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Information Performances and Illative Sequences:
Sequential Organization of Explanations of Chemical Phase Equilibrium

by

Nathaniel James Swanton Brown

A dissertation submitted in partial satisfaction of the
requirements for the degree of
Doctor of Philosophy

in

Science and Mathematics Education

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:
Professor Angelica M. Stacy, Chair
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Information Performances and Illative Sequences:
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Abstract

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Professor Angelica M. Stacy, Chair

While there is consensus that conceptual change is surprisingly difficult, many competing theories of conceptual change co-exist in the literature. This dissertation argues that this discord is partly the result of an inadequate account of the unwritten rules of human social interaction that underlie the field's preferred methodology—semi-structured interviewing.

To better understand the contributions of interaction during explanations, I analyze eight undergraduate general chemistry students as they attempt to explain to various people, for various reasons, why phenomena involving chemical phase equilibrium occur. Using the methods of interaction analysis, I characterize the unwritten, but systematic, rules that these participants follow as they explain.

The result is a description of the contributions of interaction to explaining. Each step in each explanation is a jointly performed expression of a subject-predicate relation, an interactive accomplishment I call an *information performance* (in-form, for short). Unlike clauses, in-forms need not have a coherent grammatical structure. Unlike speaker turns, in-forms have the clear function of expressing information. Unlike both clauses and speaker turns, in-forms are a co-construction, jointly performed by both the primary speaker and the other interlocutor. The other interlocutor strongly affects the form and content of each explanation by giving or withholding feedback at the end of each in-form, moments I call *feedback-relevant places*.

While in-forms are the bricks out of which the explanation is constructed, they are secured by a series of inferential links I call an *illative sequence*. Illative sequences are forward-searching, starting with a remembered fact or observation and following a chain of inferences in the hope it leads to the target phenomenon. The participants treat an explanation as a success if the illative sequence generates an in-form that describes the phenomenon. If the illative sequence does not, it is partly or entirely scrubbed, a new in-form is introduced as a starting point, and the illative sequence begins anew.

Knowledge of these interactional contributions to the production of explanations could allow researchers to better characterize conceptual understanding, be in a stronger position to support particular theories of conceptual change over others, improve assessments of conceptual understanding, and improve interviewing practices.

—to Eve
never doubt I love

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Research on conceptual change

By the late 1980s, it had been firmly established that students and other non-professionals explain scientific phenomena in ways that deeply conflict with normative conceptions and persist despite years of instruction. Since that time, the goals of research on conceptual understanding have been steadily shifting away from cataloguing differences in content between student and scientific conceptions. A new focus on *conceptual change* has emerged, in which the goal is to explain how pre-instructional understanding develops into expertise and how this process can be facilitated in science classrooms. Such a focus requires a theoretical understanding of the cognitive entities and processes that underlie conceptual change.

Unfortunately, while there is consensus that conceptual change is surprisingly difficult, there is little agreement in the field over what gives rise to this phenomenon or how change can best be effected. As a result, many competing theories of conceptual change co-exist in existing literature. These theories provide different and often explicitly contradictory descriptions of the entities and processes involved in conceptual change. This discord is especially troubling because these theories suggest distinct and largely incompatible goals for instruction.

This dissertation presents the argument that the theoretical problems of the field are the result of several extant methodological issues. In this chapter, I will first outline the various major theoretical perspectives in the field. Then I will make the claim that, while one of the field's preferred methodologies—interviewing—is deeply structured by the unwritten rules of human interaction, this structure is inadequately taken into account during analysis. As a consequence, prominent features of the same data could be interpreted by different researchers as supporting conflicting theories.

In subsequent chapters, I will apply an established methodology that is largely unknown in conceptual change research—interaction analysis—in an attempt to better characterize and take into account the contributions of interaction to interview data. Specifically, I will analyze the explanations given by eight undergraduate general chemistry students as they attempt to explain to various people, for various reasons, why phenomena involving chemical equilibrium occur. Using the methods of interaction analysis, I will characterize the unwritten but systematic rules and expectations regarding interaction that these participants follow as they explain in these contexts. The result will be a description of the interactional contributions to the production of these explanations.

Theories of Conceptual Change

The goal of any theory of conceptual change is to explain two peculiarities of conceptual understanding. First, in contrast to other forms of knowledge, a person's conceptual system is regarded as being stable and surprisingly resistant to change, even in the face of relevant instruction over the course of years (e.g., in the case of Newtonian mechanics, see Champagne, Klopfer, & Anderson, 1980; Clement, 1982; McCloskey, Caramazza, & Green, 1980). Second, the conceptual systems of lay people, including students, are often fundamentally different than those of experts or professionals, rather than simply being absent (for reviews, see Confrey, 1990; Driver & Easley, 1978; Eylon & Linn, 1988; Pfundt & Duit, 2009). This observation has led to the normative distinction between, on the one hand, scientific conceptions and, on the other hand, what have been termed intuitive conceptions, naïve conceptions, preconceptions,

misconceptions, or alternative conceptions.

Theoretical specifications of the entities and processes involved in conceptual change are striking in their diversity. Broadly, theories of conceptual change can be classified into three categories depending upon the nature and interrelations of the entities in the proposed conceptual system: concept networks, hierarchical systems, and weakly organized systems. These are post-hoc categories developed by the author in an attempt to bring some order to the manifest variety of theories described in the literature. For a more thorough review of the conceptual change literature that examines the relationships between these theories from several perspectives, see diSessa (2006).

Concept Networks

The first family of theories, and the first to be proposed in the literature, claims that a person's conceptual system is a network of *concepts* embedded in a web of relations called *beliefs* (sometimes referred to as *propositions*). A concept is a unit of mental representation that represents a category of things in the world such as *animal* or *force*; a belief specifies a relation between two or more concepts.

Concept-network theories draw heavily from a tradition in philosophy of science, exemplified by Kuhn (1962) and more recently espoused by Thagard (1992), in which the hallmark of theory change in science is the fundamental incompatibility between the scientific concepts that are invoked before and after the change. Concept-network theories apply this model of revolutionary change to cognitive concepts, the theoretical entities inherited from a tradition in cognitive science in which they function as the fundamental unit of cognition. In this tradition, concepts are the language in which declarative knowledge is stored and the entities to which production rules and other operators apply (for overviews, see E. E. Smith, 1989; Thagard, 2005).

Accordingly, concept-network theories claim that individuals think about phenomena using the network of concepts they possess and that this network excludes other ways of thinking that depend on different concepts. So, for example, a child might possess the concept *weight/density*, a developmentally early concept of heaviness or heft in which the ideas of weight, density, and size are conflated (C. Smith, Carey, & Wiser, 1985). This concept might be connected to other concepts, such as *grown-up* and *baby*, by the belief that *grown-ups are heavier than babies*. For this child, who does not possess the differentiated concepts of mass, volume, and density, the scientific beliefs that adults and children differ in mass and volume but have roughly the same density would be, in a deep sense, unthinkable. Borrowing the term from Kuhn (1962), Carey (1991) refers to this incompatibility between the child's intuitive theory and the normative scientific theory as *incommensurability*.

Researchers working in this tradition contend that conceptual change is difficult because the concepts in an individual's conceptual system have to be modified, distinguishing conceptual change from knowledge enrichment, which involves the relatively unproblematic revision of one's beliefs (Carey, 1985, 1991). Modification of concepts may take the form of differentiation (e.g., the splitting of the concept *weight/density* into new separate concepts of *weight* and *density*) or coalescence (e.g., the combination of the separate concepts *plant* and *animal* into the new concept *living thing*).

Intuitive theories. Most researchers who subscribe to the concept-network model argue that clusters of related concepts and beliefs, called *intuitive theories*, define the boundaries of mental domains. For example, Gopnik and Wellman (1992, 1994) argue that, by age 5, the

intuitive psychology of young children contains three concepts—*perception*, *desire*, and *belief*—and that these concepts satisfactorily explain all of children’s psychological judgments concerning actions taken by themselves and others. Moreover, these concepts have no bearing on physical judgments of the motions of inanimate objects, such judgments being explained by a different set of concepts. Gopnik and Wellman refer to their theory about intuitive theories as the Theory Theory, reflecting their claim that an expansive but well-defined phenomenology is explained by a small set of interrelated elements in a way reminiscent of scientific theories. Intuitive theories have also been invoked to explain early childhood conceptual understanding of living things (Carey, 1985; Inagaki & Hatano, 2002) and matter (C. Smith, et al., 1985; C. Smith, Maclin, Grosslight, & Davis, 1997).

Beyond the difficulty associated with concept modification, conceptual change involving theory change is particularly arduous because of the degree of interconnectedness within the concept network: one concept cannot be modified without affecting the other concepts involved in the intuitive theory. Consequently, and in analogy to descriptions of theory change in professional science (Kuhn, 1962; Lakatos, 1970), students are expected to invoke a variety of strategies to dismiss or minimize counterevidence and preserve their existing conceptual system before finally succumbing to theory change (Chinn & Brewer, 1993; Gopnik & Wellman, 1994). Theory change, when it does occur, has a *gestalt* and rational character (Posner, Strike, Hewson, & Gertzog, 1982; Thagard, 1992).

Intuitive theory theories have impacted instruction largely through the development of concept mapping and confront-and-replace as instructional tools in the early 1980s. A concept map is meant to be an external representation of a portion of a student’s concept network, in which concepts are represented by nodes connected by lines representing beliefs. Concept maps were originally developed as reflective aids for students and teachers (e.g., Novak & Gowin, 1984); more recently, attempts have been made to analyze concept maps quantitatively in the context of assessment (Ruiz-Primo & Shavelson, 1996; Shavelson, Ruiz-Primo, & Wiley, 2005). *Confront-and-replace* is the term used to describe strategies for prompting dissatisfaction with the current theory and satisfaction with a new theory.

Ontological categories. For the most part, researchers working in the concept-network tradition remain agnostic with respect to the underlying nature of concepts, most likely presuming that the nature of concepts is irrelevant. In contrast, Chi and her colleagues focus on a particular model of concepts known as schemas. They argue that differentiation and coalescence are relatively unproblematic processes because they involve the modification of concepts contained within the same hierarchical tree (Chi, Slotta, & de Leeuw, 1994).

For example, the concepts *plant* and *animal* both belong to the Matter tree and therefore already share a number of common ontological attributes that can modify either, such as “being colored” or “having mass”. This set of overlapping attributes makes the coalescence of *plant* and *animal* into *living thing* much easier than concept modification that involves an *ontological shift* across hierarchical trees. In particular, Chi and her colleagues have postulated that a shift from Matter concepts to Process concepts involving constraint-based interactions are particularly difficult and explain most of the learning difficulties associated with domains like electrical circuits (Slotta, Chi, & Joram, 1995) and natural selection (Ferrari & Chi, 1998).

The theory of ontological categories may appear to be a largely compatible extension of the theory of intuitive theories. However, the way in which *mass* is dealt with in each theory illustrates a fundamental difference. In descriptions of intuitive theories, *mass* is a concept just like *plant* and *animal* (C. Smith, et al., 1997). In the theory of ontological categories, however,

“having mass” is an attribute that applies to other concepts and is not identified as a concept in and of itself (Chi, et al., 1994). Whether this difference can be reconciled theoretically or whether it represents a fundamental incompatibility between the two theories is not clear.

Hierarchical Systems

Hierarchical models of conceptual change share a theoretical language with concept networks but characterize the structure of conceptual systems in a very different way. While theorists like Carey and Chi argue that the primary source of difficulty in conceptual change is change involving concepts, hierarchical theorists argue instead that the difficulty lies in the modification of deeply held beliefs that provide a foundation for all other beliefs.

Framework theories. A prominent hierarchical theory is that advanced by Vosniadou (1994), who calls attention to certain deeply held beliefs called *presuppositions* that deal with fundamental relationships between physical objects, space, and time. For example, two common presuppositions are that “space is organized in terms of the directions up and down” and that “unsupported objects fall down.” A collection of presuppositions forms a *framework theory*, which is extremely resistant to modification and guides and structures all intuitive knowledge about the physical world. According to Vosniadou, conceptual change is the result of the gradual recontextualization of these presuppositions as one accumulates new observations and learned facts about the world. In particular, children must learn to suspend these presuppositions in certain contexts, such as when thinking about astronomical bodies (in which context unsupported objects fall “in” rather than down). Vosniadou and colleagues have used this theory to explain learning trajectories associated with children’s conceptions of the shape of the Earth (Vosniadou & Brewer, 1992) and children’s conceptions of force (Ioannides & Vosniadou, 2002).

Weakly Organized Systems

In the concept network model of conceptual systems, the role of concepts as nodes within the system is crucial. Since an individual concept is shared among multiple beliefs, the collection of concepts and beliefs forms an interconnected network. In hierarchical systems, the importance of concepts is downplayed in favor of beliefs but the system still exhibits domain-level structure. In weakly organized systems, the notion of concepts as nodes that pin down the structure of a well-defined, coherent domain is abandoned. Consequently, such models portray conceptual systems as more fragmented.

Knowledge in pieces. DiSessa (1983, 1988, 1993) describes an individual’s intuitive physics as consisting of a weakly systematic collection of atomistic knowledge elements called *phenomenological primitives*. These elements, abbreviated as *p-prims*, are abstractions of common phenomena like the observation that *more effort begets more result*.

P-prims appear to share much in common with beliefs, particularly the presuppositions described by Vosniadou. However, in a concept network or hierarchical system, the concept of *force* is the same in all beliefs that deal with force. In contrast, the “force” described by two different p-prims—for example *force as mover* (diSessa, 1993) and *force of vibration* (diSessa, Gillespie, & Esterly, 2004)—are not necessarily the same. This means that p-prims do not cohere into a single system, as do beliefs that are pinned down by a common set of concepts.

Because they lack system-wide structure, p-prims do not necessarily organize into domains. The span of individual p-prims may be wildly different, with some being very specific and others extraordinarily general. On the one hand, *force of vibration* may apply only to physical phenomena that involve bell-ringing and similar phenomena, a relatively tiny subset of

Newtonian mechanics. On the other hand, *more effort begets more result* may span intuitive physics, intuitive psychology, and many other domains (diSessa, 2000).

How does scientific thinking evolve out of a weakly organized system? DiSessa and Sherin (1998) have proposed that the recognition of something like force is actually a process relying upon a collection of knowledge elements called a *coordination class*. Some of these elements constitute a set of *readout strategies* for gathering information from the world, while others constitute a *causal net* for inferring the existence of the force from that information. Moreover, the coordination required for recognizing a force is likely to be a relatively late stage in conceptual change. This includes the ability to integrate multiple pieces of information and to consistently see a force in a wide range of situations. From this perspective, conceptual change involves the recontextualization and reorganization of these basic knowledge elements into larger, more systematic structures like coordination classes.

Facets. Minstrell has developed a description of student thinking that identifies a large number of ideas, called *facets*, that students bring to class or construct as needed to answer questions (diSessa & Minstrell, 1996; Hunt & Minstrell, 1994; Minstrell, 1989). Many of these facets resemble diSessa's p-prims, but while p-prims are generally explanatory in function, facets can also resemble simple definitions or facts (e.g., *volume = length x width x height* or *the weight of an object is directly proportional to the pressure of the medium*). Like p-prims, facets are weakly organized and the process of conceptual change involves selecting and reinforcing productive ideas and downplaying unproductive ones.

The State of the Field

Clearly, variety is the rule in the conceptual-change literature. Remarkably, while this level of theoretical discord should present a major challenge to the field, awareness and discussion of this problem has been surprisingly absent. This may be because different researchers have largely been working in different domains and with different age groups, and therefore researchers have not perceived alternative theories as directly supporting or challenging their own work. However, even in those domains in which multiple theories are clearly in direct conflict (notably intuitive psychology and intuitive physics), consensus-building has largely been absent. More often, opposing sides present theoretical arguments for why their data clearly rule out competing theories.

Pedagogical Ramifications

Where does this discord leave practitioners of science and mathematics education? A possibility we must consider is that different theories, while theoretically incommensurable, are practically equivalent. In other words, it might be the case that different theories of conceptual change often make the same recommendations for instruction, making the choice of theoretical perspective irrelevant from a practical point of view.

As David Hammer (1996) has argued, some pedagogical principles are indeed shared by opposing theoretical camps, albeit for different reasons. In particular, both the misconceptions and knowledge-in-pieces perspectives imply the utility of exposing and making explicit how students actually think, rather than simply presenting the normative material. Likewise, both perspectives recommend exposing students to a wide variety of experiences, contexts, evidence, and arguments. Indeed, the awareness that students possess conceptual systems and that spending instructional time developing conceptual understanding, rather than memorizing definitions and solving problems, is a major step forward for instruction (C. Smith, et al., 1997).

Despite these similarities, however, subscribing fully to a theory of conceptual change can have important pedagogical ramifications. Two of these consequences concern whether conceptual change is revolutionary or evolutionary and whether it is rational or irrational.

Revolution Versus Evolution

A key difference between concept networks and weakly-organized systems is the degree of interconnectedness among elements in the conceptual system. Within a concept network, the modification of the concept of force is likely to have far-reaching effects because this concept is shared among many beliefs and is therefore connected to many other concepts. In contrast, in a weakly organized system like diSessa's, the modification of the *force as mover* p-prim may have limited or no system-wide effects. The *force as mover* p-prim may be downplayed only in certain contexts while remaining strongly cued in others. In addition, because other p-prim that appear to relate to the normative concept of force do not necessarily share the same sense of "force" as the *force as mover* p-prim, other p-prim may not be affected at all.

The primary consequence of the coherence of a conceptual system is the degree to which conceptual change is evolutionary or revolutionary. The historical reasons for these differences have been discussed by diSessa (2006), who traces one fault line back to competing perspectives in the history of science exemplified by Kuhn and Toulmin. Most theorists who adhere to the concept network model believe that conceptual change is revolutionary and, in particular, deeply similar to the process of theory change popularized by Kuhn (1962). Because the conceptual system is coherent, new knowledge that contradicts the system is difficult to incorporate and is likely to be ignored or rationalized (Chinn & Brewer, 1993). In contrast, theorists who adhere to the weakly-organized system model expect that conceptual change will be more evolutionary, as the importance of individual knowledge elements are raised or lowered in specific contexts. New knowledge that contradicts portions of the existing conceptual system can nonetheless be incorporated relatively easily, with the weak organization allowing contradictions to go unnoticed. Consequently, instruction should not focus on attacking existing knowledge structures, but on co-opting existing knowledge elements to be used in slightly different contexts (Hammer, 1996).

A notable exception to this dichotomy is provided by Vosniadou. Her focus on belief modification over concept modification leads to the expectation that conceptual change will be gradual and evolutionary as new beliefs are added to the conceptual system and individual presuppositions are suppressed in individual contexts (Vosniadou & Ioannides, 1998).

Reason Versus Intuition

Researchers differ in the extent to which they draw a distinction between the conceptual system one possesses, and the particular expression of a conception when an individual draws upon that system in order to answer a question. Most researchers acknowledge that concepts or their alternatives can be inarticulate in form; consequently, the process of articulation must be transformative to some extent. Some researchers go further, however, and argue that, while conceptions are constructed out of the elements in a conceptual system, the end product can be substantially different from the starting materials.

Thus, Strike and Posner (1992) differentiate between the elements of an individual's conceptual ecology, which may include some conceptions stored and recalled as units, and the spontaneous construction of a conception in response to a specific situation. They suggest that misconceptions are often examples of such spontaneous constructions, arguing that the reason

direct instruction fails to remove misconceptions may be because teachers are treating transient symptoms rather than the underlying causes.

Strike and Posner have called for considering more complex conceptual systems, arguing that different kinds of knowledge elements and structures must be involved in a *conceptual ecology* (Posner, et al., 1982; Strike & Posner, 1992), a call echoed more recently by diSessa (2002). For example, while retaining the elements of concepts and beliefs, Strike and Posner (1992) call for an ecology that also contains epistemological commitments and affective factors.

Criticizing the rational model of change described by Strike and Posner, Pintrich and his colleagues have called for an expansion to the number of entities considered during conceptual change, including affective, social, and situational variables (Pintrich, Marx, & Boyle, 1993). This still assumes that conceptual change, while perhaps more irrational, is still largely conscious and under an individual's direct control.

Vosniadou (1994) is more specific, distinguishing between the components of the conceptual system (presuppositions and beliefs), on the one hand, and the *mental model* an individual constructs in order to answer a particular question. According to Vosniadou, a mental model is an internal, analog representation, meaning that, like an image, it preserves most of the spatial features of the thing it represents. Mental models, unlike beliefs, are available for conscious inspection and can be consulted in order to make a prediction or give an explanation.

Methodology Before Theory

How, then, can this theoretical discord be resolved? DiSessa and Sherin (1998) broached this subject by describing two issues which they believe contribute to the current state of affairs: a reliance on common-sense, vague theoretical entities—like *concept*, *theory*, and *belief*—rather than a precise technical vocabulary; and a resistance to adopting a complex-systems perspective. As recommendations for improvement, they suggest researchers attend more closely to contextuality (i.e., the variations that occur when individuals think about different phenomena) and take on more accountability in explicitly and precisely articulating the form and content of an individual's knowledge.

Illustrating how methodology is bound up inseparably with theory, diSessa's and Sherin's issues are criticisms about limitations of current theory while their recommendations are suggested improvements in methodology. They point out theoretical limitations—imprecise theoretical entities and a simplistic, non-complex-systems perspective—but recommend that researchers collect new and different kinds of data—increasing the variety of phenomena in data collection and using a fine-grained, process account during analysis. To this end, when diSessa and colleagues attempted to replicate an earlier study by Vosniadou (Ioannides & Vosniadou, 2002), they chose to also include a wider range of phenomena in an effort to illustrate contextuality (diSessa, et al., 2004).

Consistent with diSessa's and Sherin's recommendations, I take the view that resolving theoretical issues is dependent upon first setting one's methodological house in order. Without data that clearly demand it, it is unlikely that researchers will feel compelled to more precisely articulate their theoretical entities or embrace complexity. It is my belief that progress toward theoretical consensus in the field is being stifled by limitations of methodology.

By focusing on methodological issues, I raise a general criticism of the existing data collection and analytic techniques in use by the field. These standard methods are not strict enough to force a single interpretation of the data and, consequently, do not produce results that confidently support one theory while clearly excluding others. Instead, these methods allow

researchers enough wiggle room to produce different results from the same data. The consequences are two-fold. First, researchers who are the guardians of a theory of conceptual change are satisfied that their data support their theory. They are therefore willing to dismiss competing theories (and methods) as *a priori* flawed. Second, neutral researchers who attempt to test competing theories are unable to conclusively decide between multiple interpretations of the data, which forces them to concede methodological problems (e.g., as discussed below, Southerland, Abrams, Cummins, & Anzelmo, 2001). In both cases, methodological issues impede the emergence of a definitive theory of conceptual change.

Four Methodological Concerns

In addition to the issues raised by diSessa and Sherin (1998), there are four specific methodological issues that plague conceptual-change research but that have yet to receive widespread attention. In brief, these four issues are *interaction*, *descriptive precision*, *instrument comparison*, and *exception handling*.

Interaction refers to the need to understand and account for how participants' responses are structured by the unwritten rules of human social interaction. Everyone recognizes that they would respond differently to a question like "What do you study in your research?" depending upon who was asking the question: a colleague, a stranger, a parent, a funding agency, etc. Likewise, when participants respond to questions on a test or during an interview, their responses depend not only on their underlying conceptual system but also on aspects of the particular situation they find themselves in: how the question is phrased, who the test-writer or interviewer is, what their relation is to the participant, what mechanisms are in place to generate or restrict feedback, etc. When researchers make inferences about conceptual understanding, they must recognize and explain how interaction contributes to the observed aspects of their written or verbal data. Without this sensitivity to interaction, it is impossible to tell whether, for example, a participant's inconsistency in the face of repeated questioning reflects an inconsistent conceptual system or different responses to a question asked in different interactional contexts.¹

Descriptive precision refers to the need for precise, explicit, and operational definitions of the several theoretical constructs—such as *coherence*—used to characterize conceptual systems. While they disagree on the entities (e.g., concepts or p-prims) involved in conceptual change, researchers nonetheless agree that any conceptual system has some degree of coherence. Indeed, it is precisely the degree of coherence, or breadth, or consistency, etc., that is at issue. However, it is far from clear what these properties mean, or what their qualitatively distinct levels might look like. Consequently, when results are described as exhibiting, for example, "high levels of coherence," it is impossible to say just how high is "high" and whether that level is consistent with or precludes a particular theory of conceptual change.

Instrument comparison refers to the need for accurate, reliable, and sample-independent measures of the relevant theoretical constructs such as coherence. To be useful, these measures must be unbiased toward the particular theories being compared. Without such measures, it is

¹ DiSessa (2007) tackles this issue directly, but at the level of "goals and interactive relationships" (p. 545) that manifest over extended activity rather than at the level of moment-by-moment interactional detail. When explicit talk about the interview process fades after the first two of a series of seven hour-long interviews, diSessa triangulates across the remaining five hours to conclude an interviewee "has turned to her own judgment as the primary factor in expressing opinions about how to think about the problematic situations posed to her." (p. 545).

impossible to compare results based upon data collected from different groups or with different methods. Ensuring comparability means much more than ensuring that the same set of questions is used. Testing situations, scoring procedures, and analytic techniques must all be the same across the contexts of data collection, and demonstrably so using appropriate statistics. Otherwise, if two groups of researchers discover different degrees of coherence in their subjects, it is impossible to know whether the subjects themselves differ or whether the questions and analytic procedures produced the difference by, in effect, measuring different kinds of coherence.

Exception handling refers to the need to deal with unusual or unique student responses. When a student responds to a question in a way that is inconsistent with other responses, there are two possibilities. On the one hand, the student may have simply “made a mistake,” perhaps misreading or mishearing the question. From a theoretical perspective, such an exception can be considered a meaningless error and can be safely ignored. On the other hand, the inconsistent response may reflect either an inconsistency in the student’s conceptual system or an element of their system that introduces a random component into their responses. From a theoretical perspective, exceptions such as the latter two are “real data” and must be accounted for. From a methodological perspective, standards are needed to consistently and appropriately differentiate between data and error.

Interaction as a Foundation

While all four of the methodological concerns described above are critical, the issue of interaction is foundational and deserves to be addressed first. In conceptual change research, all data are fundamentally records of interactions between, on the one hand, participants and, on the other hand, teachers, peers, interviewers, assessments, technology, and/or other social and material resources. As a substantial body of work in sociolinguistics, linguistic anthropology, ethnomethodology, and conversation analysis has demonstrated, these interactions are facilitated and constrained by a multitude of unwritten rules and expectations (Garfinkel, 1967; Goffman, 1967; Goodwin & Duranti, 1992; Goodwin & Heritage, 1990; Schegloff, 2007). These rules and expectations govern all aspects of human interaction, including the proper sequencing of conversational turns (Sacks, Schegloff, & Jefferson, 1974), how understanding is monitored and repaired (Schegloff, 1992b; Schegloff, Jefferson, & Sacks, 1977), how talk is designed with the recipient in mind (Schegloff, 1972), how relationships between participants are displayed and managed (Goffman, 1955; Goodwin, 1981), and how competence is performed with respect to the multiple communities in which participants are members (Goodwin, 1994; Hall, 1999).

What this work has established is that interaction contributes to the organization and content of cognitive activity in deep and complex ways. Researchers interested in conceptual systems ignore interaction at their own risk. Without methodological tools that can take interaction into account, researchers are left to speculate upon, but not identify and confirm or deny, alternative interactional interpretations for critical aspects of their data.

For example, Southerland, Abrams, Cummins, and Anzelmo (2001) attempted to describe students’ conceptions of biological adaptation as either the result of a concept network or a collection of p-prims, marking a rare attempt by neutral researchers to explicitly test competing theories of conceptual change. During semi-structured interviews, approximately 60% of students gave different explanations for different phenomena. More surprisingly, however, 40% of students gave different explanations for the *same* phenomenon in response to follow-up questions asked by the interviewer. This result was consistent across four grade levels, from

second grade to twelfth grade, and across three sites in the United States.

On the face of it, such apparent inconsistency or incoherence would seem to speak strongly for the Knowledge in Pieces theory. Indeed, the researchers found p-prims to be a useful means for describing aspects of the students' explanations. Unfortunately, the researchers were unable to rule out the competing concept network model (which they referred to as the *conceptual frameworks* theory). The difficulty lay in being unable to discount two alternative interpretations of the observed fragmentation. Participants may have interpreted the repeated questioning and other aspects of the interviewer-interviewee relationship as a form of subtle feedback that their initial responses were incorrect. Alternatively, students may have been attempting to satisfy their learned expectations of the standards of explanation used in biology, in which multiple levels of explanation (e.g., species-level vs. individual-level) are often appropriate. Ultimately, Southerland, et al., were unable to distinguish between these possibilities.

By not satisfactorily addressing the challenges presented by interaction, existing methods in use by the field are not rigorous enough to force a single interpretation of data. Consequently, different researchers are able to see different results in their data. In the broader literature, careful attention to interactional detail has produced alternative accounts of many cognitive activities, debunking mythologies of logical reasoning and sudden insight in scientific discovery (Latour & Woolgar, 1979), revealing the tactical utility of ignorance as a means of achieving social ends (Goodwin, 1987), exposing teacher and classmate collusion in the performance of learning disability (McDermott, 1993; McDermott, Goldman, & Varenne, 2006), relocating cognitive achievements outside the individual mind (Hutchins, 1995), belying the feasibility of standardizing questions (Antaki & Rapley, 1996; Suchman & Jordan, 1990), and unmasking the co-construction of "individual" knowledge during semi-structured interviews (Button, 1987; Macbeth, 2000). Studies like those above should give one pause. Unless interaction has been successfully addressed, accounts of cognitive activity are on suspect ground.

Theoretical Perspective

Because it does not raise obvious red flags or create immediate problems for researchers working within a single theory, ignoring interactional detail has been commonplace. However, as more and more researchers focus their attention on resolving the current theoretical crisis, interactional issues are becoming steadily more apparent. For example, prominent researchers have recently called for an interactional lens on the cognitive activity of explaining scientific phenomena in clinical interviews (diSessa, 2007; Sherin, Krakowski, & Lee, in revision).

The work that follows responds to and expands upon that call. Specifically, I will analyze the explanations given by eight undergraduate general chemistry students as they attempt to explain to various people, for various reasons, why phenomena involving chemical phase equilibrium occur. Using the methods of interaction analysis, I will characterize the unwritten, but systematic, rules which these participants follow as they explain in these contexts. The result will be a description of the contributions of interaction to the cognitive activity of explaining.

In this regard, I align closely with Hutchins when he explains his analytic goal in *Cognition in the Wild*:

"I have tried to move the boundary of the unit of cognitive analysis out beyond the skin of the individual. Doing this enabled me to describe the cognitive properties of culturally constructed technical and social systems. These systems

are simultaneously cognitive systems in their own rights and contexts for the cognition of the people who participate in them.” (1995, p. 287)

In other words, I believe that everyone and everything in the room is engaged in the cognitive activity of explaining. The "explanation" is the product of this collective cognitive activity. The interactional contributions described in this dissertation partially govern this activity. Other factors contribute as well, most notably the particular socio-scientific representations in use.² But, importantly, within this larger system of cognitive activity, individuals are also engaged in cognition.

Like Hutchins, I want to make sure I understand the larger system before making claims about individuals. However, with regard to individual cognition, Hutchins states:

“In this and all that follows, internal representations are identified by their functional properties only. I make no commitment to proposed mental mechanisms or computational architectures with which the behaviors of the representations might be modeled. As far as I can tell, it is not possible to distinguish among competing models on the basis of available evidence, and it is certainly not possible to do so on the basis of the sorts of evidence that can be collected in the wild.” (1995, p. 288)

In contrast, I do believe there is evidence in this data that would allow one to distinguish among competing models of mental mechanisms. That is the ultimate goal of this line of research. By improving processes of data collection and analysis, I hope to produce data that can distinguish conclusively between contradictory models of conceptual change. However, this ultimate goal is not realized in this dissertation. The analysis that follows lays out only the interactional infrastructure that supports and constitutes the collective cognitive activity of explaining.³

² These representations determine much of the content of the explanations but are not examined in detail in the present analysis. Consequently, discussion of the conceptual content of the explanations is limited.

³ Throughout, some thoughts on individual cognition are given in footnotes.

Explaining chemical equilibrium

In this work, undergraduate general chemistry students were observed as they attempted to explain four hypothetical scientific phenomena to strangers, friends, and tutors. In conceptual change research dating back to Piaget (2007; Piaget & Inhelder, 2000), explaining observed or hypothetical phenomena of everyday and/or scientific relevance has been the prototypical activity in which participants engage. Related activities are common, such as predicting which phenomenon will occur in a given situation (in the context of chemistry, see Mulford & Robinson, 2002) or identifying whether a phenomenon is of a particular class (e.g., phenomena involving force; see Ioannides & Vosniadou, 2002). However, investigating how participants explain various phenomena remains the primary focus in the field.

The focus of this dissertation is unpacking the “how” of explaining in a novel direction. The goal is to describe the cognitive activity of explaining as a sequence of interactional achievements on the part of the participants.

Sequential organization, as it is known in conversation analysis, is a means of describing the structure of interaction on a moment-by-moment basis (Goodwin & Heritage, 1990; Jordan & Henderson, 1995). The phrase refers to the observation that human social interaction consists of a sequence of moves or acts or turns, and that these units have a recognizable organization to both participants and researchers. Thus, answers follow questions and, importantly, if something follows a question that is not an answer, it is recognizably “not an answer.” That is, those involved recognize that the person who was expected to provide an answer has not done something random, but has specifically not provided an answer to the question (Schegloff, 1968, 1972, 2007).

The central role of sequences in conversation analysis leads naturally to the question: sequences of what? In the vast majority of conversation-analytic work, the de facto fundamental unit of interaction is taken to be the contiguous stretch of talk produced by a single person, called the *turn-at-talk* (Sacks, et al., 1974). The turn-at-talk is a convenient unit in ordinary conversation because it is easily identified analytically and because turns are generally short. Hence, for example, the question-answer sequence is defined as consisting of two consecutive turns-at-talk (Schegloff, 1972).

However, the turn-at-talk was never intended to be an analytic unit. Rather, turn-taking was seen as an interactive mechanism that relies upon a more fundamental unit, called the *turn-constructive unit* (Sacks, et al., 1974). According to this model, interaction consists of a sequence of turn-constructive units. At the end of each unit, a *transition-relevant place* occurs where speaker change may occur, if the current speaker yields the floor and another interlocutor takes it. However, Sacks, et al., (1974), while acknowledging the manifest variety of turn-constructive units in terms of length and grammatical function (i.e., sentential, clausal, phrasal, and lexical), did not speculate on how interlocutors determine which is appropriate in a given situation.

In practice, turn-constructive units are not a central focus of analysis. The vast majority of conversation-analytic transcripts (and transcripts in general) are organized around turns-at-talk without consideration for turn-constructive units. This central role for turns-at-talk is unfortunate, for in several cases turns-at-talk are clearly not the most relevant nor consequential aspect of interactional sequence.

First, as during a narrative or the explanations in this data, a single speaker may talk for an extended length of time. While researchers have studied narrative in the context of stories that occur during ordinary conversation, the focus has been predominantly upon how the story functions within the ongoing talk and activity of the participants—how the story is initiated, how it gets taken up or not taken up, and what follows from it (Jefferson, 1978; Sacks, 1974; Schegloff, 1992a). Perhaps because the analytic construct of the turn-constructive unit is poorly developed, far less attention has been paid to the internal structure of narrative: how the story is produced, extended, and modified during telling.

Second, multiple speakers often contribute to the construction of what appears to be a single unit. This occurs, for example, when one interlocutor finishes another's sentence. That such an action is recognizably a completion of something incomplete suggests that multiple turns-at-talk (and, hence, multiple turn-constructive units) are sometimes treated by interlocutors as subordinate to a different unit.

Third, speakers are sometimes interrupted in the middle of an utterance, by themselves or by others. If this hanging turn is eventually completed following the interruption, discontinuous turns-at-talk recognizably form a single, larger unit.

Without dismissing the importance of the mechanism of turn-taking, in none of these cases do turns-at-talk or turn-constructive units appear to be the most relevant, most consequential, or most fundamental sequential unit, either to participants or, by extension, to analysts.

In short, the goal of this dissertation is the identification and characterization of the important fundamental units of the sequential organization of explaining. To foreshadow, these units (called *information performances* and *illative sequences*) will be neither turns-at-talk nor grammatical units. Moreover, unlike either, they will be joint interactional achievements collectively involving all interlocutors.

Chemical Equilibrium

The targets of the participants' explanations in this dissertation are hypothetical phenomena involving chemical equilibrium. Chemical equilibrium is a dynamic equilibrium achieved between two or more chemical species that are interconverting. For example, an equilibrium between two species—A and B—would be reached if a reaction converting A into B ($A \rightarrow B$) proceeds at the same rate as another reaction converting B back into A ($A \leftarrow B$). Macroscopically, the system appears to have stopped reacting, with the amounts of A and B remaining constant over time. Microscopically, the two reactions proceed indefinitely, a dynamic equilibrium represented by the formalism $A \rightleftharpoons B$.

Chemical equilibrium is particularly interesting because of its pedagogical importance, the wide range of intuitive explanations reported in the literature, and the complexity and range of its normative explanations.

First, within chemistry education, equilibrium is considered a foundational yet difficult topic in the curriculum. This is illustrated by its substantial coverage in the most widely adopted texts for undergraduate general chemistry (T. L. Brown, LeMay, Bursten, & Burdge, 2003) and physical chemistry (Atkins, 1998). These texts treat equilibrium as pivotal and synthetic, a topic that draws together ideas from stoichiometry, thermodynamics, and kinetics.

Second, chemical equilibrium is a rich source of alternative conceptions. Unlike many topics in chemistry, which deal with situations and constructs that are foreign to students, most people have a rich intuition about phenomena involving equilibrium, particularly those involving

solubility (e.g., sugar dissolving in coffee, Kool-Aid dissolving in water) and phase changes (e.g., water evaporating, ice melting). A large corpus exists in the chemistry education literature documenting these alternative conceptions (Furió, Calatayud, Bárcenas, & Padilla, 2000; Niaz, 1995; Thomas & Schwenz, 1998; Voska & Heikkinen, 2000; Wilson, 1994) which have proved highly resistant to instruction (Gorodetsky & Hoz, 1985; Van Driel, De Vos, Verloop, & Dekkers, 1998).

Third, as a normative scientific concept, chemical equilibrium can be conceptualized in many different ways each associated with a different model of conceptual structure. In 1864, chemical equilibrium was first formulated as an empirical relationship codified as the Law of Mass Action (Guldberg & Waage, 1952). This purely descriptive account, concerning the ratios of the chemical species at equilibrium, is often the first introduction to, and sometimes the only treatment of, chemical equilibrium in secondary and post-secondary general chemistry texts (T. L. Brown, et al., 2003; Joesten & Wood, 1999; Kotz, Joesten, Wood, & Moore, 1994; Pimentel & Spratley, 1971). Descriptive statements about relationships are one of many kinds of knowledge described as facets (Minstrell, 1989).

In contrast, in 1884, Le Chatelier (1952) described a chemical system at equilibrium as being in balance and proposed the principle that it will resist efforts to perturb that balance. Along with the Law of Mass Action, Le Chatelier's Principle is a staple of general chemistry texts (T. L. Brown, et al., 2003), particularly those purporting to offer a more conceptual approach for learners (Joesten & Wood, 1999; Kotz, et al., 1994). The ideas of balance and perturbation used to explain Le Chatelier's Principle are prominent p-prims (diSessa, 1993).

There is a wide range of seemingly unrelated chemical phenomena described normatively as involving equilibrium, including acid-base reactions, phase changes, and solubility. Some of these phenomena are much harder than others for students to identify as involving equilibrium. Because of the need to draw upon a variety of readout strategies to successfully "see" equilibrium across multiple contexts, normative understanding can be described as involving a coordination class (diSessa & Sherin, 1998).

Some general chemistry texts (T. L. Brown, et al., 2003; Pimentel & Spratley, 1971) also present the microscopic dynamic model of equilibrium, describing the two competing chemical reactions ($A \rightarrow B$ and $A \leftarrow B$) and illustrating a chemical system as it approaches and reaches equilibrium with a sequence of visual diagrams. This emphasis on modeling is consistent with theories of conceptual change that emphasize the importance of constructing mental models (Vosniadou, 1994).

Finally, because the macroscopic features of chemical equilibrium are emergent behaviors resulting from the underlying microscopic chemical reactions, Chi and colleagues have identified chemical equilibrium as belonging to the Process ontology in a class called constraint-based interactions (Chi, et al., 1994; Slotta, et al., 1995).

Pilot work has confirmed that the topic of chemical equilibrium has the potential to illuminate a wide range of conceptual complexity and to speak to many competing theories of conceptual change (N. J. S. Brown, 2005).

Participants

Participants were recruited from the undergraduate students enrolled in the introductory general chemistry course for non-majors at the University of California, Berkeley—Chemistry 1A—during the final month of the Spring 2004 semester. This course enrolls approximately 500 students each spring, primarily first-year freshman students who could not or chose not to enroll

in the fall semester, as well as a smaller number who are repeating the course. Based on pilot work (N. J. S. Brown, 2005), by this point in the semester these participants have a rich mix of intuitive and normative knowledge about chemical equilibrium.

Participants were recruited through a form field at the end of an online homework assignment. The content of the assignment was unusual for the students and contained questions about four phenomena involving chemical equilibrium. These questions were similar to those eventually used during the interviews. Students who did not respond to or misunderstood the questions on the assignment were excluded from the study. Students who stated relevant scientific terms but did not attempt to explain the phenomena were also excluded. From the remaining pool, eight participants were randomly selected to participate in the study.

Interviews

The goal of this dissertation is to identify and characterize the fundamental sequential units of the cognitive activity of explaining scientific phenomena. Because I did not want to limit the scope of the analysis to a particular type of activity, such as explaining during a clinical interview, several different types of interaction were chosen, including explaining to strangers, peers, and tutors.

Each of the participants was invited to a series of four interviews, approximately two per week, during the last month of the semester. During each interview, the participant was asked to explain why four hypothetical chemical phenomena occur. The same four phenomena were repeated in each of the four interviews. I will first describe the four phenomena that were addressed in the interviews and then describe the variations between the four interview types.

Phenomena

Each phenomenon involved liquid alcohol in a closed, air-filled container. In response to an externally imposed event, the ratio of liquid alcohol to alcohol vapor would change, with either some liquid evaporating to form vapor or some vapor condensing to form liquid. Specifically, the four phenomena were liquid methanol partially evaporating after being placed in a container (Figure 1), liquid ethanol partially evaporating *to a lesser extent* after being placed in a container (Figure 2), additional liquid ethanol evaporating after increasing the temperature of the container (Figure 3), and ethanol vapor condensing back into liquid after shrinking the size of the container (Figure 4).

These phenomena were illustrated in printed diagrams in which “BEFORE” and “AFTER” states were depicted. The BEFORE state showed the relative amount of liquid and vapor alcohol immediately after the event, before any noticeable change in the composition of the system. The AFTER state showed the system after it had stopped changing, reaching some new relative amount of liquid and vapor alcohol by either evaporating liquid to form vapor or condensing vapor to form liquid.

These four phenomena all illustrate aspects of chemical equilibrium, the Law of Mass Action, and Le Chatelier’s Principle, but they were not identified as such to the participants. In particular, these are examples of phase equilibrium in which two phases of a single pure substance are interconverting: *liquid alcohol* \rightleftharpoons *alcohol vapor*.

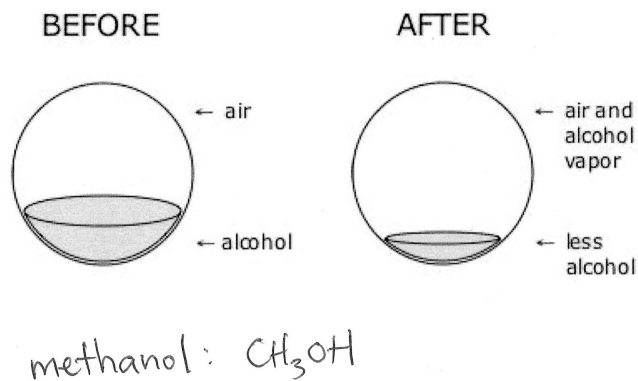


Figure 1. Liquid methanol partially evaporating in a closed, air-filled container.

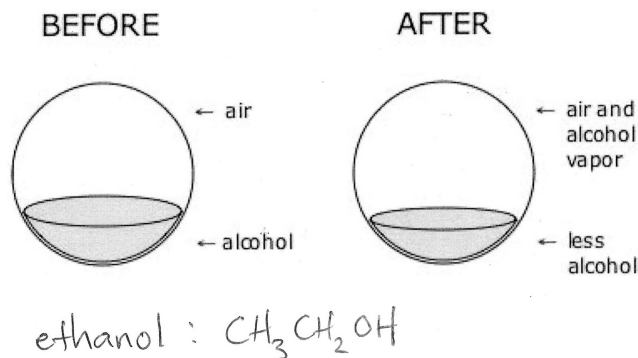


Figure 2. Liquid ethanol partially evaporating in a closed, air-filled container. Note that less ethanol evaporates than did the methanol.

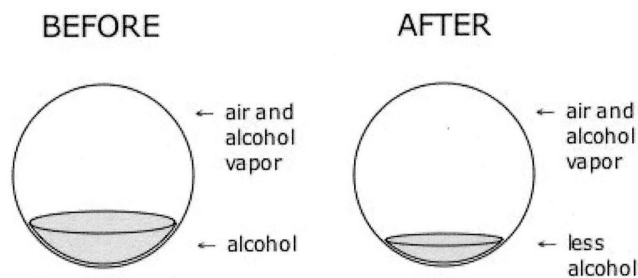


Figure 3. Additional liquid ethanol evaporating in response to an increase in temperature.

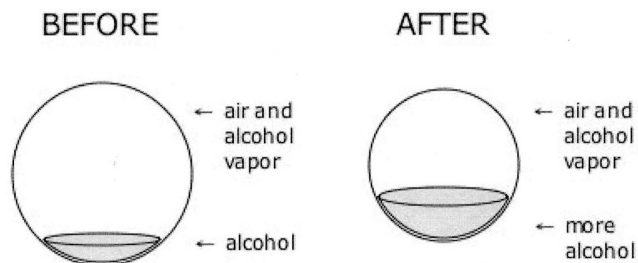


Figure 4. Some ethanol vapor condensing back into liquid in response to a decrease in the size of the container.

Phenomena involving phase equilibrium were chosen over other forms of equilibrium for their simplicity and familiarity. Phase equilibrium is relatively simple because only two species are involved and the molecular structure is not changed. Phase equilibrium is relatively familiar because the processes of evaporation (*liquid* \rightarrow *vapor*) and condensation (*liquid* \leftarrow *vapor*) visibly affect water in many everyday contexts. Because phenomena involving water are so common, they are often used as primary examples in chemistry instruction. Moreover, water is often singled out as a special case because of the unusually strong attraction between its molecules. Because of the special role for water in chemistry instruction, alcohols were chosen as a less canonical but still familiar class of liquids. In general, participants found the first phenomenon (Figure 1) to be consistent with their expectations. In the second phenomenon (Figure 2), most were initially surprised that ethanol evaporated less than methanol but were willing to accept it as fact. The third phenomenon (Figure 3), illustrating additional evaporation at a higher temperature, did not surprise anyone. The fourth phenomenon (Figure 4), illustrating condensation when the container was shrunk, was so surprising that many felt it necessary to check for tricks, such as the possibility that the smaller container made the same amount of liquid simply appear to be more.

Interview Types

Although the phenomena were the same during each interview, the interactive nature of each interview was varied by having the participant explain the phenomena to different people for different purposes: (1) answering questions during a typical semi-structured interview, in which the interviewer is a stranger probing their understanding; (2) discussing with a friend until the friend is satisfied they understand; (3) teaching a stranger until the stranger is satisfied they understand; and (4) being tutored by an expert. By varying the relative expertise and familiarity of the participant and their interlocutor, these situations were chosen to engender interesting differences in interaction. However, the exact nature of those differences was not hypothesized in detail and it is not a goal of this dissertation to characterize these different interviews as representing different but coherent activity types.

Semi-structured interviews. The first interview was structured as a semi-structured interview, one of the principal methodologies in research on conceptual change. As the interviewer, I introduced myself as an educational researcher interested in how people explain things in chemistry. The participants knew that I had taught past sections of the chemistry course from which they were recruited. That I possessed knowledge of the material was also made salient by the fact that the final interview was described as a tutoring session for the participant. While the specifics of my expertise were not discussed openly, each interviewee, usually at the conclusion of the interview, positioned me as being in possession of the “right answers” by asking to know what those answers were.

After asking the interviewee to explain each phenomenon, a series of follow-up questions were asked in order to further probe or clarify the interviewee’s understanding. These follow-up questions were tailored to the particular interviewee and often invented on the spot in response to what has just been said. Throughout, I emphasized that I was not interested in correctness but instead in whatever way the interviewee happened to think about the phenomena. Follow-up questions often asked the interviewee to explain any chemical terminology they had used and to re-explain the phenomenon in everyday language. The semi-structured interviews lasted 45 minutes to an hour on average.

Peer discussions. For the second interview, the participant was asked to bring a friend

with them to the interview, which was framed as a peer discussion. I posed the initial questions and set the goal of having the primary participant explain the phenomena convincingly to the friend. I then limited my direct involvement to interjecting when a long pause would develop and asking the friend whether they were convinced yet by the explanation. Unlike the semi-structured interview, I did not ask the students to give their explanations in everyday language, to rephrase their explanations if they relied upon chemical terms, or to answer follow-up questions, though the friends were encouraged to make these requests themselves. Despite this encouragement, the friends did not ask many follow-up questions. Consequently, the peer discussions were the shortest, ranging 15 to 30 minutes.

Teaching sessions. The third interview was framed as a teaching session, with the primary participant teaching a stranger lacking any substantial chemistry knowledge. I recruited eight colleagues who were also graduate students in education. In each case, the invited graduate student had not taken a chemistry course in about ten years and was legitimately not an expert in chemistry by their own admission, although they had personal intuitions about the phenomena. Like the peer discussion, I posed the questions, set the goal of getting the stranger to understand why the phenomena occurred, and interjected during pauses to ask the stranger whether they were yet satisfied with their understanding. Like the peer discussion, I refrained from asking follow-up questions, but unlike the peer discussion, each stranger did so freely. In fact, the strangers requested so much discussion of the phenomena that the teaching sessions were by far the longest interviews, with each lasting over an hour and with some lasting nearly two hours.

Tutoring sessions. The final interview was framed as a tutoring session, in which I asked the student to attempt to answer the questions correctly, using scientific terminology as needed. As would a chemistry tutor, I asked leading questions, corrected mistakes, critiqued each explanation, and suggested better explanations. The tutoring interview was held last in order to postpone a discussion of the “right answers” as long as possible. Tutoring interviews ranged from an hour to 75 minutes, with the bulk of the time spent reviewing and critiquing the participant’s prior explanations and developing a normative molecular kinetic model of equilibrium. Once this model had been taught in the context of the first phenomenon, each participant successfully applied it to explain the remaining three phenomena in rapid succession.

Methods

The study of interaction demands the use of video data in order to capture the moment-by-moment detail of the participants’ interactions and the multiple semiotic fields (Goodwin, 2000) they use to transmit information, including talk, intonation, gaze, gesture, body position, and external representation. In the present study, the provided diagrams (Figures 1-4) were one source of representation and a small whiteboard with colored markers were an available means of creating additional representations as needed by the participants.

Each interview was video-recorded using two cameras, one capturing a wide-angle view of all the participants and another capturing a close-up view of the provided diagrams and the whiteboard. Camera angles were chosen to reflect the theoretical assumptions of the researcher (Hall, 2000). The wide-angle view was broad enough to keep all participants in frame at all times, including the researcher who was nearly silent during the second and third interviews. This reflects the assumption that, even when the researcher does not appear to be actively involved in the discussion, his presence and non-verbal body language has the potential to structure the interaction in ways that would be lost without keeping him in frame. At the same time, the wide-angle view was kept close enough to make out gaze direction.

The close-up view was directed down onto the table surface between the principal discussants. This area, centered on the whiteboard and including the diagrams, was assumed to form a shared representational space. That this was the case is supported by three observations. First, the gazes of all participants were directed downward to this space by default, even when nothing was written on the whiteboard. Gaze shifts to another's face were temporary excursions that occurred at specific times during the explanations, to be described later as *feedback-relevant moments*. Second, when talk referred to one of the provided diagrams, the speaker moved it from the outskirts of this space to the center. Third, the majority of gestures made by the speaker were made in this space, above the surface of the whiteboard. These observations identify this area as a shared representational space used by the participants to coordinate focus.

While the camera angles were chosen to capture all relevant interactional detail, it is important to keep in mind that the views provided by the video cameras do not correspond to the views seen by any of the participants. Analysis is still necessary to determine which semiotic fields were being attended to at each moment by each participant.

The next chapter describes some contributions of interaction to the collective cognitive activity of explaining. These contributions, specifically details regarding the sequential organization of explaining, were identified using the methods of video analysis (Engle, Conant, & Greeno, 2007; Erickson, 2006; Goldman & McDermott, 2007). The entirety of the video corpus was viewed to identify regularities in how the participants interacted during the interviews. These regularities were proposed as relevant rules or expectations governing the interactions. During repeated viewings of the data, rules and expectations were added, removed, and refined until a coherent description of the sequential organization of the explanations emerged. As described in the next chapter, this description claims that explanations are an illative sequence of jointly-constructed subject-predicate relations called *information performances*.

By calling this description coherent, I mean that the following three criteria were satisfied during the analysis. First, this sequential organization applies across the various contexts of the data—the four types of interviews, eight participants, and four phenomena to be explained. Second, it describes each explanation as a continuous, contiguous sequence of interactional moves on the part of the participants. Third, it explains how the participants successfully constructed these sequences in real time using unwritten but stable mechanisms of monitoring expectations, identifying trouble, and making necessary repairs. Notably, it does not explain the content of these explanations, though jointly constructing meaning is found to be a central organizing feature of the interactions.

Limitations

Finally, three limitations of the current study should be emphasized. First, the goal of the analysis is not to explain how explaining happens in its entirety. The goal is much more modest—to describe some contributions of interaction to how explaining happens, specifically how explaining is organized as a sequence of some fundamental unit of interaction. Most dramatically missing from this account is a discussion of the conceptual nature of the explanations—what concepts or p-prims or other conceptual resources and mechanisms these participants are displaying. No relative value or importance should be construed by their omission. However, it is certainly an assumption of this work that the sequential organization of explaining is separable from the content of explaining to the extent that features of this organization are stable across the expression of many different conceptual ideas.

Second, the situations in this study, while varied, are neither naturally occurring nor typical for school settings. While extending the range of situations is a necessary next step, some evidence exists to suggest these situations do not present unusual or unnatural challenges to the participants. Specifically, unnaturalness does occur and is observable at the beginning and end of individual explanations. These are times when the researcher alone governs what happens next. The fact that such moments are observable when they occur lends confidence that this sort of trouble is not present during the explanations, an argument similar to that made by diSessa (2007). The speakers, concerned about the correctness of their explanations, may signal discomfort at times, but they don't signal that the activity they are engaged in is strange.

Third, although it is natural to want to make general statements about individuals or variables like gender, interview type, question format, etc., the small number and homogeneity of the participants and the limited time spent with each should highlight the danger of doing so prematurely. Compare the present study with the extended time spent with individuals in clinical interviews (diSessa, 1993, 2007; Ginsburg, 1997; Piaget, 2007; Piaget & Inhelder, 2000) or field work (Moerman, 1988) after which general claims about participants or contexts are better justified. Consequently, in the transcripts in the following chapter, I have deliberately made the effort to obscure who is speaking and in which type of interview each explanation occurred. I believe this knowledge is distracting at best and counterproductive at worst, given the primary goal of identifying those features of interaction that are observable and consequential *in the moment*. If my claims cannot stand up without this knowledge, they are poor candidates for being fundamental features of explaining across contexts. The limited sample that I believe requires this approach is an unfortunate necessity when performing a close analysis, but it should be recognized that this is only a first step in a program of research. Once the sequential organization of explaining is better understood, systematic studies of its variability across individuals and contexts can be undertaken.

Sequential organization of explaining

This chapter reports on the analysis of the interview data using interaction analytic methods in order to begin to address the methodological issue of interaction. The goal of this chapter is to describe some contributions of interaction to the production of explanations—specifically, the unwritten rules and expectations that govern their sequential organization. Describing these contributions is a critical step in understanding how explanations are achieved as collective cognitive activity and, eventually, in understanding the relationship between the cognitive activity of explaining and the individual cognition that occurs in that context.

Explanations

One might expect that explaining in this data would begin with the phenomenon, identify a proximate cause, and work backward to deduce an ultimate cause (or, at least, a cause that is “ultimate enough” for the given situation). Such an explanation might sound like, “The phenomenon occurs *because of X*. *X* is true *because of Y*, and *Y* occurs *because of Z*.”

In fact, this is exceedingly rare. In the preponderance of cases, explaining begins with remembering a fact or observing some feature of the provided diagram. This is followed by a sequence of further statements, each related to the prior by a logical, causal, or temporal link. Such an explanation might instead sound like, “*X* is true, *so Y* must occur, *so then Z* happens.”

This sequence continues until a statement is produced that describes the phenomenon. If such a statement is produced, the explanation is treated as successful. If such a statement cannot be reached, the sequence is repaired by starting over at some point, replacing one of the statements, and following this new lead.

An example of a brief explanation is represented in Transcript 1.¹² This sequence of statements explains the phenomenon that when equal amounts of ethanol and methanol are placed in separate closed containers, fewer ethanol molecules evaporate than methanol molecules (compare Figures 1 and 2). To be more easily read, this explanation could be represented as a quotation (Transcript 2).³

Transcript 2

Red: “Because [the ethanol molecules are] bigger, they take up more room. So there’s... With the same space, there can be less gas molecules in the air. And so there’s more of them in the liquid state, because they take up less space that

¹ Transcripts not presented within the main text can be found at the end of the Appendix.

² Each period (.) represents a half-second pause. Each color—red or blue—denotes the speech and actions of one of the interlocutors. In each transcript example, the first speaker is colored red. Colors do not represent the same people across different transcript examples. Triangles represent gaze shifts either from the table surface, containing the diagrams and whiteboard, to the face of the other interlocutor (▲) or back down to the table (▼). Carets (^) indicate nodding. Other transcription conventions are described in the Appendix. The most important will be described in footnotes as they are needed.

³ Because this representation omits a great deal of what is occurring in interaction, I refer to it as a separate transcript.

way.”

The speaker, Red, starts by stating that ethanol molecules are bigger, highlighting with a finger that their chemical formula ($\text{CH}_3\text{CH}_2\text{OH}$, see Figure 2) is longer than that of methanol molecules (CH_3OH , see Figure 1).⁴ From this, Red concludes that the ethanol molecules take up more room, but the implication of this further statement is not immediately forthcoming. After a four-second pause, Red introduces a new fact—the equal size of the two containers—and uses that fact to argue that fewer of the bigger ethanol molecules could fit in the same amount of air.

It is obvious that, during this explanation, information is being expressed. It is also obvious that one interlocutor—Red—is speaking all of this information. However, what is not immediately obvious is that the silent interlocutor—Blue—is also contributing, in important ways, to expressing this information. For one example, note that, semantically, the explanation can be considered over after Red says, “there can be less gas molecules.” Red projects this moment as a possible ending with an upswing in pitch⁵ followed by a pause. At this point, minimally, Red expects some non-verbal feedback from Blue that things are going well, such as a head nod.

When Blue does not ratify this ending with verbal or non-verbal feedback, Red begins a series of extensions to the explanation. From this point on, no new chemical information is introduced. Instead, Red is creating for Blue a series of new possible endings to ratify. First, Red appends “in the air” to the current statement. Gas molecules are, by definition, in the air portion of the container (as opposed to where the liquid is), so this is redundant information. What this appendage does is create a new possible ending, which Red designs to sound like the end of a sentence by dropping her pitch⁶ and creating another pause.

When Blue still withholds feedback, Red shifts focus from the relative amounts of gas to the relative amounts of liquid, producing a statement that, while logically equivalent, better corresponds with the visible features of the phenomenon as represented in the diagram. When even this does not elicit a response from Blue, Red has run out of ways to extend the explanation. At this point, Red performs the rare step of working backward, stating there are more ethanol molecules in the liquid state *because* they take up less space that way. This return to information already presented is expressed in a different register of voice—it is spoken more softly⁷ and more quickly⁸. As will be shown below, this register regularly coincides with, and therefore marks for the interlocutors, information that is not considered new.

The bids for concluding this explanation become more and more pronounced. First, there is another final sounding drop in pitch on “less space.” Second, that statement is extended with sensible but unnecessary speech (“that way”) and a much longer pause. Third, Red shifts her gaze to Blue, says “yes,” and begins to nod. This directness finally prompts Blue to give some positive feedback (“mm hm”), though the feedback is of a minimal, almost non-verbal nature. Blue briefly looks at Red but returns immediately to the diagram on the table. Red apparently

⁴ This and other gestures have been omitted from Transcripts 1 and 2 for clarity.

⁵ An upswing in pitch is represented by forward slashes (mole/cules/).

⁶ A drop in pitch is represented by backward slashes (\air\).

⁷ Speech produced more softly than surrounding speech is contained within vertical lines (|because they take up less space that way yes|).

⁸ Speech produced more rapidly than surrounding speech is italicized (*because they take up less space that way*).

isn't satisfied with this level of feedback and continues to nod. After this stalemate continues for four seconds, the researcher intervenes (not shown) and ends the explanation by officially moving on.

This dissertation argues that explaining is a joint activity—both interlocutors contribute substantially to what is said and how it is expressed. The major findings of this dissertation take the form of describing how this is accomplished through interaction that appears, on the surface, to be one-sided. One purpose of producing this description is to allow researchers to better understand the relationship between the collective cognitive activity of explaining and the individual cognition that occurs in this context.⁹

Information Performances

Explanations are constructed out of a series of steps. Each step is the means by which a piece of information is expressed in interaction by the joint activity of the interlocutors. This performance of information—specifically a single subject-predicate relation—I term an *information performance* (*in-form*, for brevity's sake).

The information performed during an in-form is often expressed (1) as a grammatical clause; (2) verbally; and (3) by a single speaker, as was the case throughout most of Transcript 1. However, none of these three conditions are a requirement and satisfying them is secondary to performing the information to the satisfaction of all interlocutors. Violations of these three conditions are evident in Transcript 3, which could be represented as the dialogue in Transcript 4.

Transcript 4

Red: “And then these [gas molecules], this little...”

Blue: “I would assume that's where gravity would pull [them]?”

Red: “Yeah, this little combination is just like, ‘Wait a minute, we don't have... OK, crap, here we go.’”

Blue: “Yeah, that's what I... OK...”

First, the information performed during an in-form need not be a grammatical clause. Two incomplete phrases are evident in the first in-form in Transcript 3: “‘Wait a minute, we

⁹ For example, in Transcript 1, the long pause at the end of line 3b does not appear to have an interactional basis. By not backing away from the diagram or shifting gaze to Blue, Red conveys the desire for Blue to wait. Blue, in turn, respects Red's silence and does not interrupt. Blue's eventual gaze shift lets Red know that Blue is still waiting for Red to finish rather than also trying to think of something to say. So, while there is an interactive mechanism to allow a pause of this length to occur, the question of why it occurs remains unanswered.

While there is not sufficient space to support these claims properly, I believe there is a basis in a model of individual cognition for this unusually long pause. As explainers produce their explanations, they monitor how things are going by occasionally comparing, in rough terms, the current statement to the desired end statement describing the phenomenon. When current statements appear to be narrowing the gap, there is no perceived problem. But while this speaker is aiming toward a description of *less*—less ethanol evaporating—this speaker is generating statements emphasizing *more*—bigger molecules, more room. This raises a red flag that stalls the explanation until the speaker can do the difficult work of turning *more* into *less*.

don't have..." and "Yeah, that's what I... OK..." In the second instance, Blue makes no attempt to finish the incomplete phrase and Red treats the incompleteness as a non-issue, continuing on with the explanation by starting a new in-form (not shown in Transcript 3).

The first instance is more complex, grammatically. After revising the subject of the first in-form to be "this little combination" (In-Form 1h¹⁰), Red's first attempt at a predicate fails to reach an ending ("is just like, 'Wait a minute, we don't have..."). Rather than attempt to complete this phrase—one possibility might be "enough kinetic energy"—Red repairs the second half of the predicate by revising what "this little combination" says ("OK, crap, here we go."). Red then *simultaneously starts over again with a completely different predicate* in which Red draws a squiggly line on the whiteboard representing "this little combination" (the pair of dots) falling down toward the liquid. Grammatically diagramming this in-form would be both impossible and, to the interlocutors, irrelevant.¹¹ Once the information has been performed to their satisfaction, the interlocutors move on, leaving grammar behind.

As has already been hinted at in Transcript 1, the opposite never happens. Regardless of whether a clause has been completed with correct grammar, indication of trouble in coming to a consensus of meaning leads to the extension of the in-form until the trouble is resolved (in the case of Transcript 1, by the researcher). Together, these observations imply that the grammar of an in-form is secondary to the primary concern of performing the information.

Second, the information performed during an in-form need not be, entirely or in part, verbally expressed. Meaning can be transmitted through other semiotic fields (Goodwin, 2000), including gesture and external representation. In the first in-form in Transcript 1 (because they're bigger), both the subject—the identity of "they"—and the predicate—what it means to be "bigger"—are underdetermined by the speech. These blanks are filled in by the gesture described earlier: Red draws a finger back and forth along the chemical formula for ethanol written on the diagram (see Figure 2), identifying "they" as ethanol molecules and "bigger" to mean, specifically, longer.

However, gestures and representations do not simply play a subsidiary role of resolving ambiguities created by deixis. They can also be the primary channels for conveying information. In the second in-form in Transcript 3, the predicate is initially conveyed entirely through gesture: a hand partially open as if holding a tennis ball, pulling inward to the body, paralleling (above the diagram) the path a gas molecule would follow if it were grasped and pulled down into the liquid (I would assume that's where gravity would [pull down]¹²). While Blue

¹⁰ In the transcripts, numbers enumerate in-forms. For example, Transcript 1 contains six in-forms and Transcript 3 contains two in-forms. Each in-form may be broken into pieces, later described as *joint prosodic units*; these pieces are labeled with letters. For example, the first in-form in Transcript 3 is made up of nineteen pieces (1a–1s) and is interrupted twice (between 1f and 1g and between 1h and 1i).

¹¹ In the transcripts, repairs or revisions are left justified. Consequently, in Transcript 3, \OK ↓crap\ is aligned below ^wait a ^minute, both of which follow on from the first half of the predicate: is ^just ^like. However, the drawn representation [falls down] is aligned below is ^just ^like because both are the beginnings of predicates that follow directly on from the subject **this little combination**.

¹² Indexical gestures—that is, gestures that convey meaning rather than emphasis—are transcribed as if that meaning were spoken. Such "gesture speak" is contained within square brackets. If the gesture supplements the verbal channel, it is placed either above or below the

does eventually speak this predicate, Red treats Blue's initial gesture as fully adequate by backing away from the diagram, nodding, and agreeing emphatically (↑[^]**yeah**¹³). While there is a clear preference for verbal communication throughout the data, this example illustrates that the purpose of performing the information trumps the desire to convey that information verbally. If a predicate is difficult to convey verbally, a gesture will suffice or even be the preferred method of conveyance.¹⁴

Third, the information performed during an in-form need not be expressed by a single speaker. We have already seen two examples in which the in-form contains speech by the second interlocutor in the form of feedback: in Transcript 1, In-Form 6d ("mm hm") and in Transcript 3, In-Form 2a ("yeah"). The end of the first in-form in Transcript 3 (In-Form 1o-1s) provides an example of even more verbose feedback: "Y- yeah, tha-, that's what I... OK...". Such feedback, as has been alluded to above and will be described in more detail below, contributes to determining what information is expressed, sometimes leading the speaker to provide additional information and sometimes discouraging them from doing so.

Information performances are the means by which pieces of information—subject-predicate relations—are expressed in interaction by the joint activity of the interlocutors. While often expressed by a single speaker as a verbal grammatical clause, none of these conditions take precedence over the co-construction of meaning by the interlocutors. As we will see, explanations are built out of these information performances. But to understand how this is done, it is first necessary to describe how in-forms themselves are initiated, propagated, terminated, and, if necessary, repaired.

Initiation

Like all talk and interaction, information performances do not exist in a vacuum. They exist within a sequence of other in-forms and are therefore considered and positioned in relation to what has just occurred (Schegloff, 1968, 1972, 1992b, 2007). In these explanations, these relations are often marked by *discourse connectives* (Schiffrin, 1988), words or phrases that signify a relationship between two clauses. In particular, the in-forms in these data are most often initiated with *so*, *then*, and related connectives (e.g., Transcript 1, In-Form 5a: *and so*; Transcript 3, In-Form 1a: *and then*, In-Form 2a: *that's where*). These discourse connectives are useful for the interlocutors because they position the upcoming in-form as following from the previous without having to specify whether the relationship is logical, causal, or temporal.

regular speech, as if it were a second interlocutor speaking in unison with the speaker. If, as in this case, the gesture occurs alone, it is placed in line with the regular speech, highlighting its role as the primary conduit of information.

¹³ Vertical arrows represent shifts in body position either straightening up away from the diagram on the table (↑) or leaning back into the table (↓). Body position shifts do not imply and do not co-occur with gaze shifts unless explicitly indicated by the presence of both transcription marks.

¹⁴ Here is another instance where a feature of the explanation is not explained by the interactional model. Gesture allows Blue and Red to move on, but it is not clear why this particular predicate is difficult to produce verbally. Again, without adequate evidence, I will claim a cognitive basis: at this moment, Blue is accessing kinesthetic knowledge about what happens to things when gravity gets hold of them. To report this knowledge verbally, it must be translated. It can be more naturally and therefore more quickly reported physically.

Indeed, a relationship of “following-on” between the upcoming in-form and the previous is generally known immediately, given the context of explaining and the tendency to explain forward toward rather than backward from the phenomenon. Consequently, a common feature of talk in this data is a discourse connective left hanging for a period of time before the information in the in-form is expressed. For example, nearly every discourse connective in Transcripts 1 and 3 are followed by a pause. The pause following “so there’s...” (Transcript 1, In-Form 3a-3b) is four seconds long. Pauses of ten seconds or more were observed.

That pauses of such length are allowed to persist is evidence of a general finding: in these explanations, the preference is for the initiator of the previous in-form to initiate the next in-form as well, regardless of whether the other interlocutor was involved in co-constructing the ending or providing any verbal or nonverbal feedback. This preference is different from those operating during ordinary conversation and during monologues. In ordinary conversation, the preference is for the next speaker to be a different person (Sacks, et al., 1974). During monologues, such as public speeches, the other interlocutors are expected to yield the floor for an extended period of time (Goffman, 1981). Instead, speaker preference during explanations appears to be more like storytelling in ordinary conversation, where a single speaker is expected to tell the story while the other interlocutors may give or withhold comment (Jefferson, 1978; Ochs, Taylor, Rudolph, & Smith, 1992). Indeed, the notion of information performances may help shed some light on the sequential organization of storytelling.

Finally, initiations are opportune moments for *face work* to be accomplished. Face work consists of talk and other forms of self-presentation which aim to maintain social relations by softening what might appear to be criticism (Goffman, 1955, 1959, 1967). An example is in Transcript 3, In-Form 2a, when Blue begins what amounts to an interruption with “I would assume...” At the end of In-Form 1 (1o-1s), Blue acknowledges knowing the effect of gravity on the “little combination.” By presenting this knowledge earlier in In-Form 2a as less than certain, Blue is overstating a lack of confidence. Presumably, this is to help Red save face during what appears to be trouble completing In-Form 1.

Propagation

The importance of the in-form as an analytic unit follows from the fact that the interlocutors themselves orient toward the performance of information as the fundamental activity in which they are collectively engaged. This orientation can be seen most clearly during breakdowns in the production of an in-form.

While the performance of an in-form can be uninterrupted, as in the first two in-forms in Transcript 1, most in-forms are broken into more than one sub-unit, what I call a *joint prosodic unit*. In sociolinguistics and linguistic anthropology, a prosodic unit is speech produced by a speaker with a single pitch contour and a consistent rhythm (Duranti, 1997). Such a unit is also known as an intonation unit, breath group, or utterance. Prosodic units are most often but not necessarily bounded by pauses; a shift in pitch contour or rhythm indicates a new unit even in the absence of a pause. For example, in Transcript 1, In-Forms 5b and 6a are different prosodic units because the prosody employed by Red in 6a is different: the speech is softer and faster.¹⁵

In the literature, prosodic units are defined to be performed by a single person; a change in speaker ends one and begins a new prosodic unit. In contrast, the present analysis identifies

¹⁵ That this is a shift between in-forms as well as prosodic units is indicated by the discourse connective *because*.

many instances in which a new speaker's talk, at least initially, matches and continues the intonation and rhythm of the previous speaker's talk. This can be seen in Transcript 3, in which Red's assessment of 2a ("yeah") and Blue's assessment of 1o ("y-") both follow immediately and use the same rhythm and intonational contour as the other interlocutor's preceding speech. In 2a, "yeah" is placed precisely at the end of Blue's gesture and continues the pitch and speed of Blue's previous talk. In 1o, "y-" is placed precisely at the end of Red's previous talk and continues Red's heightened speed. That joint production like this is observed is the reason for calling these sub-in-form units *joint prosodic units*.

Interlocutors orient toward performing in-forms as the fundamental activity in which they are engaged by positioning joint prosodic units as incomplete performances. This is done in several ways. First, when an in-form break lasts longer than a second, there is a strong tendency on the part of the speaker to insert sounds into what would otherwise be silence. I call these sounds *pause fillers*. Pause fillers include non-lexical verbalizations¹⁶ (*um, er*), drawing out the final sound of the previous word (in written form, this is sometimes represented as *sooooo...*), and tongue clicks. Pause fillers coincide with non-verbal signals that the speaker is not finished: gaze and body position remain or return downward, oriented to the table surface occupied by the diagrams and the whiteboard.

Second, while speakers use pause fillers to position joint prosodic units as incomplete entities, the other interlocutors ratify this position by remaining silent during the pauses. As was described above, the tendency of a listener is to let the speaker hold the floor for an indefinite length of time without hijacking the performance of information. Note again Blue's gaze shifts during the long pause in Transcript 1, In-Form 3b that position Red as the person who will continue the in-form that Red started.

Third, perhaps the strongest evidence that the other interlocutors routinely expect the speaker to finish the in-form comes from moments when the speaker must shut down a failed in-form and explicitly hand the floor over to the listener. As illustrated in Transcript 5, this can be accomplished simply by shifting gaze toward the other interlocutor. In In-Form 3b, Red looks up from the table surface and turns to Blue. In the same motion, Blue turns away from Red, looks down at the table, and begins to speak (In-Form 4a). When Red adds an explicit request for Blue to speak, Blue waits, motionlessly, until Red finishes then immediately continues the new in-form. That Blue had something to say ready at hand, yet waited until Red officially ceded the floor with a gaze shift, is evidence of an expectation that in-forms are, in the first instance, non-interruptible. Of course, interlocutors can hijack pauses within in-forms if they wish, but such instances are hearable as interruptions precisely because of the expectation that pauses within in-forms "belong" to the speaker.

¹⁶ Not all non-lexical verbalizations are used to fill a pause. As mentioned above, a joint prosodic unit has a characteristic rhythm. A primary function of this rhythm is to provide a resource for emphasizing certain words by placing them "on the beat" (Erickson, 1991). Consistent with this previous research, in this data certain words such as *like* are inserted with the effect of shifting the subsequent word to the beat, giving it emphasis. Non-lexical verbalizations are not inherently either a pause filler or a rhythmic device. What matters is the function they serve in the talk. Some verbalizations, such as *uh*, are used as pause fillers in some contexts and rhythmic devices in other contexts.

Termination and Feedback-Relevant Moments

As mentioned above, one of the things that set explanations apart from ordinary conversation is the preference for whom should speak after a turn at talk is completed. In ordinary conversation, another interlocutor is expected to begin the next turn (Sacks, et al., 1974). Because the preference at the end of turns is for speaker change, these moments are called *transition-relevant places*. In the explanations observed in these data, the speaker is expected to continue the story with a new in-form. Consequently, the role of the other interlocutor between in-forms is restricted to providing feedback on the just-completed in-form. These moments, which I call *feedback-relevant places* (FRPs), are the most obvious examples of how in-forms are the result of a joint performance.

Through the use of intonation contour, pacing, and gaze, the speaker designs the end of their turn to anticipate the nature of the expected feedback. This design varies along two dimensions. The first dimension projects the degree to which the in-form is problematic and needs repair. The second dimension projects how explicit the feedback should be. These two dimensions suggest four general classes of FRP recipient design: *requests for evaluation*, *confirmation checks*, *uncertain monologues*, and *confident monologues*.

Requests for evaluation. The first class of FRP projects the in-form as needing explicit repair on the part of the other interlocutor. This type of FRP is characterized by a slowing pace, a gaze shift to the other interlocutor, and a pause. This design gives the impression of a request for evaluation. In some cases, the FRP includes a rise in intonation evocative of a question, but this is not universally true. The excerpt below, represented as a dialogue, illustrates a series of implicit requests for evaluation without intonation upswings. In each case, Red shifts gaze to Blue at the FRP. Note that the final FRP, an extreme version of this class, is designed as an explicit request.

Transcript 6

Red: “So, is it right... So if I think of it as there's going to be this range of energies in here...”

Blue: “Mm-hm.”

Red: “And they either have enough energy to be in gas or not...”

Blue: “Mm-hm.”

Red: “And the ones that aren't plomp down here in liquid.”

Blue: “Mm-hm.”

Red: “Okay. Which would suggest that how many are in gas depends on temperature, is that right?”

Blue: “Mm-hm.”

Red: “Okay, I guess that makes sense.”

Confirmation checks. The second class of FRP projects the in-form as not needing repair but still requests explicit feedback from the interlocutor. This type of FRP is characterized by a constant pace, an opening of body position to the other interlocutor, and a pause. This design gives the impression of a check for confirmation that the listener is following the information laid out by the speaker. It projects the desire for a response but also projects the expectation that the feedback will be positive and the speaker can continue without challenge. Compared with the first class of FRP, this design has neither the *ritardando* nor the requirement for a gaze shift associated with a request for evaluation. Again, a rise in intonation is sometimes

present but not required. The excerpt below, represented as a dialogue, illustrates two checks for confirmation, both with intonation upswings. Note that the second FRP, an extreme version of a confirmation check, is designed as an explicit request (“Does that make sense?”).

Transcript 7

Red: “So kinetic energy is a... is a function of mass and velocity?”

Blue: “Mm-hm.”

Red: “So, because kinetic energy is going to stay the same, yet mass is now a great deal higher, velocity is going to be a great deal lower. Does that make sense?”
[one-second pause]

Red: “I mean to make this, um...”

Blue: “That makes some sense, yes.”

Red: “...to make this the same.”

Blue: “The same kinetic energy.”

Red: “Right.”

Uncertain monologues. The third class of FRP projects the in-form as problematic but does not anticipate the other interlocutor will provide feedback at this particular moment. (Eventual feedback may be expected at a later time.) This type of FRP is characterized by slow pacing (not just a *ritardando*), rising intonation, and a pause. Gaze remains fixed downward at the table surface. This design evokes a lack of confidence in what is being said without the expectation that the in-form will be repaired. Examples of this class of FRP can be seen throughout the first half of Transcript 8, specifically at the ends of In-Forms 4, 6, 9, 15-17. Face work that serves to hedge one’s statement is often appended to the end of in-forms designed with this class of FRP. Examples in Transcript 8 are In-Form 4 (“I suppose”) and In-Form 17 (“I suppose... I don’t know”). While all four classes of FRP were seen in each of the four interview types, this third class was especially prevalent during the semi-structured interviews, of which Transcript 8 is an example, and relatively rare in the other types of interview. This reflects the unique character of the semi-structured interview in which both the interviewer and interviewee expect that the explanations will not be evaluated by the other interlocutor.

Confident monologues. The fourth and final class of FRP projects the in-form as not needing repair and that the interlocutor will withhold explicit feedback. This type of FRP is characterized by rapid pacing, no pause, and gaze maintained downward at the table surface. This design evokes a confident monologue in which the speaker is not projecting possible failure. Examples of this class of FRP can be seen throughout the second half of Transcript 8, specifically at the ends of In-Forms 19-21, 23, 25-29, 33.

After describing these four classes of FRP design, it is important to emphasize that they are exemplars of regions within a continuous two-dimensional space rather than discrete bins. In the data, there are examples of FRP design that fall nearer the middle of one or both dimensions. Also, as Transcript 8 illustrates, the design of FRPs can vary within a single explanation and are properly thought of as properties of in-forms.

The choice of a particular FRP design depends in part upon the speaker’s audience. The same speaker who expressed the first half of Transcript 8 as an uncertain monologue expressed the same basic explanation differently to different people. For example, in the peer discussion and teaching session, this speaker largely designed the FRPs as confirmation checks. This design, projecting no trouble with the in-forms and expecting explicit feedback, is the polar

opposite of an uncertain monologue. A similar pattern, in which their apparent level of confidence varied depending on the interactional situation, was observed for many of the other participants. Thus, the impression of confidence given by a participant has some basis in interaction.¹⁷

Feedback, Trouble, and Repair

The design of the FRP displays the expectations of the speaker—whether the in-form is satisfactory or in need of repair and whether the listener’s contribution at this point needs to be explicit. It is then up to the other interlocutor to ratify or reject this expectation. Whether or not they do has dramatic implications for the ongoing production of the explanation, as their reaction has the potential to either end the current in-form or initiate a process of producing different in-forms to repair any trouble in communicating.

Positive feedback, when given, is scaled to the expectation projected by the speaker. When explicit feedback is designed for, using requests for evaluation or confirmation checks, it is given, as is illustrated in Transcripts 6 and 7. The more explicit the request, generally the more explicit the feedback, as Transcript 7 illustrates. When explicit feedback is not designed for, using monologues, non-verbal feedback such as head nodding or the absence of feedback altogether can be regarded as positive. These forms of feedback are illustrated throughout Transcript 8. When positive feedback is given, the speaker continues the explanation by beginning a new in-form. This larger structure of explanations as sequences of in-forms is discussed in a later section.

Negative feedback can be verbal but it is rarely an explicit objection to what has been said. When it does occur, negative verbal feedback positions the trouble as being on the part of the listener, taking the form of an expression of mishearing or not understanding such as “wait,” “what?,” or “ummm...” This is another form of face work that attempts to mitigate the fact that the speaker has produced the problematic in-form. Because verbal negative feedback rarely occurs, far more often negative feedback takes the form of an absence of positive feedback. As described above, the absence of feedback is sometimes regarded as positive. That the absence of feedback can be identified as positive in some cases and negative in other cases depends upon the design of the FRP.

When the other interlocutor fails to ratify the current in-form, either by providing negative feedback or withholding positive feedback, the ongoing explanation is placed on hold until the trouble with the current in-form is repaired. In other words, when there is a moment of confusion, the conversation is sidetracked until it is resolved. When trouble is indicated by the withholding of positive feedback, the most common and subtle tactic used by the speaker to initiate repair is to extend the in-form grammatically. After the extension, another FRP occurs.

¹⁷ While having some basis in interaction, FRP design also appears to have some basis in individual cognition. In Transcript 8, for example, the switch from a lack of confidence to a confident monologue correlates with the switch from a “scientific” molecular kinetic explanation to a more “psychological” explanation involving people.

How do we determine the extent to which this particular shift has its basis in interaction or individual cognition? In this instance, there is evidence that a shift in the interactional context *does not* occur: the kind and frequency of feedback from the other interlocutor—extended head nodding—is the same both before and after the shift in explanation. Thus, in this instance, attributing this shift in explanation to an aspect of the participant’s cognition seems warranted.

This tactic nicely illustrates and takes advantage of the joint constructional aspect of in-forms. Because the end of the in-form is negotiated and does not necessarily coincide with the end of a grammatical sentence, the speaker can position the extended in-form as just now reaching its conclusion, giving the other interlocutor a second chance to ratify the in-form and allow the explanation to continue. This tactic was illustrated in the discussion of Transcript 1 at the beginning of this chapter.

The tactic of in-form extension is also illustrated in Transcript 9. In In-Form 1, the speaker not only wants the other interlocutor to give positive feedback, but an explicit statement that they understand. During the pause at the end of 1b, Blue nods, initially giving only non-verbal feedback. In response, Red extends the in-form with additional joint prosodic units and Blue's feedback escalates from repeated nodding to a gaze shift directly at Red and finally to an explicit response ("yeah"). At this point, Red accepts the feedback by shifting gaze back to the table surface and beginning the next in-form. Note that there remain possible further extensions ("of the liquid... alcohol... at the bottom... of the container...") upon which Red could have drawn. That this explanation ends when it does is the result of a negotiation between Red and Blue as to the appropriate level of evaluative feedback.¹⁸ Neither Red nor Blue is in complete control of the in-form.

When positive feedback continues to be withheld, or when negative feedback is given, repair of the in-form requires more drastic efforts. This can happen in several ways: (1) reattribution, (2) disproving an alternative, (3) rephrasing, and (4) shifting frame.

Reattribution. The first and by far the least common repair strategy was to reattribute the content of the in-form to an authoritative other.¹⁹ In most cases, this other is a vague entity—perhaps their current chemistry professor—as illustrated in Transcript 10.

Transcript 10

Red: "I never really understood how you could cram a bigger molecule into the same space that you could cram a smaller molecule. But that was just what I was told so I just believed it."

Blue: "Okay..."
[both laughing]

However, some reattributions were surprisingly specific, as was the case for one participant who responded to disbelief concerning a graph showing the relationship between intermolecular distance and intermolecular attraction by (incorrectly) attributing the graph to Linus Pauling.

¹⁸ Note that, even though the in-form is being extended, the aspect of the in-form that requires evaluation—in this case, that there exists a "net flow"—is uniquely identified by the specific location of the emphasis and raised intonation (**net** / **flow**/).

¹⁹ *Footing*, as the term is used in sociolinguistics, refers to the ways that a speaker can position what they are saying in relation to themselves and others (Goffman, 1981). As it is commonly formulated, footing has three aspects: (1) the *animator*, the entity who is producing the speech, (2) the *author*, the entity who composed the speech, and (3) the *principal*, the entity to whom the content of the speech is attributed. In this data, reattribution consists of disavowing being the principal—and in some cases even the author—of the in-form, highlighting one's role as the animator.

Reattribution is a means for the speaker to prop up an in-form they know to be true yet can't otherwise justify. Yet, despite the appeal to authority, this strategy uniformly failed to repair the problematic in-form to the other interlocutor's satisfaction, forcing the speaker to shift to one of the other three repair strategies.

Shifting terminology. A more common but still relatively infrequent repair strategy was to rephrase the in-form using different scientific terminology. For example, in Transcript 11, Red is trying to convince Blue that more liquid molecules would be able to “fly out” of the liquid and become gas molecules if the temperature of the liquid were increased. To do so, Red shifts from talking about temperature to talking about energy.

Transcript 11

Red: “It goes... [The liquid] will have higher energy, right? Because temperature is an indication of energy? So, when you're increasing the temperature, you're increasing the energy? So, more of them are going to be able to fly out?”

Similarly, in Transcript 12, Red is explaining to Blue how gas molecules can become liquid molecules. To do so, Red shifts from talking about the molecules sticking together to their having an inelastic collision.

Transcript 12

Red: “Say you initially start out with something resembling a gas form, in which molecules are separate.”

Blue: “Mm-hm.”

Red: “They're going to run into each other and then, if they don't have sufficient kinetic energy to bounce off, they're going to kind of stick together. It'll be kind of an inelastic collision. So they'll kind of clump.”

In Transcript 11, the shift in terminology was from one normative scientific concept—temperature—to another—energy. In Transcript 12, a non-normative idea—“stick together”—is replaced by a normative scientific concept—“inelastic collision.” A shift in terminology is always in the direction of scientific terminology. (Shifts in the other direction—from normative to non-normative—have a distinct character and are discussed below as examples of frame shifts.)

In both examples, the attempt at repair is not particularly successful. In Transcript 11, Red repeats the terminology shift several times but receives no feedback from Blue. Eventually, Red continues the explanation without having the in-form ratified by Blue. In Transcript 12, Red shifts back to the non-normative account (“they'll kind of clump”) before carrying on with the explanation. These examples are emblematic of repair attempts making use of shifting terminology. They rarely receive positive feedback, but they also rarely receive negative feedback. Sometimes the speaker interprets this lack of feedback as positive and, as in Transcript 11, continues the explanation. Other times the speaker interprets this lack of feedback as negative and, as in Transcript 12, abandons the new terminology and tries to repair the current in-form in a different way.

Disproving the alternative. The third repair strategy, about as frequently observed as shifting terminology, was to disprove the alternative to the problematic in-form. The logic underlying this strategy appears to be that if one of only two possible outcomes can be shown to

be false, the other outcome must be true. An example is in Transcript 8 where Red is explaining why gas molecules “need space.” In In-Form 3, Red asserts that “you can’t cram [the gas molecules] all together.” That this must be true is established by stating the opposite (“because, if you cram them all together...”) and claiming that the consequence creates a problem (“...then their little intermolecular forces will condense them back to the liquid alcohol.”). In other words, a gas needs space because, if you denied it that space, it would turn back into a liquid.

The use of this strategy is signaled through a combination of grammar and prosody. The two in-forms that represent opposites are spoken using an identical grammatical formulation, intonation contour, pacing, and rhythm. In this case, the common phrase is “cram them all together” with primary emphasis on “cram.” The “false” alternative and its consequence are distinguished only by an overall lower pitch, a design that makes them sound like an aside.

Like shifting terminology, this repair strategy often resulted in no further feedback by the other interlocutor. Consequently, similar to the shifting terminology strategy, the speaker sometimes treated the strategy as successful and sometimes not.

Shifting frame. The fourth and final repair strategy, and by far the most common, is to revise the in-form by changing the subject while maintaining, as close as possible, the same subject-predicate relationship. In a sense, this shift of frame results in an analogy for the original in-form. Often, as illustrated in Transcript 13, the speaker acknowledges the analogy by positioning the new in-form as a simile (“It’s like...”).

Transcript 13

Red: “And that means that, like, they're kind of, you know, they're bigger. So, it takes more energy to get them, kind of, to fly out. So they're like heavier and more complicated.”

Blue: “Okay, so, um, because they're longer, they're heavier, uh, it takes more energy to get them out?”

Red: “Yeah. It's like trying to throw, like, a big ball, like, compared to a little Whiffle ball or something.”

Blue: “Okay.”

Frame shifts can be as simple as the above example, in which a single in-form is inserted by Red and immediately ratified by Blue. However, frame shifts can be much more complicated. For example, in Transcript 8, Red constructs a frame shift in which gas molecules condensing back to a liquid become people sitting down and taking a break after running around. This shift doesn’t occur at a single moment. Rather, Red begins to break the current frame in In-Form 8, saying “they were just happy floating around.” After attributing happiness to the gas molecules, the anthropomorphization continues in In-Form 10, when they are given agency as well (“they were all trying to bounce all over the place”). While the frame shifts back to an agentless, emotionless “scientific” mechanism in In-Forms 14-17, Red returns to the frame in which the molecules are happy when they are able to bounce around. Then, in In-Form 24, Red shifts frame even further and describes people running around in circles.²⁰ In all, this frame shift is fluid,

²⁰ Of interest is the fact that, while Red distances the frame involving people running around (“I mean, I know they’re molecules and they don’t have feelings or desires or whatever...”), this frame is clearly more comfortable for Red than the initial kinetic molecular frame. Red’s speech throughout the people frame is faster, with far fewer pauses. Across the

appearing and disappearing over the course of many in-forms.

Frame shifts were observed of many different sorts. Anthropomorphization, as in Transcript 8, was very common. Some speakers shifted frames to a more familiar chemical phenomenon, as when the discussion of alcohol evaporating turned to water evaporating in Transcript 5, In-Form 10. Others shifted to a simplified situation, moving, for example, from a collection of gas molecules colliding with each other to a single gas molecule hitting another. Still others shifted from a general statement to a specific example or an extreme case (an exaggeration of the original in-form). Not surprisingly, in many cases, a frame shift coincided with a representational shift. More interesting is the observation that, in some cases, a representation became the new subject in the subject-predicate relation. For example, during the third phenomenon in which the liquid alcohol is heated (see Figure 3), several participants shifted frame from energy being added to the liquid to a molecular energy distribution function, drawn by them on the whiteboard, being pushed along an axis representing energy.

Unlike the previous three in-form repair strategies, frame shifts were almost uniformly successful in generating positive feedback from the other interlocutor and allowing the explanation to proceed. Moreover, even when a frame shift was not immediately ratified by the other interlocutor, a productive negotiation often ensued in which the two participants were able to use both frames to reach an eventual consensus. In Transcript 14, there are at least four frames being used to explain why it takes more energy to move a molecule of ethanol out of the liquid and into the gas than a molecule of methanol.

Transcript 14

Red: "Okay, so these molecules... If you look at the chemical structures, just basically [ethanol] is made up of four... or three more atoms than [methanol]?"

Blue: "Yep, okay, I understand that."

Red: "So they're going to be bigger, fatter, heavier molecules?"

Blue: "Okay."

Red: "And [...] since these are bigger? They have less individual kinetic energy? Because it..."

Blue: "Say that again. Say that again, okay?"

Red: "[...] Since these molecules are bigger? They don't move around quite as much."

Blue: "Oh! Okay, okay. I can accept that. Okay, yeah."

Red: "Yeah, it takes more energy to get them to move around?"

Blue: "Okay."

Red: "Which means that, as a result, if this one has less energy? Then it might take more of these molecules to donate their energy to each individual molecule in order to get it into the gas phase?"

Blue: "Oh, okay."

Red: "And so it's kind of, just basically like, if these were bowling balls and those were golf balls, they're going to take... these [ethanol] molecules will take more energy per molecule to reach the gas phase? [...]"

Blue: "That... that makes sense to me, I think. Yeah! Yeah."

Red: "Cool."

data, psychological explanations like this proved to be very productive and convincing. The question of why this would be the case, I assert, must have a cognitive answer.

Blue: "Yeah. That makes sense."
Red: "Whew!"
Blue: "It sounds like it's just... it sounds like it's... somewhat more... sluggish, basically."
Red: "Yeah."
Blue: "Because it's... a different..."
Red: "These ones, you can just think of them as being fatter."
Blue: [*laughing*] "Yeah! That, that... that helps. Yeah."
Red: "Like, they need two of their little friends to be, like, 'Oh my gosh, get OUT of here!'"
[*both laughing*]
Blue: "That works! Yeah, okay. I'll buy it."

At first, Blue is on board with thinking about the ethanol molecules as being bigger. However, when Red introduces scientific terminology ("they have less individual kinetic energy"), Blue signals trouble ("Say that again, okay?"). In response, Red shifts frame away from talking about kinetic energy and toward a less formal description ("they don't move around quite as much"). Blue ratifies this new frame ("Oh! Okay, okay. I can accept that.") which allows Red to proceed with the explanation. Red introduces a new in-form explaining that more molecules in the liquid will need to give up their energy to get an ethanol molecule into the gas. However, during this in-form, Red creates four feedback-relevant places—two are marked in the transcript with question marks—before Blue gives any positive feedback. This prompts a further frame shift away from molecules and toward bowling balls and golf balls. This final shift, which is blurred when Red talks about molecules again, is enough to allow Blue and Red to negotiate what appears to be a (well-deserved) ending to the in-form.

And yet, the in-form does not end here. Blue attempts a frame shift back to the idea of the molecules being "sluggish" and not moving around very much. To this, Red responds by shifting frame to the anthropomorphic idea of the molecules being fat and requiring more of their "friends" to physically push them out of the liquid.

Several features of this exchange are interesting. From a scientific perspective, these frames—ethanol evaporating less because it is either more sluggish or fatter—are not equivalent. Earlier in the example, Red positions "not moving around as much" as implying less kinetic energy. In contrast, while being sluggish may be a stereotype of someone who is fat, in this context fat clearly implies heavy. After describing the ethanol molecules as being fatter, Red animates with her arms pushing something away with great effort. Heavy, in turn, implies having more mass. Kinetic energy is equal to mass times the square of velocity, so, in the absence of a discussion of velocity, having less kinetic energy contradicts having more mass.²¹

²¹ From a normative perspective, neither differences in kinetic energy nor mass are relevant. The two systems are at the same temperature, so they have the same average kinetic energy by definition. At molecular scales, gravity is so weak that differences in mass are negligible. The relevant property is the strength of the intermolecular attractions between molecules of ethanol versus between molecules of methanol. Because a molecule of ethanol has more "surface area" than a molecule of methanol, the overall attraction per molecule is greater (i.e., ethanol molecules are in a deeper potential energy well). Because the kinetic energy of both systems is the same, it is this stronger intermolecular attraction that results in fewer molecules of

From the participants' less scientific, more informal perspective, these frames are treated as being consistent. "Sluggish" implies that the ethanol molecules are moving slower to begin with. "Fat" implies that they are harder to push out of the liquid regardless of how fast they were moving. So something that is both sluggish and fat would be doubly hard to push out of the liquid. However, though the participants do not seem to notice, these are distinct, independent explanations. The participants have not established the relative importance of being sluggish versus being fat. Despite this, they treat these distinct frames as equivalent, responding "yeah" to each other and letting the discussion end without further comment.

Summary

The description of interaction so far establishes the means by which discussions like this can occur and be meaningful for the participants. For example, it explains many of the observed features of Transcript 14, including why frame shifts occur in the places they do. (These are the places where feedback-relevant places are designed to elicit positive feedback but do not, leading to an attempt to repair the in-form.) Yet, it does not fully explain the final sequence in Transcript 14, in which additional in-forms are produced after the discussion had appeared to reach a conclusion, and in which those distinct, technically contradictory in-forms are treated as equivalent. Such unresolved matters fall most likely in the domain of the interaction between the collective cognitive activity of explaining and the individual cognition that is occurring in this context.²²

Illative Sequences

Each explanation a participant gave during the interviews consisted of a sequence of information performances. However, many things may potentially be described as a sequence of information performances, including ordinary conversation. There are additional aspects of interaction that determine whether a particular sequence of in-forms constitutes an explanation and whether that explanation is successful or not.

ethanol per second having enough total energy (kinetic + potential) to "escape" from the liquid.

²² I believe the issues of individual cognition at work here are as follows. Although the mental elements induced in Blue by the time of the first apparent conclusion are "convincing" in the sense that they were successfully triggered, they are not "convincing enough" upon further reflection. Using diSessa's (1993) terminology, their *cuing priority* is high but their *reliability priority* is low.

The subsequent interaction induces in both Blue and Red new mental elements—dealing with sluggish and fat—that have higher reliability priority. The reason for this higher reliability priority, I would argue, is because they are more kinesthetic and/or psychological in nature. That is to say, they draw upon existing stores of cognitive resources regarding how objects and people react to our actions. As these stores have a longer and more successful history than the largely visual kinetic molecular model, their reliability priority is much higher even though they are not necessarily cued first in this context.

Even though the two mental elements are not equivalent, and contradictory from a scientific point of view, they cue each other because sluggishness and being fat are often experienced together in kinesthetic or psychological contexts. Consequently, no red flags are raised, and their combined reliability priority is high enough to allow this interaction to satisfactorily conclude without further reflection.

As described at the very beginning of this chapter, explaining in these data begins with remembering a fact or observing some feature of the provided diagram. This fact or observation is expressed as an in-form. This in-form is then followed by a sequence of further in-forms, each related to the prior by a logical, causal, or temporal link. Such an explanation might sound like, “X is true, *so* Y must occur, *so then* Z happens.”

This sequence continues until a statement—a final in-form—is produced that describes the phenomenon. If such an in-form can be produced, the explanation is treated as successful by the participants. If such an in-form cannot be reached, the sequence is repaired by starting over at some point, replacing one of the in-forms, and following this new lead.

I call this sequence an *illative sequence*. I use the word *illative* to emphasize that the links between in-forms are inferential without being specifically, or necessarily, deductive, inductive, causal, or constraint-based. In an illative sequence, the most that can be said generally is that something happens next. In most cases, the inferential link is wrapped up in a single word—*so*—and the nature of the inference is unexamined.

That an illative sequence appears to have a linear quality is an important but misleading constraint. Not all explanations are linear sequences of causal elements. In particular, many scientific explanations are not causal at all and instead consist of a number of mathematical constraints which, when one variable is given a specific value, constrain the value of one or more other variables. In the case of chemical equilibrium, a normative explanation might involve the emergence of what appears to be stasis as the result of an underlying dynamic equilibrium. However, when one *expresses* such explanations, I argue that it takes the form of a linear sequence. Note the inescapable linearity of the previous two examples: *when* one variable is specified, the math constrains another variable; *when* dynamic equilibrium is reached, the result is the appearance of stasis. Throughout the data, especially during the tutoring interviews, there were many cases in which a non-linear (e.g., mathematical or emergent) explanation was expressed. In each case, it was expressed as an illative sequence. Indeed, the participants were constrained while explaining to use inherently linear, inferential speech, which emerged as an important consequence of the existence of illative sequences.

In sum, while in-forms are the building blocks out of which explanations are constructed, they are held together as an explanation by the overarching structure of a linear illative sequence. Consequently, to understand explanations in these data, it is important to understand both the individual bricks (in-forms) and the mortar (the illative sequence) that creates the structure of the explanation.

Construction

When discussing the initiation of in-forms, it was noted that a pause was common immediately after the discourse connective (i.e., *so...*, *and then...*, etc.). In this moment, the mortar for the next brick has been laid, establishing that the illative sequence is going to continue. However, the next in-form—the next brick—has not yet been formulated. While the preference is for the speaker to articulate the next in-form, these are special moments when one of several other things is allowed to happen, each of which is a means of better supporting the in-form that is on its way: (a) the speaker can insert an in-form as a dependent clause that places a *condition* upon the upcoming in-form, (b) the speaker can *recap* the previous in-form, especially after a long side-track, to refresh the participants’ memories, or (c) the speaker can *represent* the previous in-form when its inspection would make easier the next inference.

Conditioning. In Transcript 1, Red pauses just after the start of In-Form 3 (“so,

there's...). When Red resumes, In-Form 4 is inserted ("With the same space,") before In-Form 3 continues ("there can be less gas molecules in the air"). One can imagine that In-Form 3b, had it been spoken fully, might have been "there's less gas molecules in the air." But that would only be true if the air was constrained and not allowed to expand. Here, the insertion identifies the condition—constant volume—under which In-Form 3 is true. Similarly, in Transcript 5, In-Form 5 ("If it was, like, below the boiling point,") is an "if" statement that places a condition upon In-Form 6 ("would, like, part of it evaporate?"). The latter is part of the illative sequence proper; the former is part of the specific context that gives the latter meaning.

Recapping. A particularly troublesome in-form may require multiple revisions and repair attempts over the course of several minutes. When the trouble is finally resolved, a common move by the speaker is to recap the story up to this point. This means repeating, often in abbreviated form, the in-forms that make up the core of the illative sequence. For example, in Transcript 8, Red has trouble constructing the illative sequence at first, as evidenced by the large number of pauses and restarts (represented in the transcript by the vertical height of the in-forms). After seventeen in-forms, Red begins the switch to her "crazy people running around a room" analogy. But before this analogy gets underway in In-Form 24, Red recaps the first seventeen in-forms in In-Forms 21-23: "They had more room in [that larger container] and they were happy with that, but they couldn't bounce all over the place in [this smaller container]." The speaker projects this as a recap by giving this speech a much more rapid pacing than the first time and not pausing at the end of each in-form.

Representing. As mentioned above, illative sequences are inherently linear. This often causes trouble during an explanation when the speaker needs to make a comparison between two things or describe an emergent property of a system. Both of these occur in Transcript 9. First, in In-Form 1, Red is trying to express a "net flow of molecules out" of the liquid, but this requires comparing the "rate of escape" with the "rate of capture." After the initial discourse connective, Red inserts an in-form that includes a series of gestures that animate the comparison. The "rate of escape" is paired with two forceful pushing-away motions made with both hands while the "rate of capture" is paired with a single, weaker pulling-toward motion. This in-form, in particular its gestural component, serves to represent (literally re-present) the preceding steps in the illative sequence (not shown in Transcript 9) in a visual way that makes it easier to "read out" the correct inference needed to get to In-Form 1: that "there's going to be this net flow of molecules out."

Likewise, into In-Form 3, Red again inserts an in-form ("once the rate of capture gets fast enough") with a strong gestural component. In this case, the gesture involves one hand pushing away repeatedly while the other hand pulls back repeatedly, both moving very quickly in opposite directions. From this, now Blue is able to "read out" the correct inference, which is that the two rates will "be equal." Moreover, Blue follows this with a further inference (In-Form 5: "you won't be able to tell") that correctly reports the emergent behavior of the system (no macroscopic change). All of this explanatory work is done under the constraint of a linear illative sequence, made possible by representing the non-linear aspects of the situation with gesture, rendering them visible and therefore able to be reported upon.

These three speaker strategies—conditioning, recapping, and representing—are all means of strengthening the illative sequence by making sure the next in-form is given a solid foundation upon which to build.

Trouble and Repair

Trouble can manifest during an illative sequence at two locations. The first is, as for in-forms, the feedback-relevant place that occurs at the end of an in-form. The second is during a pause after the initial discourse connective.

First, because illative sequences are constructed out of in-forms, there is always the possibility that trouble manifesting at a feedback-relevant place may have its source at the level of the illative sequence rather than at the level of the current in-form. In other words, although each in-form up to that point may have been individually understood, the inferential links holding the in-forms together may be problematic.

When a speaker suspects that this is the case, their first course of action is to repeat the prior linkage in the reverse direction. This might sound like, “X is true, so Y happens, *because of X*.” This sort of back step happens frequently in two places: the very beginning and very end of an illative sequence.

Beginnings of illative sequences are special in that the only way to solve trouble is to step back, because there is no previous in-form to revise (“Y happens, *because of X*.”). An example of this kind of back step occurs in Transcript 15, where Red begins the explanation by stating that gas molecules take up space.

Transcript 15

Red: "Okay, like, this molecule? Like when it evaporates? It's still taking up space in the air?"

Blue: "Okay."

Red: "It's not like it just kind of disappears."

Blue: "All right."

Red: "So when it's in the air it takes up more space? Because, like, gas molecules? Like, they're faster? And they move around more? Because they have higher energy?"

Blue: "Okay."

Red: "So they need, like... they need more space."

Instead of moving forward from this statement, Red takes a step back to explain *why* gas molecules take up space (“Because...they’re faster and they move around more.”). Red then takes another step back to explain why gas molecules are faster and move around more (“Because they have higher energy.”). At the end of this series of back steps, Red picks up again from the beginning by recapping (“So...they need more space.”). The rare instance of an explanation that runs backward rather than forward is an illative sequence that gets into trouble right at the start and requires a series of back steps to repair that trouble.

The other time when back steps are common is at the very end of an explanation. A back step is often the last attempt for a speaker to end an explanation in the face of highly negative feedback. For example, as was discussed previously, in Transcript 1, Red has already exhausted several in-form-level repair strategies by the end of In-Form 5 in an attempt to evoke any kind of feedback from Blue. Furthermore, In-Form 5 itself cannot be revised because it is a description of the target phenomenon (see Figure 2). Consequently, In-Form 6 takes the form of a back step. This checks to see whether the current source of trouble is the prior linkage (“and so”) between In-Forms 4 and 5, rather than the formulation of In-Form 5. In general, it appears that trouble manifesting at a feedback-relevant place is always interpreted in the first instance as trouble at

the in-form level. It is only when in-form-level repair strategies have failed, or in the special cases of the very beginning and very end of the explanation, that trouble is interpreted at the level of the illative sequence.

In contrast, trouble in the form of a long pause after the initial discourse connective (e.g., *so...*, *and then...*) is treated as trouble with the illative sequence. When this occurs, the other interlocutor will often jump in and attempt to provide the next in-form. Indeed, while the preference is still to let the speaker complete the in-form on their own (see Transcript 1), pauses or other indicators of trouble after discourse connectives are by far the most frequent place where interruptions are attempted (see Transcript 3, where Red's stumbling results in an interruption by Blue).

That there exists an increased tendency for the other interlocutor to jump in during trouble after a discourse connective is a fact of which the speaker sometimes takes advantage. In some cases, the speaker wants the other interlocutor to take over. A common strategy for achieving this handoff is to express just a discourse connective. For two successful examples, see the hanging "or"s at In-Forms 9 and 12 in Transcript 5. In both cases, the other interlocutor speaks next.

The speaker may also purposefully enlist the other interlocutor to co-construct the explanation. This was a frequent occurrence in the teaching interviews. For example, in Transcript 9, Red (the tutor) lets the discourse marker "but" hang in In-Form 3 as an attempt to get Blue (the tutee) to complete the in-form. As discussed above, with the assistance of the representing in-form insertion (In-Form 4), this attempt is successful and Blue expresses the bulk of In-Form 3. These moments, when a participant's expectation of the interaction is successfully exploited by another participant, are particularly nice evidence that an interactional structure exists and does, in fact, constrain how the participants construct an explanation together.

Summary

This chapter has described how explanations, even those that appear to be monologues, are jointly constructed and expressed through the interaction of the interlocutors. The focus has been on the contributions of interaction to structuring the process of explaining—the unwritten but ever-present set of expectations regarding who can and should say what at any particular point during the explanation.

Each building block in each explanation is a jointly performed expression of a subject-predicate relation, an interactive accomplishment I call an *information performance* (in-form, for short). Unlike clauses or sentences, in-forms need not have a coherent grammatical structure. This makes them difficult to represent in written form without "cleaning up" a lot of non-lexical action by the speaker—action that may have important interactional functions. Unlike speaker turns, in-forms have a clear denotive function. When explaining, the interlocutors are expressly attempting to perform a piece of information. This goal overrides several interactional conventions of ordinary conversation, such as the preference for alternating speakers. Unlike both clauses and speaker turns, in-forms are a co-construction, jointly performed by both the primary speaker and the other interlocutors. The other interlocutors strongly affect the form and content of an in-form by giving or withholding feedback at the end of each in-form, moments I call *feedback-relevant places*.

While the in-forms are the building blocks out of which the explanation is constructed, they are held in place by a series of inferential links I call an *illative sequence*. Illative sequences are forward-searching, starting with a remembered fact or an observation triggered by the

provided diagrams and following a chain of inferences in the hope the chain will lead to the target phenomenon. If the illative sequence generates an in-form that describes the phenomenon, the explanation is treated by the participants as a success. If the illative sequence does not arrive at the phenomenon, it is partly or entirely scrubbed, a new in-form is introduced as a starting point, and the illative sequence begins anew.

The educational implications of this description may not be immediately obvious. In the final chapter, I will discuss some of those implications and describe how these results could be used to answer several questions of educational importance.

Implications and next steps

The description presented in the previous chapter of how interaction contributes to the production of explanations allows us to predict many of the features of the explanations in the data. In particular, it exposes how, as is the case in other interviewing situations (Antaki & Rapley, 1996; Button, 1987; Macbeth, 2000; Suchman & Jordan, 1990), the responses “given” by the interviewee are actually an interactional accomplishment involving the person asking the questions. This observation should raise a flag of caution for any researchers attempting to “extract” a student’s understanding without leading or biasing the student’s responses.

While they are a methodological advance, these results by themselves do not immediately address any outstanding questions of educational importance. To do so, one would need to apply them in a research program aimed at answering those questions. What follows are brief descriptions of the types of questions that could be addressed.

As described in Chapter 1, one application of the results would be to apply them during data analysis to generate results that would stand a better chance at distinguishing between competing theories of conceptual change. Any theory of conceptual change should be able to account for the interconnected contributions of both interaction and individual cognition to the production of explanations of scientific phenomena. For better or for worse, most current theories focus exclusively on characterizing individual cognition. Armed with a better understanding of the contributions of interaction, researchers would be better equipped to characterize the contributions of individual cognition. Existing theories could then be judged based upon their consistency with this more valid knowledge about how individual cognition contributes to the production of explanations.

A second application of the results would be to work toward a new theory of conceptual change. Throughout Chapter 3, several footnotes hinted at an adaptation of diSessa’s (1993) theory of knowledge in pieces. Such an adaptation might describe and attempt to explain the heightened ability of kinesthetic and psychological cognitive elements, in comparison to visual or verbal elements, to convince students and allow them to productively generate new explanations.

A third application of the results would be the improvement of assessments that attempt to measure students’ conceptual understanding. With a new definition of what constitutes an explanation, the quality of students’ explanations can be redefined and reevaluated in terms of information performances and illative sequences. For example, the length of an explanation might be defined, not by the overall number of words or the time it takes to produce, but by the number of in-forms in the illative sequence. Likewise, gut impressions of confidence or assuredness could be defined more precisely using the number and length of internal pauses and/or the number of joint prosodic units within each in-form. New constructs like these would be more valid as they would better take into account students’ actual response processes while answering the questions (American Educational Research Association, American Psychological Association, & National Council on Measurement in Education, 1999).

Finally, a fourth application of the results would be to make and test recommendations for improving interviewing, lecturing, and tutoring practices. For example, knowing how silence and the withholding of feedback affects the form and content of explanations, an interviewer could design interview settings in which feedback-relevant places are more likely to be

confirmation checks and confident monologues than uncertain monologues. As another example, lecturers and tutors could take conscious advantage of the tendency for the other interlocutor to jump in during pauses after discourse connectives. By creating such pauses, teachers may better involve their students in co-constructing explanations during class.

The above are a few of the educational issues that could be addressed were the results described in this dissertation to be applied during a program of research. It is the intention of the author to pursue these questions and his hope that others may do so as well.

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Transcripts and conventions

Transcript conventions are a mixture of some standard conversation analytic conventions and some new elements. When a symbol used in the Jeffersonian transcription system (Jefferson, 1978) appears in a transcript, it retains its meaning from that prior convention. Formatting, in particular, is very different from how it has traditionally been used. Details are given below, but this system has been designed so that one should be able to read the colored text in the normal manner (top to bottom and left to right) to extract the content. When the full system is not necessary, transcripts in the text follow a more conversational form, with most of the interactional detail removed and the speech cleaned up considerably (e.g., removing false starts, adding punctuation, etc.).

Format

Full transcripts (those rendered in color after this appendix) are organized by in-forms. Each in-form is numbered and separated from other in-forms by a blank line. For example, Transcript 1 contains six in-forms and Transcript 3 contains two in-forms.

In-forms are broken down into joint prosodic units, each of which appears on a separate line. Joint prosodic units are lettered within each in-form. Lettering continues from where it left off after an in-form interruption. For example, in Transcript 3, In-Form 1 consists of nineteen joint prosodic units (1a-1s) that occur in three contiguous stretches. The in-form is interrupted twice, once between 1f and 1g and once between 1h and 1i.

At the end of each joint prosodic unit, one of two possible symbols appear. An equals sign (=) indicates the following joint prosodic unit begins without any break or pause. Otherwise, parentheses () surround a combination of pauses and pause-fillers. This combination is called a *boundary marker*. Within a boundary marker, silence is represented by one or more periods (.). Each period represents silence of up to one half second. Place-holding sounds like *er* or *um* are also contained within the boundary marker. A word that is drawn out (e.g., *sooooo*) covers what would otherwise be a pause; the extension of such words is represented by one or more colons (:). Each colon represents extension of up to one half second. All of these symbols may be combined within a single boundary marker, for example, *so (: : er . . . um :)*. In this example, *so* is extended an additional second, there is a 1.5 second pause after *er*, and *um* is extended by up to one half a second.

After a boundary marker, the subsequent joint prosodic unit is vertically stacked below the boundary marker, so that speech flows down one line every time it is interrupted (however briefly). The width of each boundary marker gives a simple visual indication of how long the interruption is.

Speech that is a repetition, rephrase, or correction is vertically stacked below the speech that it is repeating, rephrasing, or replacing. Consequently, the “final” version of the in-form can be read from left to right along the bottom of each stack. Likewise, the vertical height of an in-form gives a simple visual indication of the number of its internal pauses, restarts, and corrections.

Overlapping speech is contained within linked boxes. For example, Transcript 5 contains three simple examples of overlapping speech. In In-Form 3b, “I don’t know” is spoken at the same time as “um” in In-Form 4a. In In-Form 7, “or” overlaps “evaporate” in In-Form 6c. Later,

the same is true for “low” and “yeah.” Boxes indicate both the beginning and ending of overlaps to the nearest word. If overlapping speech consists of multiple joint prosodic units, the box breaks across several lines. For example, in Transcript 3, the gesture “falls down” in In-Form 1m overlaps the entire stretch of speech in In-Forms 1n-1q.

Participants

Speech and actions produced by an interlocutor are rendered in color. Colors have no meaning other than to distinguish speakers within the current transcript segment. The first speaker is Red and the second speaker is Blue. The identity of Red and Blue change with each transcript. The same person may be represented by different colors in different transcript segments.

Color-coding means that speakers need not be identified by pseudonyms, alleviating the problem of presuming the relevance of certain analytic categories (like interviewer or interviewee) that may not be consequential for the participants at a particular time (Ochs, 1979; Schegloff, 1972). Color-coding makes it easier to determine relative participation levels through a cursory visual inspection. Color-coding also makes it unnecessary to place a carriage return before every speaker change, allowing a joint prosodic unit with more than one speaker to appear as the single unit it is (e.g., Transcript 3, In-Form 2a).

Semantics

Both lexical (molecule, the) and non-lexical (um, heh) speech is transcribed. Although it is common practice in conversation analysis to attempt to capture aspects of pronunciation in the transcript (becuz, gonna), Bucholtz (2000) has noted that particular pronunciations that pass without notice in everyday speech become marked as deficient when “captured” in written form. For example, while the natural pronunciation of the word the may be either thuh or thee, either inscription stands out misleadingly in text and therefore could be construed as deficient. Because unusual pronunciations or differences in dialect do not appear to be relevant in this data, no attempt has been made to represent the phonetic aspect of speech. Instead, all speech is represented using written forms that evoke competently produced mainstream American talk.

A word that is cut off before its natural ending is ended with a hyphen (molec-). Speech that cannot be confidently transcribed due to low volume or overlapping speech is transcribed as a best guess and struck through (~~them~~). If not even an educated guess can be made, one or more question marks are struck through (???). Each question mark represents unknown speech of up to one half second.

Paralinguistics

Pitch and intonation are represented in the following ways. Back-slashes surround speech produced with initial falling pitch that then remains lower than surrounding talk. When enclosing a word or syllable, the falling intonation often evokes resignation in American English (e.g., \no\, that's terri\ble\); think “sighhhhh.” When enclosing a more lengthy passage, the lower pitch often marks an aside. Forward-slashes surround speech produced with initial rising pitch that then remains higher than surrounding talk. When enclosing a word or syllable, the rising intonation often marks a question in American English (e.g., /really/, are you /sure/). When pitch falls then rises, one of each slash is used as appropriate (e.g., \no/, \sure/). In American English, this construction often marks an expected continuation that

might be represented in written form as a comma (no, ...).

An emphasized word or syllable, often produced with a combination of heightened pitch and volume, is marked with boldface type (e.g., **what**, **terrible**). Speech that is consistently louder than surrounding speech is likewise marked with boldface type. Speech that is consistently softer than surrounding speech is enclosed by vertical bars (|well|, |at least I think so|).

Speech that is produced at a consistently faster rate than surrounding speech is italicized (*you know, I mean not really but still*). Speech that is drawn out and produced at a consistently slower rate than surrounding speech is underlined by word (so that means, now pay attention to this).

Laughter is indicated by one or more tildes (~). Each tilde represents laughter of up to one half second. When a participant laughs while speaking, each word is preceded by a tilde (~so ~then).

Gesture and Body Movement

Gestures are recorded only when they index something like an object or an action. Gestures used for emphasis or other non-semantic purposes are not recorded. Indexical gestures are transcribed as if the participant were speaking the content represented by the gesture; this “gesture-speak” is contained within square brackets ([falls down], [this molecule]). This obviously requires interpretation. To minimize what is read into each gesture, language is borrowed from nearby speech when possible and representations, including of actions, are described as concisely as possible.

When gesture occurs by itself or, as in Transcript 3, In-Form 1m, conveys different information than the co-occurring speech, it is placed on a line by itself. When gesture replaces part of the speech in a joint prosodic unit, as in Transcript 3, In-Form 2a, the “gesture-speak” is placed on the same line within the surrounding speech. When gesture parallels or repeats speech, as in Transcript 3, In-Forms 1c and 1d or In-Forms 1g and 1h, the gesture is placed on an adjacent line, left-justified to the speech, as if it were a spoken repetition.

Nodding during speech or silence is represented by a caret (^) placed before each word or pause during which the nodding occurs.

Shifts in body position are indicated by vertical arrows. When a participant backs away from the table surface, where the diagrams and whiteboard are, this is represented by an up arrow (↑). When a participant leans in to the table surface, this is represented by a down arrow (↓). Arrows are placed either before or after words or pauses, depending on whether the movement occurred in the first or second half of the word or pause.

Shifts in gaze are indicated by triangles. When a participant looks down at the table surface, this is represented by a downward facing triangle (▼). When a participant looks up and shifts gaze to the other interlocutor, this is represented by an upward facing triangle (▲). When a participant shifts gaze away from either the table or the other interlocutor “out into space,” this is represented by a forward facing triangle (►). Triangles are placed either before or after words or pauses, depending on whether the shift occurred in the first or second half of the word or pause.

Some transcripts begin with a series of symbols indicating the starting positions of each participant’s body position and gaze. For example, in Transcript 5 (↓▼↑▲; the first two symbols are red and the last two are blue), Red begins with body leaning into the table and gaze fixed downward while Blue begins with body leaning away from the table and gaze fixed on Red.

Summary of Transcription Conventions

Convention	Meaning
text	Transcription is uncertain.
ɤ*	Speech cannot be determined.
=	No pause. Next line continues immediately.
(<i>symbols</i>)	One or more pauses or pause-fillers before the next line continues. Called a <i>boundary marker</i> .
er, um	Non-lexical sound.
.*	Silence.
:*	The previous word is extended or drawn out.
tex-	Word is cut off before its natural end.
\text\	Pitch drops then stays low until the second slash.
/text/	Pitch rises then stays high until the second slash.
\text/	Pitch drops then rises.
text	Speech is louder than surrounding speech.
text	Speech is softer than surrounding speech.
<i>text</i>	Speech is faster than surrounding speech.
<u>text</u>	Speech is slower or more drawn out than surrounding speech.
[text]	The content of <i>text</i> is represented by an indexical gesture.
text text1 text2	text2 is a repetition, rephrase, or correction of text1.
boxes connecting text1 and text2	text1 and text2 occur simultaneously.
^	Nodding.
~	Laughter.
↑	Body position shifts up away from table.
↓	Body position shifts down toward table.
▲	Gaze shifts up toward the other interlocutor.
▶	Gaze shifts away “out into space.”
▼	Gaze shifts down toward the table.

* Each symbol represents a period of time of up to one half second.

Transcripts

Transcript 1

1 because they're bigger▲ (: .)

2 they take up more room (: .▼)

3a so (:)

b there's (.....▲▼.)

4a *with the* =

b *with the same* \space/ (: .)

3c there can be (.)

d **less** (: ..)

e gas mole/cules/ (.)

f in the \air\ (.)

5a and so (.)

b there's more /of them/ in the liq/uid state/ =

6a |*because they take up less space*\ (:)

b *that way* (...)

c ▲yes| (^.^.^...)

d \mm hm\ (^▲^▼^.^.^...)

Transcript 3

1a and (.)
 b then (.)
 c [these two dots]
 d these guys (.)
 e this (.)
 f little

2a I would as/sume/ that's where gravity would [pull down] ↑**yeah** =

1g [this pair of dots]
 h **this little combination** i- (.)

2b /pull them/
 c [pull down]

1i is ^just (.)
 j ^like (.)
 k ^wait a ^minute we don't (.)
 l have (.)

m [falls down]
 n \OK ↓crap\ (.)
 o here we go y- (.)
 p yeah =
 q ^tha- (.)
 r ^that's what I (^.)
 s ^\OK/ (^.^.)

↓▼↑▲
1a it =
b it needs to be **constantly maintaining** it at a certain ▼temperature =

2a and I /guess/ (. . .)
b if there was e/nough/ (. ▲. . . .)

3a I don't know if it would like **all** e/vap-/ (. . . .)
b ▲I don't know what do you /think/ =

4a (▼um)
b it would depend on like (.)
c the melt- or =
d not the melting =
e the (um . . .)
f like the boiling▲ point of the methanol =

5a if it was like bel- =
b below the boiling point =

6a would like (.)
b **part** /of it/ (.)

7 ▲OR
6c /evaporate/ (.)

8a I'm not really sure if there i- (. . . .)
b where you draw the (.)
c ▲line between like (.)
d ▲boiling and (.)
e evaporation =

9 or (.)

10a because I know like water will evaporate even at like low temperatures (:)
b yeah

11a so (.)

10c that's true (▼.)

11b is it just like the vapor ▲pressure that keeps it from all evapo/rating/ =

12 or (. . .)

11c I don't know (~~▼~~. . .)

```

1  !^!^
1a well I think this is going back to my sort of idea about how =
b   the gas molecules (.)
c   like they \need (: ^.)
d   ^space\ (^: ^.)
e   [space]
f   ^okay =

2a ^and (^.)
b   ^they can't (.)

3a like you can't (.)
b   cram them [all together] =
c   [cram them]

4a because =

5 if you cram them all together =

4b then their (..)
c   little (..)
d   ^intermolecular forces will ^sw- (.)
e   condense them /back/ to an al/cohol/ (.. .)
f   or =
g   ^the ^liq/uid ^alcohol (^.)
h   I suppose/ (..)

6a so it's like (.)
b   when they were in /this one/ ^mm-hm =
   [the before container]

7 ^they ^had ^\plenty ^of ^room/ =

8a ^and ^they ^were ^just ^happy (.)
b   ^floating around and everything (.)
c   [[floating around]]

9a but when they were in /here/ (..)
b   [[the after container]]

```

```

10a and they were all trying to (. .)
    b bounce all over the place =

11a ^like (^.)
    b |^gases ^apparently ^\do/| (^ . ^ . ~^.)

12 [[floating around]]
13 ~they ~-didn't ~-have enough room/ =

14a and (: . .)
    b then (: . .)
    c they (. . .)
    d like (. . .)
    e I'm guessing that =
    f they ran into more (. . .)
    g molecules =

15 or they lost energy through too many col/lisions/ (: . .)

16a ^and ^then (^ . . . .)
    b they (. . .)
    c like is- =
    d m- =
    e less molecules had (. . .)
    f the available ener/gy/ (. . .)
    g to re/main in the gas phase/ (: . .)

17a ^so ^they ^became (^ . .)
    b ^went ^back ^to ^the ^liq/uid ^phase ^I ^suppose/ (^ . . . . ^ . .)
    c |^I ^don't ^know\ =

18 ^it ^just ^seems ^like (^ . .)

19a ^I ^mean (^ . .)
    b ^I ^know (^ . .)
    c ^they're molecules =

20 and they don't have feelings or desires or whatever =

```

```

21a ~but ~like| (~!..)
b   ▼they had▲ more |room in here =
c   [the before container]

22 and they were happy with \that/ ^right (^v.)

23a but they couldn't|bounce all over the place in here =
b   [the after container]

24a so (▲.)
b   it's kind of like (. . ▼.)
c   would you rather be a bunch of \people/▲ (. .)

25a you would =
b   ^you ^could ^have ^more ^\people/ (^.)
c   [running around in circles]
d   ^running ^around (:^. )
e   ^all (^.)
f   ^crazy ^like ^in ^this ^big ^space =
g   [before container]

26a than you could have running around in this|small space =
b   [after container]

27 because then eventually people would start running into each other =

28 and it wouldn't be any fun =

29a so you'd just|want this like (.)
b   [the bottom of the container]
c   ^you ^know =

30 ^▲sit ^down (^^.)
31 ^^take ^a ^break (^.)
32 ^^get away from all these crazy |people |running around (^^.^.)

```

```
33a ^but ^that isa (.)  
b     doesn't (.)  
c     really (.)  
d     molecules ▼don't behave that way =  
  
34 but that's ~the ~way ~I ~always ~think ~about▲ ~it (~,~.)  
    ▼that's ~fine▼  
    that's ~fine (um . . . . . um)  
    ▲cool  
    all right
```

Transcript 9

```
1a and (: .)
2a as (: .)
b as long as the rate of escape is greater than the rate of capture (.)
1b there's going to be this net ( . ^.)
c ^/flow/ (^. )
d ^of ^molecules ^out (^. )
e ^\yeah\ ( . .)
3a but =
4 once the rate of capture gets fast enough ( . ^.)
3b |they'll be equal =
c they'll be equal =
5 you won't be able to tell| (.)
```