virtual symbolic space and simultaneously experience the effects of manipulated and imagined physical processes.

How Visual Representations Structure Scientific Storytelling

Throughout their interactions, the physicists themselves are not unaware of the constructed nature of their interpretations and arguments. Indeed, they explicitly label their own interpretive discourse as "stories" in utterances such as "Are we all following what the story is so far?"; "It's a different story"; "Why don't you: (.) let me: (.) finish the story?"; "But that's a different story I think." This is not to say that the physicists believe themselves to be mere storytellers, but that their interaction routinely reveals that they are conscious of the interpretive nature of their research enterprise.

Building Intertextual Stories

One of the tremendously important vehicles for moving scientific narratives along is the sketching of graphs on the blackboard. Indeed, the physicists rarely tell their narratives using language as the sole resource and occasionally even stop talking until some form of visual representation is introduced. At the blackboard, they can build up representations over narrative time, by, for example, representing (for current purposes) a published graph as an abstracted sketch and overlaying it with other lines and marks to represent different past and possible experimental trajectories and results. As mentioned, they routinely produce highly mutable, intertextual representations of multiple scientific narratives as they go about their interpretive work. No graph is sacred; even often-referenced

action or transcriber's comment; . = falling intonation; ? = rising intonation; , = continuing intonation; ?, = slightly rising intonation; bolded text = phenomenon of focus; [= overlapping talk or actions; ( ) = doubtful hearings; bu- = cutoff sound or syllable; °you° = low in volume; >well< = speeded-up speech; CAPS = loud volume; ^ = sudden pitch rise; * = vocal fry. Several of the segments from transcript (1–3) include descriptions of hand movements made on a complex blackboard sketch (see discussion of Figs. 1-5 below); to capture the precision of these hand movements and gestures, we have annotated one version of this sketch with lowercase letters roughly corresponding to the places that the participants point to or touch in the course of the interaction. See Appendix for the key to the nonverbal description.

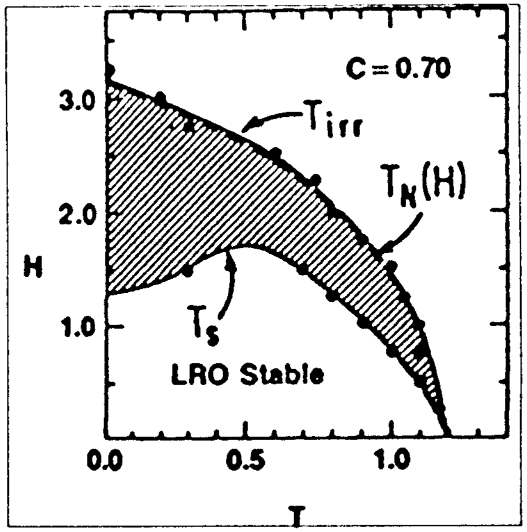


Figure 1. Original phase transition diagram. From Gary S. Grest, C. M. Soukoulis, and K. Levin, *Physical Review B* 33 (1986), p. 7667. Reproduced with permission.

representations are deconstructed and transformed into records of ongoing collaborative thinking.

For instance, one particular blackboard sketch, frequently drawn in the course of discussing certain experimental results, is an abstraction of a published graphic representation by Grest, Soukoulis, and Levin; in its original version, this theoretical model is a phase-transition diagram for a diluted antiferromagnet obtained from mean field simulations (see Fig. 1).[4]

In laymen's terms, Grest et al. argue in this figure that, depending on the combination of temperature and strength of magnetic field, atomic spins in a diluted antiferromagnet can be predicted to exhibit different states of order. In Figure 1, these states are an unstable "paramagnetic" state (above the shaded region), a metastable "domain" state (the shaded region), and a possibly stable "long range ordered" state (below the shaded region). However, when this phase-transition model is referred to in the group's deliberations, it is typically sketched on the board in an abstracted form.

In one particular meeting, the Grest et al. model is introduced into the discussion when a graduate student is given the floor to re-

4. Gary S. Grest, C. M. Soukoulis, and K. Levin, "Comparative Monte Carlo and Mean-Field Studies of Random-Field Ising Systems," *Physical Review B* 33 (1986): 7659–7674; in the original publication, this figure appears as Figure 5.

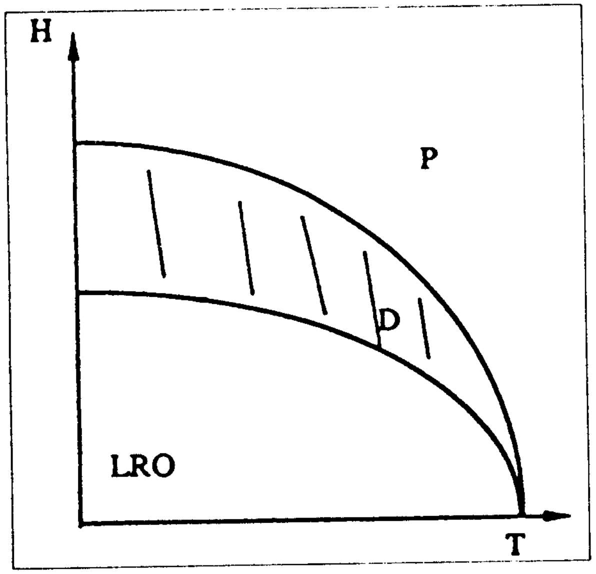


Figure 2. Sketched version of Grest et al. diagram.

port on his most recent thinking about a line of experimental research he has been pursuing: trying to find experimental evidence for the Grest et al. phase-transition argument in a diluted antiferromagnet. Preliminary to his recapitulation of the theoretical background to his work, the student sketches a version of Grest et al.'s phase diagram on the board (see Fig. 2). As can be seen, the published diagram has been abstracted to an *x* versus *y* axis graph on which a relationship between magnetization (*H*) and temperature (*T*) is plotted. The three atomic order states are indicated by initials: *P* for paramagnetic state, *D* for domain state, and *LRO* for long range ordered state.

Later in the same discussion, an experimental study by another group (the "Kleemann" experiment)[5] is introduced. As he narrates, the student traces a line representing that group's protocol with his

5. The members are referring to the experimental work at another institution of a group of condensed matter physicists, one of whom is W. Kleemann. A previously published report coauthored by Kleemann and relevant to the work of the group we observed is P. Pollack, W. Kleemann, and D. P. Belanger, "Metastability of the Uniform Magnetization in Three-Dimensional Random-Field Ising Model Systems II: Fe0.47Zn0.53F2," *Physical Review B* 38 (1988): 4773–4780.

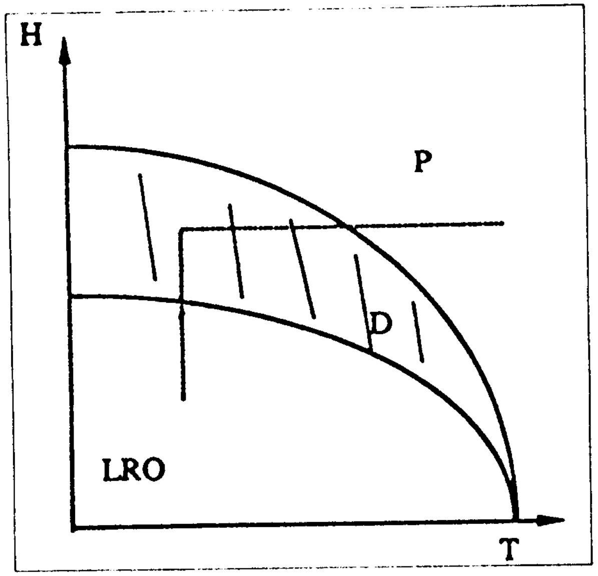


Figure 3. Grest et al. sketch with Kleeman experiment added.

finger on the Grest et al. sketch, beginning from a point within the paramagnetic region of the graph and ending in the long range ordered region. The visible path of his finger tracing in the chalk dust is represented in Figure 3 by a dotted line.

Soon after, as the principal investigator is checking his understanding of the graduate student's experimental arguments, he adds a line to the sketch, representing the student's own protocols at a particular lower magnetic field (see Figure 4).

The sketch contains lines and spaces that represent three scientific "texts": the Grest et al. theoretical simulation, the "Kleemann" experiment, and the graduate student's experiment. In addition, the sketch is itself a text representing a record of this scientific discussion, and it will be even further modified as the thinking-through process of the participants evolves.

Indeed, the discussion lasts over one hour, during which time the participants continue to come to the board and orient to the graph through various modes (speech, gesture, and writing). They make additional amendments to the intertextual graphic representation, such as darkening lines already made or traced, adding *x* marks on critical points, and cross-hatching to indicate individual

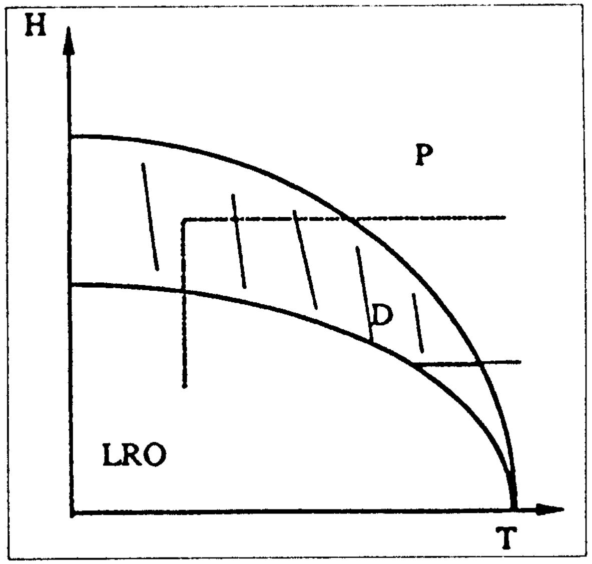


Figure 4. Addition of graduate student's experimental protocol.

incremental intervals along a line. Figure 5 is a rendering of what the sketch looks like well into this meeting.

Figures 1 through 5 illustrate how scientists can take seemingly immutable inscriptions, such as published graphic displays, and, over narrative time, transform them into highly mutable, highly intertextual and symbolic narrative spaces through which they verbally, gesturally, and graphically journey. Paradoxically, perhaps, these contingently transient visual representations, which are not written down by the participants and which eventually get erased, are nevertheless an important means by which physicists work through problems of understanding and come to a consensus on matters of interpretation.

Attention to Physical Properties of the Visual Representation

But whether visual representations are made of chalk dust or paper and ink, they all have important physical properties to which the participants attend. Three of these are (1) boundaries that delimit conventionally defined spaces; (2) visual aspects of the spaces themselves; and (3) a static quality that works against the dynamic nature of the stories these physicists tell.

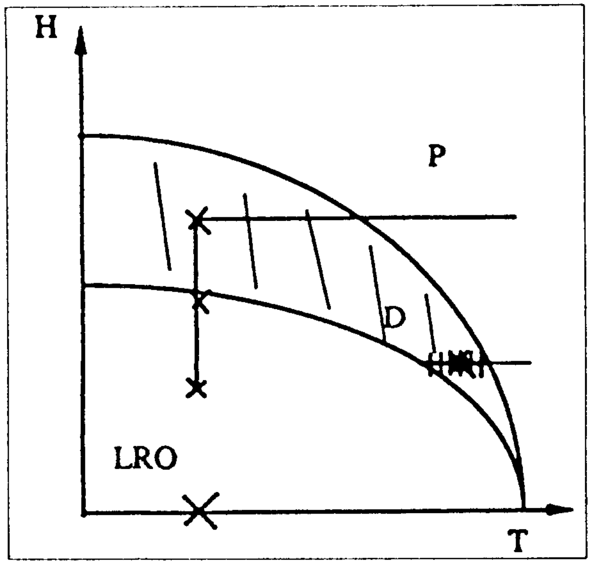


Figure 5. Intertextual representation with additional annotations.

Boundaries Visual representations make scientific narrative possible because they organize a physical and symbolic space for sense-making in an otherwise undifferentiated blank plane. When participants sketch a graph, the first lines they draw are the vertical and horizontal axes. Once these external boundaries have defined the narrative stage space, other internal lines and marks are added that partition this space into more particular points and locations, so that a specific story may be told. As noted, the same narrative space can also be redefined to tell another narrative. However, the narrative spaces defined by internal and external boundaries are not necessarily taken to be clearly understood, agreed with, or possible. In one interactional moment, the physicists may construct a visual representation to further a physical argument, while in the next moment, a group member may suggest it be altered or totally reconsidered.

Visual Aspects Members routinely frame their narratives in terms of the visual aspects of graphic representations, including reference to their visible nature,

```
               ((Student standing at whiteboard on which by now there are
                    three sketched graphs))
   Student:    [THE GREAT PICTURE is my uh::
               [((big shoulder shrug, arms turn outward, head tilts left,
                    takes a few steps back))
               [static picture.
               [((steps toward chair))
```

[3a] RO LAB (11-14)

shapes,

```
              ((Student has just completed drawing a diagram on the
                   board))
   PI:        You you have it flat up there and then you have it
              curving over.
```

[3b] RO LAB (10-17)

colors,

```
   Student:  Well but (.) experimentally: (0.5) at- for the
             green curve (.) you use these parts (.) these
             deltas only. (1.0) and for the [other one maybe
             these deltas and              [((points to different
                                                 curve))
             [for the blue curve these deltas
             [((points to different curve))
             and [for the black curve these deltas (0.8)
                 [((points to different curve))
             because of (0.5) they grow logarithmically.
```

[3c] RO LAB (10-17)

and two-dimensionality:

```
   PI:         If you take your li:ne there (0.2) and you-
               temperature [quench (0.5) down to:: where I
                           [((Student looks at board))
               have that word [long range order,
                              [((Student rises, goes to board))
   Student:    Yeah,
   PI:         will you see any dynamics at all down there?,
```

[3d] RO LAB (1-3)

Such semiotic practices indicate that graphs are treated by the interlocutors both as objects for representing some constructed physical world and as objects having their own semantic and deictic importance. When narrators are speaking, gesturing, and drawing, they are thus asking coparticipants not only to look *through* a graph to some represented world but also to look *at* the graph as a referential object in and of itself.

Static Quality The narratives told by physicists as they travel through graphic space concern conventionally recognized substances undergoing dynamic processes within a conventionally constructed physical world. One significant constraint on the telling of such narratives is that dynamic processes are constructed visually onto an atemporal, static, symbolic plane. While members may supply a sense of temporality and dynamism on the basis of their background knowledge when interpreting such symbolic planes, the properties of the static display thwart adequate representation of time and change. Temporality and change of state often are not directly indexed in the graphic representations themselves. And even when, for example, time is mapped onto a graphic display, its representation relies on the spatial properties of line length, directionality, and calibration to indirectly depict the passage of time. Participants often become confused about the dynamics that the display represents and request clarification. In the absence of computer-animated images, these scientists are faced in their day-to-day interpretive work with the limitations of a relatively primitive technology of representation.

Bringing Dynamism into the Visual Representation

Despite the static nature of two-dimensional graphic displays, participants in scientific storytelling in the laboratory that we observed routinely create a dramatic sense of the dynamism of actions and processes by putting into play (1) dynamic gestures in the graphically defined space, and (2) grammatical constructions that denote motion, change of state, transitivity, duration, and time of events.

Dynamic Gestures

Gestural journeys within the frame of a graphic display usually involve moving a finger (or other tool) along the trajectory of a line, crossing over a line, or moving from one symbolic point in the display to another. Thus, for example, laboratory members may pantomime the process of an increase or decrease in temperature by moving a finger along an axis representing temperature increments (see segment [4c] below). Or they may dramatize a change in the atomic order of a magnetic substance by moving a finger across lines that conventionally index phase transitions (see segments [1] and [2] above). Specific experimental procedures may also be iconically reenacted within the visual display. For example, a storyteller may gesturally reenact cutting the magnetic field by drawing an *X* on the graphic display (Fig. 5).

The combination of dynamic gesture and grammar is a ubiquitous practice in the interactions of the physicists. They not only direct their joint attention to static, two-dimensional graphic representations, they also animate those representations by gesturally and verbally enacting dynamic events.

Dynamic Grammar

The physicists draw on a wide range of linguistic resources for imbuing static displays with dynamism. These grammatical constructions include:

- *motion/change-of-state verbs*
  (e.g., "come," "go," "leave," "cross over")
- *transitive verbs*
  (e.g., "cut," "cool," "freeze," "heat")
- *experiential predicates*
  (e.g., "experience," "has knowledge of")
- *conjunctions*
  (e.g., "then," "as," "when," "before," "after")
- *tense and aspect marking*
  (to indicate completion, on-goingness, etc.)

Such grammatical resources bring to life the otherwise stationary quality of a two-dimensional representation. They can be used to depict dynamic events such as experimental procedures, results, or phase-transition processes.

Bringing Participants into Constructed Worlds

Dynamic grammar and dynamic gesturing through a visual representation are also a means of bringing scientists more intimately into the visual representation and the worlds it represents.

Sensori-Motor Construction of Narrative Involvement

Sensori-motor activity is one mode of learning through which humans come to know the world, especially in the earliest stages of

life.[6] By touching and manipulating objects, we experience our world in a way different but complementary to other perceptual and intellectual means of knowing. In the physics laboratory, members are trying to understand physical worlds that are not directly accessible by any of their perceptual abilities. To bridge this gap, it seems, they take embodied interpretive journeys across and through see-able, touchable two-dimensional artefacts that conventionally symbolize those worlds. While in some cases the members do not actually touch a representation, they may journey to some part of it by gesturing along a delineated trajectory or toward a particular point, even at some distance (e.g., while seated at a table). In this sense, their sensori-motor gesturing is a means not only of representing (possible) worlds but also of imagining or vicariously experiencing them.

Interpretive journeys are thus akin to the activity of virtual witnessing, through which a detailed printed and visual representation of an experimental procedure affords a reading audience a sense of having directly perceived and been involved in its undertaking, enlisting them in the validation of experimental claims.[7] In the physics laboratory, visual representations play a similar role in that they allow interlocutors to (re)experience protocols and results depicted on blackboards, printouts, and transparencies. In both types of virtual witnessing, visual representations are annotated to enhance the ability of the interlocutor/reader to symbolically reconstruct the procedures of other scientists and experience the physical conditions, states, and processes that are claimed to have occurred. In the physics laboratory, however, this virtual witnessing is embedded in a collaborative face-to-face problem-solving activity, and thus the details of experimental and theoretical stories are often reviewed, reenacted, and reexperienced numerous times over the course of a single laboratory meeting, or even across meetings, through gestural and verbal journeys in graphic spaces.

Grammatical Construction of Narrative Involvement

In addition to sensori-motor ways of experiencing physical phenomena, physicists use certain grammatical constructions that situ-

6. See, for example, Jean Piaget, *The Construction of Reality in the Child* (New York: Basic Books, 1954); Jean Piaget and Baerbel Inhelder, *The Psychology of the Child* (New York: Basic Books, 1969).

7. See Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life* (Princeton: Princeton University Press, 1985); Charles Bazerman, *Shaping Written Knowledge: The Genre and Activity of the Experimental Article in Science* (Madison: University of Wisconsin Press, 1988).

ate them within a visual representation and the constructed physical worlds indexed by that representation. More aptly, we should say that the use of particular grammatical constructions situates the physicists in a *liminal* world that appears to hover between the representational world of the visual display and the constructed worlds it indexes.

In this liminal world, sharp boundaries are not drawn linguistically between subject (i.e., researcher) and object (i.e., the physical phenomenon under study). That is, the physicists' grammatical choices deconstruct place and identity, and a referential indeterminacy results. One particular grammatical construction that creates liminality and indeterminacy is composed of a *personal pronoun,* prototypically referring to an animate, usually human referent, and serving as grammatical subject, and a *predicate denoting change of state,* which prototypically would be attributable to an inanimate referent:

$$\text{Personal Pronoun}_{\underline{\text{animate}}} \parallel \text{Predicate}_{\underline{\text{inanimate}}}$$

The personal pronouns most commonly used as grammatical subjects in these utterances are "I" and "you."[8] The predications are generally change-of-state expressions, such as "breaking up into domains" and "go below in temperature." The personal pronouns "I" and "you" orient the interlocutors to attend to one another as possible referents in a here-and-now world of ongoing laboratory discussions. On the other hand, the predicates that accompany these pronominal forms pull the interlocutors into the world of physical entities. These constructions thus place interlocutors in an unsettled, liminal context, which is neither entirely here (i.e., in the interactional setting) nor entirely there (i.e., in the constructed physical world).

Other grammatical details of these utterances contribute to the construction of liminality and indeterminacy. For instance, the predicates tend to be formulated with simple present or present progressive verb tenses that index generic, normative, enduring, and possibly ongoing conditions. Rather than denoting specific events or states occurring at some specific time, these predications denote events and states that take place, or might take place, whenever or if ever certain conditions hold.

Additionally, while the personal pronouns index the immediate speaker-addressee relationship of the interlocutors, they also convey a sense of indefiniteness. Specifically, given that physicists could not be "breaking up into domains" or "in a domain state," the referent of "I" appears to include not only the speaker but anyone or anything in the speaker's situation, and the referent of "you" includes not only the addressee but anyone or anything in the addressee's situation. The use of pro-forms "I" and "you" in this indefinite sense does not limit the boundaries of the referent to a specified entity, but rather seems to extend the referential boundaries of the grammatical subject to include an unspecified class of entities.[9]

8. In the interactions we have examined, all the members produce these utterances with "you" (and sometimes "we"), while the principal investigator seems to be the only one who produces such constructions with the pronoun "I."

Examples of these liminal, indeterminate grammatical constructions are given below. These constructions are boldfaced for ease of identification:

"I"

```
PI:       .hh and I will tell you that there is a barrier
          (that) [I just can't hop over.
                 [((bounces hand in air with each word))
```

[4a] RO LAB (10-10)

```
          ((Student at whiteboard; PI mostly out of frame))
PI:       And then why am I breaking up into domains at
          a::ll.
```

[4b] RO LAB (11-14)

```
PI:       [Y- you're saying he:re [that
          [((points to b; Student moves toward board))
                                  [((Student turns away from
                                   board & toward table))
          [this point (0.5) corresponds to
          [((moves finger off & on b))
          the [absence of (a) domain structure.
              [((Student turns to board))
          [If  I  go    [below in temperature,
          [((finger to g)) [((looks at Student))
               [(0.2) the domain structure [(.) (is gone).
               [((Student vertical headshakes)) [((flips left
                                              hand up in air))
```

[4c] RO LAB (1-3)

9. See Elinor Ochs, Patrick Gonzales, and Sally Jacoby, "'When I Come Down I'm in the Domain State': Grammar and Graphic Representation in the Interpretive Activity of Physicists," in Ochs, Schegloff, and Thompson, *Grammar and Interaction* (above, n. 1) for a detailed linguistic analysis of the referential properties of these utterances.

"YOU"

```
Post-Doc: You: you: get the formation of the
          barri[ers (.) and=
PI:            [(Right.)
Post-Doc: =you're inside (a) barrier and all you're doing is
          you're fluctuating inside that barrier on that
          time scale,
PI(?):    Yeah
```

[4d] RO LAB (10-10)

```
Student:  [And let me tell you (0.2) there's something (.)
          [((moves toward board; adjusts glasses))
          mo:re I can say: mtsk is [that that (0.2) those gu-
                                   [((points to j))
          that dynamics starts (0.5) not at the moment you
          [reach this point (0.5)    [but [at the moment
          [((points to b, looks at PI))  [((looks at board))
                                          [((points to a))
          you [cross this line.
              [((looks at PI))
```

[4e] RO LAB (1-3)

These constructions are utterly commonplace and unproblematic for the laboratory members. Participants do not appear to take these utterances at face value. Instead, they seem to construct other interpretive frames for such constructions.

A Figurative Interpretation Since the physicists do not appear to interpret these utterances literally, it may be that these liminal, indeterminate constructions make sense figuratively. Perhaps the interlocutors, as storytellers would, are assuming the perspective of some inanimate physical entity protagonist that is undergoing a change of state. In this interpretation, an utterance such as "Why am I breaking up into domains at all?" might be interpreted as meaning "Why am I [a physicist in the role of physical entity] breaking up into domains at all?" Such a reading allows the referent of "I" to be at least double-voiced: it is both the physicist and the anthropomorphized constructed physical system. Like an actor who has assumed a character, the physicist laminates the identity of the physical construct onto his or her own identity. The result is that the physicist-as-constructed-subject and the physical-entity-as-constructed-object become intertwined; the boundaries that might otherwise distinguish them become indistinct. The "I" or the "you" is both subject and object, animate and inanimate, with the identity of the physicist in the here-and-now world of ongoing interaction being backgrounded, and the anthropomorphized identity of the physical constructs being foregrounded.

An Activity-Based Interpretation While it is reasonable to imagine that physicists engage in this figurative kind of referential transposition, through which they project themselves into the constructed world of physical entities, this interpretive frame is not entirely adequate. Crucially, it does not consider the role of visual representations in the meaning-making. First, these constructions often refer to "lines," "points," etc., which exist only in the world of the visual representation. An exclusively figurative interpretation of an utterance such as "that dynamics starts (.) not at the moment you reach this point (0.5) but at the moment you cross this line" fails to take into account that the constructed worlds of physical systems have neither points that can be reached nor lines that can be crossed.

Secondly, these constructions contain numerous deictic expressions, such as "here," "there," etc., which also index locations and trajectories within a visual representation. The constructions, therefore, thrust the referent of "I" and "you" into the visual display, which in turn bridges the here-and-now and the constructed physical systems under study. Thirdly, and perhaps most importantly, all these expressions that index aspects of the graphic display are typically accompanied by gestures that trace, point to, and move through the visual representation. When members of the physics laboratory produce constructions containing a personal pronoun plus a change-of-state predicate, their eyes and bodies, hands and fingers usually orient to the graphically defined spaces, points, and lines on blackboard sketches, overhead transparencies, and computer-generated printouts.[10]

Indeed, the design of the graphic display can be so powerful that gestural trajectories may follow it, rather than the common meanings of words in the utterance. For instance, in interactional segment [4c], when the speaker says "If I go below in temperature,"

10. Once particular visual conventions have been introduced into the ongoing discourse, physicists may index them with "personal pronoun + change of state" constructions but will not necessarily continuously look at or touch them. In our observations, however, the physicists do not seem to be able to sustain talk for very long without focusing their visual and gestural attention on graphic tools.

his hand takes a gestural journey from right to left, rather than downward, along the horizontal temperature axis of the graph. He is thus "go[ing] below in temperature" because part of his body is enacting the change of state in the physical system according to the conventions of the graphic display. The sequence of video stills in Figure 6, taken from [4c], illustrates how, when talking of "go[ing] below in temperature," the principal investigator gestures horizontally from point [b] on the diagram to point [g].

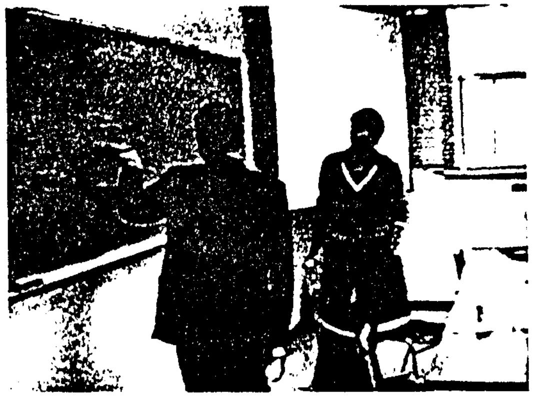
An activity-based interpretation takes into account the larger interpretive activities of the physicists, which include not only their talk, but also their gestures and the visual representations to which they orient in the course of their scientific storytelling. When this multimodal activity is seen in its entirety, the referential meaning of "I" and "you" in indeterminate constructions is qualitatively different. Specifically, through verbal and gestural (re)enactments of constructed physical processes, physicist and physical entity are conjoined in simultaneous, multiple constructed worlds: the here-and-now interaction, the visual representation, and the represented physical processes. These indeterminate grammatical constructions, along with gestural journeys through visual displays, constitute physicist and physical entity as coexperiencers of dynamic processes and, therefore, as coreferents of the personal pronouns.

Implications

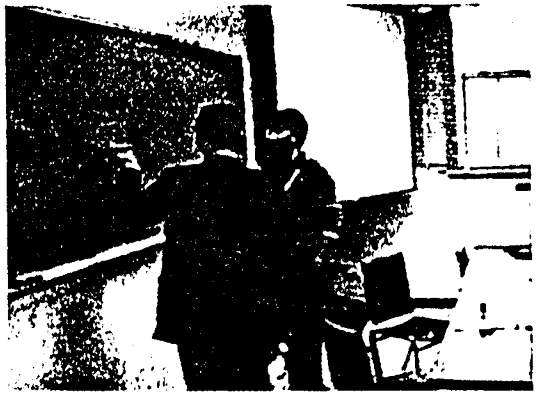
The present study of communicative practices in a physics laboratory suggests that visual representations together with the interactional employment of grammar and gesture can diffuse the boundaries between the scientist as subject and the constructed physical world as object. This multimodal interpretive activity deconstructs the distinction between animate subjects and inanimate objects by providing a locus wherein physicists and constructed objects are symbolically conflated. Visual representations are thus interpretive frames for understanding the dynamics of both inanimate physical entities and those who are visually, verbally, gesturally, and/or imaginatively journeying through a two-dimensional display.

Studies of scientific practice have promoted the view that scientists exploit discursive practices to either express or suppress their subjective involvement as agents in scientific "discovery."[11] But

11. See, for example, Shapin and Schaffer, *Leviathan and the Air Pump* (above, n. 7); Bazerman, *Shaping Written Knowledge* (above, n. 7); and Latour, "Drawing Things Together" (above, n. 2).



PI: [Y- you're saying he:re [that
[((*points to b; Student moves toward board*))
[((*Student turns away from board & toward table*))
[this point (0.5) corresponds to
[((*moves finger off & on b*))
the [absence of (a) domain structure.
[((*Student turns to board*))



[If I go [below in temperature,
[((*finger to g*)) [((*looks at Student*))

Figure 6. Gesturing at the board.

[(0.2) the domain structure [(.) (is gone).
[((Student vertical headshakes)) [((flips left hand up in air))

whether their agency is discursively encoded or masked, both these rhetorical choices presuppose a fundamental discreteness between scientist as subject and constructed physical world as object. This study has focused on a third pervasive rhetorical practice, which, through the media of language, visual representation, and gesture, *conjoins* physical entities and physicists in two ways: (1) as *coexperiencers* of physical conditions and processes, and (2) as *coreferents* of personal pronouns in grammatical constructions composed of a personal pronominal subject and a change-of-state predicate. Visual displays thus promote moments of shared biography and shared narrative between physicist and physical entity.

When members of the physics laboratory journey across visual displays through talk and gesture (or in their imagination), they may construct themselves grammatically and somatically both as subjects engaged in interpretive activity and as objects of interpretation. Utterances such as "When I go below in temperature" deconstruct the distinct social identities of scientist and scientific object, constructing in their place a blended, indeterminate identity. Like the image of the cyborg,[12] this conjoined social identity conflates animacy and inanimacy and thrives in a liminal zone between here-and-now interaction, visual representation, and represented physical worlds, rather than in any single constructed world.

12. See Donna Haraway, *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York: Routledge, 1991).

Acknowledgments

This study is part of a larger project, "The Socialization of Scientific Discourse," directed by Elinor Ochs and funded by The Spencer Foundation (Grant no. M900824, 1990-1993). Additional funding was provided by a UCLA Faculty Senate Grant.

Appendix

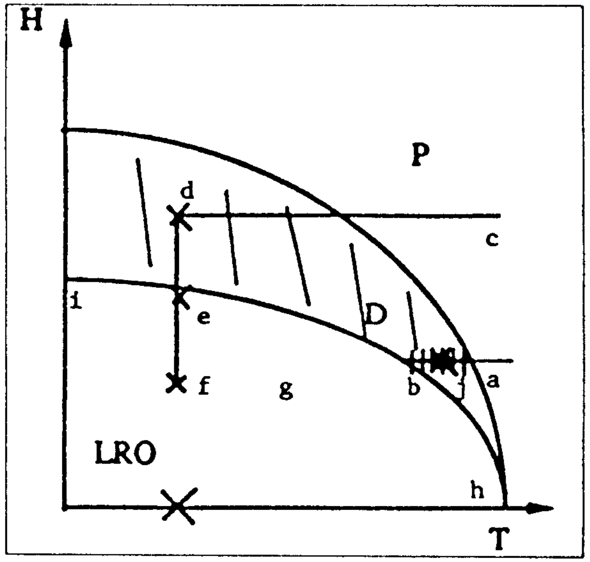


Figure 7. Built-up sketch with gestural key.